Infometrics

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Flood Protection: Option Flexibility and its Value

for Greater Wellington Regional Council

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Contents

1. Summary

This paper looks at the value of pursuing flood protection options that are flexible, rather than adopting a single solution that cannot be adapted to deal with changing and unpredictable external conditions – namely climate change and its effect on peak river flows and consequent flooding.

In broad terms the results show that a flexible investment strategy that enables a change of course in the future is more likely to deliver a lower cost outcome than pursuing a single option, unless the probability of a climate change induced change in flood frequency and its associated economic loss is almost certain. This holds true regardless of whether the outcome is based on Multi-Criteria Analysis or on minimising the expected total cost (cost of flood protection investment plus the residual risk of property loss in the event of a flood) of each option.

Section 2 briefly discusses the concept of Dynamic Adaptive Policy Pathways (DAPP) as a framework for assessing the value of a flexible investment strategy. By applying Real Options Theory to the main flood protection investment options set out in the *Hutt River City Centre Upgrade Project River Corridor Options Report*, it is demonstrated that there is generally value to be gained from adopting a flexible investment approach. The effects of changing the benefit metric from avoiding expected loss, to Value for Money based on a Multi-Criteria Analysis, are also presented.

Based on feedback from the HVFMS Hutt Valley Flood Management Subcommittee, a subset of investment options and adaptive pathways that are flexible were subject to further analysis and sensitivity testing, which is presented in Sections 3-6. This analysis confirms the value of flexibility. In particular most sensitivity testing supported investing in Option 4 initially and deferring investment in Option 2C until policy triggers indicate that Option 4 is no longer adequate to meet the agreed design standard. At some stage Option 1A may also be worthwhile.

We caution, however, that refining the costs of Options 4 and 2C is advisable before a final decision is made. It is our understanding this will occur after the next round of consultation which will lead to a preferred option/pathway.

The methodology is explained in detail in Appendix A using a simplified example with two climate scenarios and two investment options available at the start of the planning period, but where it is possible to design a flexible strategy under which one of those options can be delayed.

2. Options and Flexibility

Introduction

Investment in flood protection can be expensive, but not investing in flood protection can also be expensive. Balancing the cost of investment in increased flood protection against the value of the reduction in economic loss from a flood is not an easy calculation, especially in the context of uncertain impacts of climate change that could substantially alter flood frequency and severity.

The aim of this paper is to demonstrate that the risk of under-investment or over-investment can be reduced if a flexible investment strategy is maintained, rather than simply making a single (irreversible) investment at the start of a planning period.

Maintaining a flexible strategy involves an on-going monitoring regime. Flood return periods could be recalculated after each river 'event' and compared with other new knowledge about the frequency of intense rainfall in the catchment, and with the characteristics of intense storms across New Zealand. The trigger to act might be a stipulated percentage change in the intensity and duration of rainfall; it could also reflect the coping capacity of those affected by repeat flood events at particular damage levels.

Other considerations could be related to the intensity of surface flooding in low-lying urban areas affecting access and egress for periods of time that have economic and social consequences. Such environmental feedback could be based on a combination of past experience and likely future consequences of different flood damage scenarios. Reaching triggers, or the use-by date of particular flood protection options, could initiate a review of options for the future, having made initial decisions that retain flexibility to enable future changes of course. Figure B1 in Appendix B provides an illustration of the options and decision system.

Summary of Options

The *Hutt River City Centre Upgrade Project River Corridor Options Report* has a number of options for enhancing flood protection in the Hutt Valley. These are described in the accompanying report by Boffa Miskell.[1] Table 1 presents the discounted costs and expected loss of the various options. The assumed discount rate is 3%, with other rates explored in Section 4.

We are interested in ascertaining whether there is any benefit in delaying implementation of the more expensive options designed to provide greater security against more frequent and greater magnitude floods associated with climate change.

For our analysis we assume the following:

1. The planning horizon is 100 years, with the first round of investment occurring in 2015-2020.

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[1] Boffa Miskell (2015): *Hutt River City Centre Section Upgrade Report:* Options Evaluation Report, Prepared for GWRC, HCC and NZTA, 19 July.

2. A review of flood defences occurs after a series of pre-determined trigger points; that is when the level of service (security) falls below the design standard. For modelling purposes we have estimated the point of change from a less protective option (Option 4) to a more protective option, such as Option 2, to be in 2045, although the required planning period may entail a decision ten years earlier in 2035. Another decision point occurs in 2075, when from Option 2 could be upgraded to Option 1. Deployment of the options might need 10 years of prior planning. Other review dates are examined in Section 5 to test the sensitivity of results to this issue.

3. Two climate scenarios are examined initially; no change in climate from the present and the SRES Scenario A2, 50th percentile.[2] A third climate scenario, 2° stabilisation is examined in Section 3. These scenarios are derived from climate models that quantify uncertainty in relation to projected changes in emissions and from uncertainty in the climate models themselves. Additional uncertainty comes from the relatively short historical flood records used in New Zealand.

Table 1: Discounted Costs and Expected Loss ($m)

Option	Cost	Expected Loss	
		No Climate Change	SRES A2-50%
6	0.0	43.0	190.7
5B	58.4	30.4	136.8
5A	89.3	20.9	96.8
4A	105.5	20.9	96.8
3	167.5	3.5	21.2
2C	132.5	3.5	21.2
1A	248.5	3.5	21.2

Socio-economic conditions have not been varied in response to different climate scenarios. This increases the uncertainty around the results, but in ways that we are currently unable to quantify.

Also to avoid the impression of spurious accuracy and assist computation, the analysis is undertaken in five year blocks.

Once Only Decision

In Table 2 the column labelled 'Once only decision' presents a number of pairwise comparisons between options. For example, the expected total cost of Option 5A is the same as that for Option 2C if the probability of A2-50% climate change is 44.1%.

[2] Lawrence, J., A. Reisinger, B. Mullen & B. Jackson (2013): "Exploring climate change uncertainties to support adaptive management of changing flood risk." *Environmental Science & Policy* 33 133-142 presents a simplified, yet physically realistic and location-specific methodology for estimating changes in flood frequencies based on Ministry for the Environment (2010) *Tools for estimating the effects of climate change on flood flow-a guidance manual for local government in New Zealand*. Woods, R., Mullan, A.B., Smart, G., Rouse, H., Hollis, M., McKercher, A., Ibbitt, R., Dean, S., Collins, D, (NIWA) Once downscaled New Zealand specific rainfall data is available before decisions are taken on options for the Hutt River these will be compared with the above analysis and a sensitivity analysis undertaken.

Appendix A provides the calculation details. If the probability is higher than 44.1%, pursuing Option 2C directly is a better strategy.

Similarly Option 2C is a better bet than Option 5B if the probability of greater flood frequency and intensity from climate change is more than 53.5%. The logic here is that because the investment cost of Option 5B is less than for Option 5A, more expected damage from flooding is required to offset the higher cost of Option 2C.

Only two other pairwise comparisons have a cut-off probability of climate change of less than 100%. They are Option 4 compared to Option 2C and Option 6 (do minimum) compared to Option 2C. In cases where the cut-off probability exceeds 100% the expected discounted total cost of the lesser option is unambiguously lower.

Options 2C and 1A cannot be compared in an analogous manner as they produce the same expected value of loss, but Option 2C is always cheaper to build. In terms of Figure A1 in (Appendix A) the lines do not intersect. It is possible that a more detailed estimation of expected losses associated with these two options could produce some differences.

Table 2: Which Pathways are Flexible?

					Cut-off value for Pr(A2-50%)	
	Discounted Cost + Expected Loss ($m)	2015-2020	2045-2050	2075-2080	Once only decision	With delay option
(i)	199.6	5B	4		>100%	>100%
(ii)	172.7	5B	2C		53.1%	77.2%
(iii)	166.2	5A	2C		44.1%	77.5%
(iv)	217.4	5A	1A		>100%	>100%
(v)	182.9	4	2C		16.4%	48.2%
(vi)	236.5	4	1A		>100%	>100%
(vii)	235.6	2C	1A		NA	>100%
(viii)	191.5	5B	4	2C		63.1%
(ix)	213.3	5B	4	1A		>100%
(x)	206.1	5B	2C	1A		>100%
(xi)	216.2	4	2C	1A		>100%
(xii)	178.0	6	4		>100%	>100%
(xiii)	144.1	6	2C		71.5%	>100%
(xiv)	191.2	6	1A		>100%	>100%

How do the cut-off probabilities change if it is possible to delay investment in the more expensive options (until the case for them is stronger) while investing in a cheaper option in the interim? We explore this question below.

Flexibility

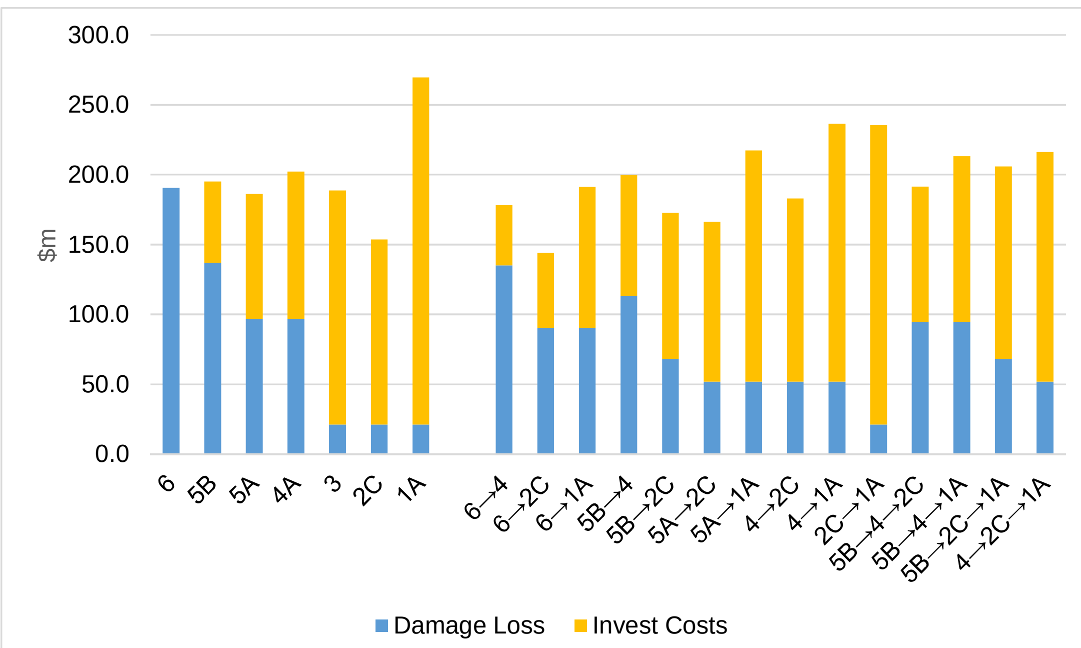
Using Real Options Theory[3], the flexibility of being able to delay leads to a more cautious investment stance. For example if Options 5A or 5B are pursued initially with the possibility of moving to Option 2C in 2045, even more certainty about the effects of climate change is required to make Option 2C immediately preferable to Options 5A or 5B. The calculations are shown in Appendix A.

The same argument applies to the Option 4 to 2C pathway. For the Option 6 to 2C pathway the cut-off probability now exceeds 100%, so it is always better to delay the more expensive option.

The flexibility of the double review pathway (5B to 4 to 2C) makes it a good strategy when viewed from 2015-20 if the probability of greater damage from climate change is more than 63.1%. All of the other double review strategies which could eventually lead to Option 1A are also good flexible policy pathways.

Figure 2 presents a comparison of the discounted costs and expected loss of all options and pathways. The left hand section of the graph for the single options has no climate change while the pathways, by definition, allow for A2-50% climate change.

Figure 2: Discounted Costs and Expected Loss



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[3] Ranger, N., Millner, A., Dietz, S., Fankhauser, S., Lopez, A & Ruta, G. 2010: Adaptation in the UK: a decision making process, *Grantham/CCCEP Policy Brief.*
Ranger, N., Reeder, T., & Lowe, J. (2013). Addressing 'deep' uncertainty over long-term climate in major infrastructure projects: Four innovations of the Thames Estuary 2100 Project. *European Journal of Decision Process, 1*(3-4), 233-262.

All of the pathways listed in Table 2 with a cut-of probability of >100% have a lower total expected cost than the cost of proceeding with the ultimate option immediately.

Pathway (i) which begins with Option 5B and proceeds to Option 4 around 2045 has a (just) lower total expected cost than proceeding with Option 4 (also labelled 4A) immediately.

The pathways with climate change cut-off probabilities that are less than 100%, could have a lower cost than the ultimate option depending on the likelihood of damage from climate change.

Value for Money

Table 3 presents the results from a Multi-Criteria Analysis (MCA) of the options.[4] Also shown is a measure of Value for Money (VfM) defined as the MCA score divided by the discounted investment cost (x100). On this criterion Option 2C is best and Option 3A is the worst.

Table 3: Value for Money: Single Investment

	MCA pts	Discounted Investment ($m)	VfM (pts/$ x100)
Option 1A	4.79	249	1.927
Option 1B	4.46		
Option 2A	3.73		
Option 2B	3.27		
Option 2C	3.79	132	2.861
Option 3A	2.31	167	1.379
Option 4A	2.72	105	2.579
Option 5A	2.08	89	2.328
Option 5B	1.47	58	2.515
Option 6A	1.38	0	NA

Table 4 shows the A2-50% climate change cut-off probability calculated on the basis of VfM for the four flexible pathways in Table 2 that have a climate change cut-off probability of less than 100%. All end with the possibility of Option 2C.

For example the cut-off probability for pathway 5A to 2C (ii) is 88.9%, slightly higher than the cut-off under the total expected cost approach of 77.5%. For pathways (ii) and (v) the differences are again positive, and for pathway (viii) the cut-off probability exceeds 100% so the difference is also positive. In this case even if the probability of A2-50% climate change is 100% certain, delay has lower expected discounted cost and retains flexibility.

Beginning with Option 4 and possibly proceeding to Option 2C later (pathway v) requires the least certainty about the loss associated with climate change.

[4] See Boffa Miskell *op cit*.

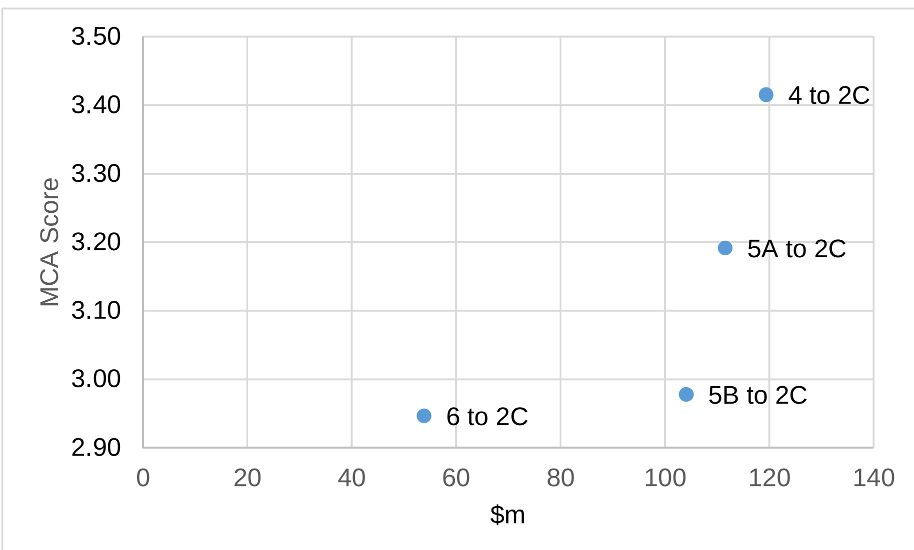
Table 4 Value for Money: Flexibility

		MCA pts*	Discounted Investment ($m)	VfM (pts/$ x100)	Cut-off probability of Climate Change	Cut-off probability ex Table 2
(ii)	5B to 2C	2.98	104	2.861	99.1%	77.2%
(iii)	5A to 2C	3.19	112	2.861	88.9%	77.5%
(v)	4 to 2C	3.42	119	2.861	54.5%	48.2%
(viii)	6 to 2C	2.95	NA	NA	>100%	>100%

* Individual MCA scores weighted by the share of the planning period over which each option applies.

Figure 3 shows how a higher MCA score requires more investment, although (by definition) all pathways except for 6 to 2C where delay is always preferable, have the same VfM. Hence those three points lie on a straight line.

Figure 3: MCA Score v Investment Cost



Conclusion

Interpreting these results collectively shows that:

- Delaying investment until policy triggers indicate that an existing protection option is no longer adequate to meet the agreed design standard, is usually a good strategy.
- The more investment one does initially the lower the probability of damage from climate change needs be, to justify even more investment later. This is because the incremental cost of each successive option declines, so less expected damage from climate change effects is needed to offset it.

- However, the total cost still increases as more protection is provided for more of the planning period.
- The VfM metric based on the MCA results implies an even more cautious approach to investment in flood protection than does Real Options Analysis. However, this inference is partly driven by the (assumed) invariance of the MCA scores over time and over climate change scenarios. In contrast the estimates of expected loss due to a breach do rise with climate change impacts on flood frequency.

Further Analysis

Evaluation of the above results at a meeting of the HVFMS on 5 May 2015 selected a subset of the above options/pathways for further analysis, notably:

- Option 4 (also known as 4A)
- Option 2C
- Option 1 (also known as 1A)
- Pathways based on the above options

The diagram in Appendix B shows how the options and pathways relate to each other. From the existing situation represented by the grey line it is possible to go directly to any of Options 4, 2C or 1. It is also possible to begin with Option 4 and then transition to Option 2C via the red line at a later date. Further into the future flood protection could transition to Option 1 via the purple line, or the move to Option 1 could be much sooner, completely by-passing Option 2C. As illustrated the transition paths occur in 2035 and 2095 to account for lead-time, but for costing purposes we looked at 2045 and 2075. In Section 5 we consider earlier and later transition dates. Note also that the use-by dates for each option depend on the climate scenario, with more extreme global warming bringing forward the likelihood of flooding.

The panel to the right of the pathways diagram provides summary measures for each option. More favourable (that is cheaper) construction costs and better flood protection are indicated by more plus (+) signs under Relative Costs and Target Effects respectively. The last three columns show qualitative ratings for social costs (mostly related to property purchase), transport effects and ecological/environmental effects. These are not directly addressed in this report, but they are incorporated into the multi-criteria analysis.

In the following four sections we examine the robustness of the above results with respect to a number of assumptions and parameters:

- An alternative climate change scenario – 2° stabilisation.
- The discount rate (currently 3% pa).
- Earlier or later decision review dates.
- Variations in the costs of flood protection measures and in expected losses.

While beyond the scope of this report, other ways of mitigating flood risk should not be ignored – for example planning and regulatory solutions, and insurance. These may be complementary to the construction of large stop banks where decisions may need to be made to reduce the design flood level if affordability becomes an issue.

Also it is worth noting that the Annual Exceedance Probabilities and associated river flows used in the above analysis are based on a Poisson distribution which assumes a known mean and variance, even though the historical record is really too short to establish a reliable mean and variance. A form of conjugate or extreme value distribution may be more appropriate to reflect the uncertainty around the mean and variance.

3. Sensitivity Analysis: Climate Scenario

The foregoing analysis relates to SRES Scenario A2-50%, which is a high GHG emissions scenario with accompanying changes in global temperature (central estimate of +3.4°). Here we repeat the analysis for a scenario where emissions are such that the expected increase in the mean global temperature is limited to 2° Celsius. Again we take the mean results from the various climate models.

Unsurprisingly, if the A2 type of climate change presents a strong case for a pathway approach, so does the less extreme 2° warming type of climate change. Even in the case of a once-only decision, Option 2C is better than Option 4 only if the probability of damage is more than 41.5% (16.4% under A2).

Table 5: The Case for Flexibility

	2015-2020	2045-2050	2075-2080	Once only decision	With delay option
				Cut-off probability	
		Climate Scenario: A2-50%			
(v)	4	2C		16.4%	48.2%
(vi)	4	1A		>100%	>100%
(vii)	2C	1A		NA	>100%
(xi)	4	2C	1A		>100%
		Climate Scenario: 2° Stabilisation -50%			
(v)	4	2C		41.5%	48.0%
(vi)	4	1A		>100%	>100%
(vii)	2C	1A		NA	>100%
(xi)	4	2C	1A		>100%

With the chance to delay Option 2C until 2045 the cut-off probability for not doing so is nearly identical in the two scenarios. One might have expected a more pronounced difference – and in the other direction. Why?

Under the 2° climate scenario the expected discounted damage cost is less than under the A2 scenario, but this is true regardless of whether Option 4 or Option 2C is pursued, so the net effect of deferral becomes an empirical issue – dependent on the relative changes in damage costs and on the discount rate. The net effect may change with a different discount rate (which we have tested in a sensitivity analysis in Section 4 below).

In summary, both climate change scenarios suggest starting with Option 4 unless the probability of increased loss from climate change is more than about 50%, in which case Option 2C would be pursued immediately. Option 1A is currently not favoured, but could be at a later date.

Based on current expectations Option 2C would be pursued in 2045, but of course this could and should be re-evaluated at the time. Similarly, with regard to the case for Option 1A.

Value for Money

The VFM calculations in Table 4 also apply here without change because:

- The investment costs do not change with the climate scenario. (Only the damage costs change).
- The MCA scores also do not change with the climate scenario as they are relative rankings.

Thus in Table 6 the results for pathway (v), Option 4 to 2C are repeated, while those for the other selected pathways are included for completeness even though the climate change cut-off probabilities exceed 100%.

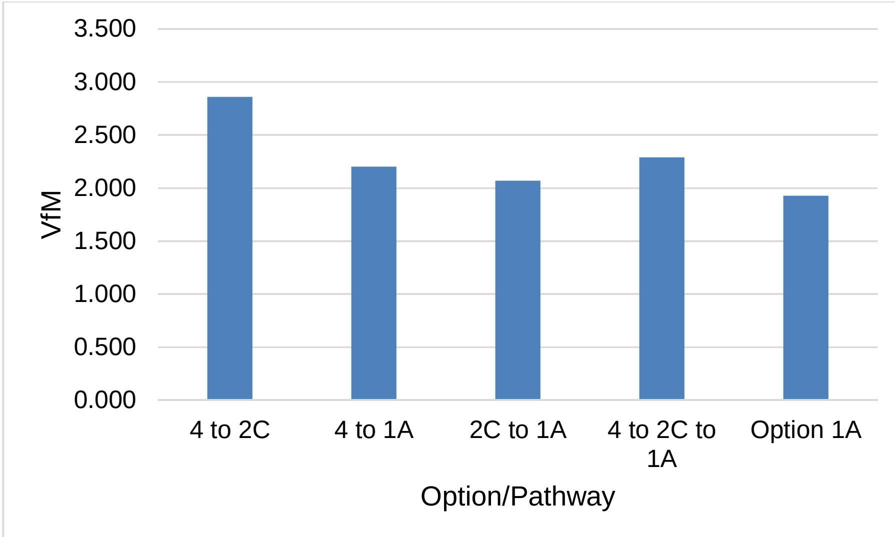
Table 6: Value for Money: Flexibility

		MCA pts	Discounted Investment ($m)	pts/$ x100	Cut-off probability of Climate Change	Cut-off probability ex Table 5
(v)	4 to 2C	3.42	121	2.861	54.5%	48.0-48.2%
(vi)	4 to 1A	4.07	185	NA	>100%	>100%
(vii)	2C to 1A	4.44	214	NA	>100%	>100%
(xi)	4 to 2C to 1A	3.72	164	NA	>100%	>100%

From a VfM perspective beginning with Option 4 and delaying Option 2C is better than proceeding immediately to Option 2C unless the probability of climate change is higher than 54.5%, only slightly different to the cut-off probability of 48.0-48.2% in Table 5.

For the other pathways which all involve an expected eventual move to Option 1A there is no probability of climate change that does not warrant a delay. As shown in Figure 4 all pathways produce a VfM that is higher than the 1.927 that is associated with proceeding immediately to Option 1A (from Table 3).

Figure 4: Value for Money


3.500
3.000
2.500
2.000
1.500
1.000
0.500
0.000
VfM
4 to 2C
4 to 1A
2C to 1A
4 to 2C to 1A
Option 1A
Option/Pathway

4. Sensitivity Analysis: Discount Rate

Discount Rate Theory

There are two fundamental properties of discount rates that are relevant to investment in flood protection:

1. If a project delivers returns that can be reinvested at the same rate and risk profile as the project itself, the cost of capital is an appropriate discount rate. This discount rate should incorporate a market based risk premium.

2. However, the capital cost of the project must truly represent the opportunity cost of that capital used for other investment. A social discount rate is likely to be more appropriate if this is not the case.

The first property is essentially a description of the Capital Asset Pricing Model (CAPM), a description of which can be found in Treasury (2008).[5] Treasury's current discount rate for infrastructure projects is 7.0%.[6]

The cost of capital is equal to the social opportunity cost of investment if a particular project displaces other investment that would have earned a rate of return. However, in the case of investment in flood protection by local government this is unlikely, especially if property rates are higher than they would otherwise be. Most of the opportunity cost of this funding is likely to be in the form of lower private consumption, not lower (private) investment.

In that case the cost of capital is not the appropriate discount rate to use for flood protection projects, or at least it should be substantially reduced towards something like the social rate of time preference (SRTP), which is the appropriate rate for discounting when the opportunity cost of the project is in the form of less consumption.

The SRTP is usually expressed as:

$$r = d + \varepsilon . g$$

r is the social rate of time preference

d is the rate at which future consumption is discounted over current consumption

g is the annual growth of consumption per capita

ε is the elasticity of the marginal utility of consumption

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[5] Treasury (2008): Public Sector Discount Rates for Cost Benefit Analysis.

[6] See http://www.treasury.govt.nz/publications/guidance/planning/costbenefitanalysis/currentdiscountrates

The variable d is frequently further disaggregated into two components:

$d = \rho + C$

ρ is the pure rate of time preference

C is the risk of a catastrophe which severely disrupts life on earth. See for example Stern et al (2006)[7] in connection with climate change.

There is much debate on the values of these variables, but the debate is beyond the ambit of this paper. The interested reader is referred to Parker (2009).[8] Parker suggests that a reasonable value of the SRTP for New Zealand is around 3.0% - 4.0%.

Results of Changing the Discount Rate

Our analysis so far has used a 3% discount rate. Table 7 shows the cut-off probability – the probability of climate change beyond which delay is more expensive – for the base 3% discount rate and for discount rates of 5% and 1.5%.

Table 7: Cut-off Probabilities

Pathway	3%	5%	1.5%
(v) 4 to 2C			
Financial analysis: SRES A2-50%	48.2%	71.3%	41.7%
Financial analysis: 2°stabilisation-50%	48.0%	92.0%	28.0%
VfM analysis	54.5%	99.5%	34.8%
(vi) 4 to 1A			
Financial analysis: SRES A2-50%	>100%	>100%	88.0%
Financial analysis: 2°stabilisation-50%	>100%	>100%	95.9%
VfM analysis	>100%	>100%	85.1%
(vii) 2C to 1A			
Financial analysis: SRES A2-50%	>100%	>100%	92.6%
Financial analysis: 2°stabilisation-50%	>100%	>100%	91.3%
VfM analysis	>100%	>100%	76.2%
(ix) 4 to 2C to 1A			
Financial analysis: SRES A2-50%	>100%	>100%	89.1%
Financial analysis: 2°stabilisation-50%	>100%	>100%	97.5%
VfM analysis	>100%	>100%	71.6%

Unsurprisingly, with a higher discount rate climate change needs to have a higher probability of occurring to justify immediate investment in a higher cost option, so the stronger is the case for a flexible pathway. Hence all of the flexible pathways are better (either lower total cost or higher VfM) than immediately adopting a more

[7] Stern, N. et al (2006): *The Economic of Climate Change. HM Treasury.*

[8] Parker (2009): "The implications of discount rate reductions on transport investments and sustainable transport futures." *NZTA research report* 392.

expensive flood protection option. Conceptually, the more one discounts the future the less inclined one is to invest in something that does not quickly deliver benefits.

We may infer that at even higher discount rates (such as at Treasury's 7%) the case for a adopting a flexible pathway is even more robust.

At a lower discount rate (1.5%) the narrative naturally moves in the other direction, lessening the argument for delay. However, decision implications do not really change – flexibility is still desirable.

Those pathways that have cut-off probabilities of more than 100% at discount rates of 3% and 5% now slip below 100%, but not by much in most cases. However, some extra insights are revealed:

- Under the 2° stabilisation scenario, the case for immediately proceeding with Option 2A is quite strong.
- For Pathways (v) 4 to 2C and (vi) 2C to 1A the possibility of more severe climate change raises the cut-off probability, whereas for the other two pathways the cut-off probability falls. As noted previously, the cut-off probability is subject to a number of competing effects which mean that the net change in direction may not be determinable *a priori.*
- From a VfM perspective Pathway (vii) 4 to 1A has the strongest case for deferral. If Option 1A is the eventual end point, it is better to arrive there via Options 4 and 2C.

5. Sensitivity Analysis: Decision Review Dates

In the foregoing analysis it is assumed that that the first phase of investment in flood protection (for any option) occurs between 2015 and 2020, although in reality this may be ambitious. There is a review beginning in 2045 and any further investment is completed by 2055. For one pathway there is another review and investment period between 2075 and 2085. The planning period does not go beyond 2115. As noted previously, analysis is undertaken in five year blocks, both to aid computation and to avoid producing an impression of what would be spurious accuracy.

While those time intervals are intended to be realistic, it is entirely possible that a climate or weather event (not necessarily in the Hutt valley), or acceleration of a trend toward greater rainfall, could bring forward a review date. Almost any decision review time profile is plausible. Indeed adopting a flexible flood protection strategy means flexibility, not only with respect to what is done, but also with respect to when something is done.

For explanatory purposes we look at the effects of:

- Bringing forward the 2045 and 2075 review dates (and their accompanying ten year construction periods) by 15 years to 2030 and 2060 respectively.
- Postponing the review dates to 2060 and 2090.

Earlier Review Dates

As the initial investment phase is still assumed to occur between 2015 and 2020, it means that any option that is pursued initially could have a short life, implying a possible waste of resources. On the other hand, if increased potential loss from climate change is slow to materialise, an earlier review date may not assist the case for the more expensive options.

Table 8 shows the cut-off probabilities, repeating those for the original review dates.

Table 8: Cut-Off Probabilities and Review Timing

	2015-2020	1st Review	2nd Review	Cut-off probability	
		2045-2055	2075-2085	Financial	VfM
(v)	4	2C		48.2%	54.5%
(vi)	4	1A		>100%	>100%
(vii)	2C	1A		>100%	>100%
(xi)	4	2C	1A	>100%	>100%
		2030-2040	2060-2070		
(v)	4	2C		49.0%	48.8%
(vi)	4	1A		>100%	98.0%

(vii)	2C	1A		91.5%	82.3%
(xi)	4	2C	1A	>100%	>100%

For Pathway (v) 4 to 2C the effect of bringing forward the review date is small; on the basis of the financial criterion, the case for flexibility is marginally stronger. Conversely for Pathway (vii) 2C to 1A the cut-off probability drops from over 100% to 91.5% so the case for flexibility is slightly weaker, but still overwhelming.

The VfM results are somewhat more sensitive. The numerator (MCA score) increases as greater protection is provided sooner. However, the denominator (the discounted cost of investment) also rises as investment is brought forward, so the net effect on VfM could be in either direction.

However, we know from the earlier analysis that the option to delay raises the cut-off probability. Thus we would expect any compression of that delay to reduce the cut-off probability, which is what happens. The shorter the opportunity to delay the more risk averse one has to be.

Nonetheless, while the VfM cut-off probabilities are lower than before, that for Pathway (v) 4 to 2C is still around 50% and for those pathways that end at Option 1A, it is still over 80%. So the case for adopting a flexible pathway is still robust.

With respect to the 2° stabilisation scenario, Section 3 established an even stronger case for flexible pathways than for the SRES-A2 scenario. This will remain true if review dates are brought forward.

Later Review Dates

Instead of bringing the review dates forward by 15 years we push them out by 15 years, giving review dates of 2060-70 and 2090-2100. This effectively means that what is the second review date in the 'Earlier Review' scenario becomes the first review date here.

Intuitively the longer the wait until a higher cost option is implemented, the lower is its discounted cost. In the meantime, however, there is a greater potential for a breach and thus an increase in the expected economic loss. So again the direction of change in the cut-off probability could go either way.

In fact the financial analysis shows that only Pathway (v), 4 to 2C has a cut-off probability less than 100%; it is 44.2%, which is slightly lower than the 48.2% in the base case. So for this pathway the case for flexibility is marginally weaker meaning that the increment in the potential discounted loss due to a breach outweighs the incremental benefit of the lower discounted cost of investment. For the other pathways the implication is that deferral and the maintenance of flexibility is always preferable.

For Pathway (v), 4 to 2C the VfM analysis produces a cut-off probability of 51.0% which is a change in the same direction as when the review dates are brought forward, so under the MCA metric the attraction of greater protection is offset by the reduction in the discounted investment cost on this occasion. The size of the change, however, is small. For the other pathways the VfM analysis still produces cut-off probabilities that exceed 100%.

Overall we may conclude the case for flexibility is robust with respect to a wide range of decision of review dates.

6. Sensitivity Analysis: Costs and Losses

Advice from GWRC is that cost estimates have an error margin of up to ±15%. Some are lower. For the purposes of analysis we treat this as a 95% confidence interval which, assuming that cost estimates are normally distributed, implies a standard deviation of 7.65%. We also apply this to the estimates of economic loss in case of a breach of the flood banks.

A Monte Carlo analysis is undertaken to test the sensitivity of the A2 climate change cut–off probability to errors in the estimates of costs and losses. From Section 3 if the A2 type of climate change presents a strong case for a pathway approach, so does the less extreme 2° warming type of climate change. We ran 20,000 simulations which are summarised in Table 9.

Table 9: Sensitivity of A2 Climate Change Cut-Off Probability to Errors in Estimates of Cost and Losses

	Mean	Std Dev
(v) 4 to 2C		
Base case	0.482	NA
Only stand-alone investment costs	0.469	0.202
Only pathway transition cost	0.499	0.098
Both of the above	0.489	0.234
Only losses	0.485	0.047
All losses and costs	0.493	0.244
(vi) 4 to 1A		
Base case	1.302	NA
Only stand-alone investment costs	1.303	0.175
Only pathway transition cost	1.323	0.181
Both of the above	1.327	0.255
Only losses	1.304	0.050
All losses and costs	1.325	0.261
(vii) 2C to 1A		
Base case	1.343	NA
Only stand-alone investment costs	1.345	0.196
Only pathway transition cost	1.385	0.251
Both of the above	1.385	0.334
Only losses	1.343	0.027
All losses and costs	1.390	0.337
(xi) 4 to 2C to 1A		
Base case	1.596	NA
Only stand-alone investment costs	1.601	0.221
Only pathway transition cost	1.629	0.244
Both of the above	1.633	0.341
Only losses	1.599	0.074
All losses and costs	1.646	0.360

It assumed that errors are independent; that is over- or understatement of one particular cost is not related (either positively or negatively) to over- or under-statement of any other cost. For example, if the cost of Option 4 is understated it does not imply that the cost of Option 2C is understated – or overstated. It would be a relatively straightforward task to simulate the effects of correlation in the errors, but at this stage we have no knowledge of the possible extent or even direction of any correlation.

Path (v) 4 to 2C: The results reveal that transition investment costs and losses have a relatively small effect on the climate change cut-off probability; the probability of climate change above which it is optimal to proceed immediately to a higher cost option – in this case Option 2C.

The largest impact comes from the stand-alone investment costs. This is primarily because these costs are faced sooner. At two standard deviations away from the mean (approximately equivalent to a 95% confidence interval) the cut-off probability gets close to zero if Option 4 costs were overstated by 15% while Option 2C costs were simultaneously understated by 15%. This is probably unlikely, but it does imply that more refined cost estimates are advisable before a final decision is made.

Path (vi) 4 to 1A: Recall from Table 2 that the climate change cut-off probability for this pathway is over 100%. In other words there is no probability that justifies proceeding immediately to Option 1A – given current knowledge. At two standard deviations from the mean the cut-off probability would fall to about 80%, but nonetheless the case for flexibility is very strong.

Path (vii) 2C to 1A: The results here are similar to those for Pathway (vi). Errors in the estimates of expected losses have a very small effect, mostly because they are the same for the two options (see Figure 2). Errors in the investment cost estimates have a slightly larger effect than under Pathway (vi), but the results still provide a robust case for delaying possible investment in Option 1A.

Path (xi) 4 to 2C to 1A: Again this is a pathway for which the climate change cut-off probability is over 100% – well over 100%. Even with a 95% confidence interval the cut-off value remains above 90%, so the value of flexibility associated with this pathway is very robust.

Summarising, while the case for flexibility is generally insensitive to errors in the estimates of costs and losses, with the case for delaying a move to Option 1A being particularly robust, it would seem sensible to revisit the investment costs for Options 4 and 2C before final decisions are taken, to ensure that the cost of Option 4 is not being understated while the cost of Option 2C is not simultaneously being overstated.

Appendix A: The Value of Delay - An Example

For the purpose of illustrating the methodology used to assess how a flexible investment strategy can deliver benefits, consider the following:

1. The planning horizon is 100 years.
2. There are two flood defence options, Option 5A and Option 2C.
3. There are two climate scenarios; no change and SRES Scenario A2, 50th percentile.
4. There is a review of flood defences in 2045, at which point a change from Option 5A to Option 2C is a possibility.

The values in Table A1 are used for the calculations. The analysis is done in 5-year blocks to avoid spurious accuracy. For analytical purposes it is assumed that the climate scenario (A2-50%) evolves over time between 2020 and 2100. Table A2 presents the flood parameters with and without climate change.

Table A1: Costs and Parameter Values

	Variable	Value
1	Discount rate	3%
2	Economic cost of a flood caused by a breach or over-topping between the Melling and Ewen bridges, on either bank.	$338m, $604m, $1097m depending on breach scenario
3	Cost of new Melling bridge, in both options	$28m
4	Cost of Option 5A. Assume built over 5 years between 2015 & 2020	$96m
5	Cost of Option 2C if built instead of Option 5A.	$143m
6	Incremental cost of Option 2C if built after Option 5A during 2045-2050.	$66m as save on some costs

Table A2: Climate Scenario Flood Parameters

	No Climate Change		SRES A2-50%	
	Option 5A	Option 2C	Option 5A	Option 2C
Capacity (m^3/s)	2300	2800	2300	2800
ARI (years)	440	2800	24	225
Probability of breach, given flood				
1800-2100 m^3/s	0	0	0	0
2100-2550	0.12	0	0.12	0
>2550	0.37	0.11	0.37	0.11
5-yr AEP				
1800-2100 m^3/s	0.0627	0.0627	0.3239	0.3239
2100-2550	0.0202	0.0202	0.1394	0.1394
>2550	0.0045	0.0045	0.0817	0.0817

Once Only Decision

The matrix below shows discounted total costs (expected economic loss plus the cost of investment in flood protection) for the two climate scenarios and the two options for flood risk management action (from Table 1).

Table A3: Scenarios and Discounted Costs

Action	No climate change	Climate Change (A2-50%)
Option 5A	[1] $110m	[3] $186m
Option 2C	[2] $136m	[4] $154m

There are four scenarios in total:

1. No climate change and invest in Option 5A
2. No climate change and invest Option 2C
3. Climate change and invest Option 5A
4. Climate change and invest Option 2C.

The two scenarios on the leading diagonal in Table A3 (cells 1 and 4) are optimal in the sense that a correct decision is made. If we postulate a Null Hypothesis of no impact of climate change on flood frequency, the second scenario is a Type I error – the relative cost penalty of over-investing in flood protection ($26m) if the risk of economic loss associated with climate change does not increase, while the third scenario is a Type II error – the relative cost penalty of underinvesting in flood protection ($32m), that is not pursing Option 2, when climate change does change flood frequency upwards.

For any probability of climate change affecting rainfall frequency and severity and causing economic loss (p), the statistically expected total discounted cost of Option 5A, E(5A) is:

$$E(5A) = 110(1-p) + 186p$$

Similarly the expected total discounted cost of Option 2, E(2) is:

$$E(2) = 136(1-p) + 154p$$

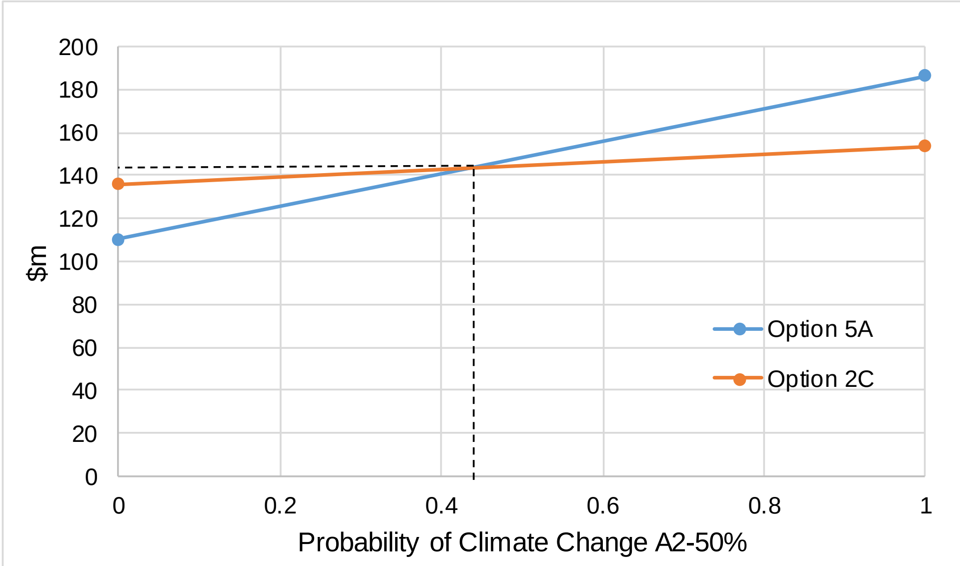
These two equations yield the same solution if p=44.1%. So for p in excess of this value Option 2C should be pursued; otherwise Option 5A is preferred.

Figure A1 illustrates the situation. The cut-off point is where the two lines intersect.

Value of Delay

However, the above is all based on the assumption that a decision is made only once to pursue a single option at the start of the planning period (2015-20). When we know that climate and societal conditions are changing, is there value in pursuing Option 5A initially and delaying a decision to upgrade to Option 2 until the policy trigger is reached (plus lead-in time for implementation)?

Figure A1: Actions and Climate Change



We assume that Option 5A is implemented at the start of the period and that a review is undertaken in 2045, at which point either Option 2C is implemented if the policy trigger point has been reached, or nothing extra is done until the next policy trigger point.

As before, consider a probability (p). For what value of p does the expected cost of delay E(D) equal the cost of proceeding with Option 2C at the start?

The calculations in Table A4 on the next page show that the expected discounted cost of pursuing Option 5A at the start of the planning period and then implementing Option 2C in 2045 is $166m. Hence the equation we need to solve is:

$$E(D) = 110(1-p) + 166p = 154$$

Table A5 shows E(D) expected cost for various values of p. At p=77.5% the expected cost of delay at $154m is the same as the expected value of pursuing Option 2 at the start of the period in the situation where climate change is certain.

Table A5: Expected Costs under Uncertainty

Probability of A2-50%	Expected cost with delay ($m)
0%	110
20.0%	121
50.0%	138
77.5%	154
80.0%	155
100%	166

Table A4: Expected Loss and Cost of Flood Protections Works

		No Climate Change				Possible SRES A2-50% Climate Change					
		Option 5A		Option 2C		Option 5A		Option 2C		Option 5A then 2C	
		Loss ($m)	Invest ($m)	Loss ($m)	Invest ($m)	Loss ($m)	Invest ($m)	Loss ($m)	Invest ($m)	Loss ($m)	Invest ($m)
0	2015										
1	2020	3.3	96.3	0.5	142.8	3.3	96.3	0.5	142.8	3.3	96.3
2	2025	3.3		0.5		5.7		1.1		5.7	
3	2030	3.3		0.5		8.0		1.6		8.0	
4	2035	3.3		0.5		10.4		2.2		10.4	
5	2040	3.3		0.5		12.7		2.7		12.7	
6	2045	3.3		0.5		15.1		3.3		15.1	
7	2050	3.3		0.5		17.4		3.8		17.4	66.24
8	2055	3.3		0.5		19.8		4.4		4.4	
9	2060	3.3		0.5		22.1		4.9		4.9	
10	2065	3.3		0.5		24.5		5.5		5.5	
11	2070	3.3		0.5		26.8		6.0		6.0	
12	2075	3.3		0.5		29.2		6.6		6.6	
13	2080	3.3		0.5		31.5		7.1		7.1	
14	2085	3.3		0.5		33.9		7.7		7.7	
15	2090	3.3		0.5		36.2		8.2		8.2	
16	2095	3.3		0.5		38.6		8.8		8.8	
17	2100	3.3		0.5		40.9		9.3		9.3	
18	2105	3.3		0.5		43.3		9.9		9.9	
19	2110	3.3		0.5		43.3		9.9		9.9	
20	2115	3.3		0.5		43.3		9.9		9.9	
Discounted total at 3%pa		20.9	89.3	3.5	132.5	96.8	89.5	21.2	132.5	51.9	114.3
Total cost			110.2		135.9		186.2		153.6		166.2

This table shows the statistically expected loss and cost of investment in flood protection infrastructure for two flood protection options (Options 5A and 2C and two climate scenarios (no climate change and SRES A2-50%). The discount rate is 3%.

Therefore if the probability of A2-50% climate change is more than 77.5%, Option 2C should be pursued immediately. Otherwise it should be delayed.

It is revealing to note that the cut-off probability when delay is possible is 77.5%, but that if delay is not possible the cut-off probability is only 44.1%. This difference is as expected; incorporating option values will normally lead to a more cautious investment strategy than relying on a standard CBA analysis.

Multi-Criteria Analysis and the Efficiency of Options

Table A6 compares the results of the Multi-Criteria Analysis evaluation (from the Boffa Miskell report)[9] with the investment costs of the options – that is excluding the expected residual loss from a flood event. The reason that expected loss is excluded is because we wish to examine the efficiency or Value for Money (VfM) expressed as the ratio of benefits to costs, and as the flood avoidance benefit is the major component in the MCA score, it would be illogical to also include that benefit (in the form of the expected loss) as a cost.

The MCA scores have been scaled so that Option 1A has a score of 100. This makes no difference to the analysis.

Ignoring any climate change effect on flood frequency and magnitude, Option 2C represents 23% better VfM than Option 5A.

Table A6: Efficiency of Options

	Probability	MCA pts*	Probability Weighted Discounted Investment ($m)	pts/$ x100	Comment
			No Climate Change is Certain		
Option 2C		3.79	132	2.861	Build Option 2C at start
Option 5A		2.08	89	2.328	Build Option 5A at start
			Probability of Climate Change (A2-50%) is Uncertain, Delay Option 2C until 2045		
	0.0%	3.19	89	3.572	
	25.0%	3.19	96	3.339	
	50.0%	3.19	102	3.134	
	80.0%	3.19	109	2.919	
	88.9%	3.19	110	2.861	
	100.0%	3.19	114	2.792	

* The MCA score for the pathway 5A to 2C is a weighted average of the individual scores, with the weights equal to the share of the planning period over which each option prevails

Under more realistic scenarios in which the extent of the effect of climate change is uncertain, does VfM improve further if a decision to invest in Option 2C is delayed? Before answering this question we need to decide how to treat the MCA scores when a time dimension is added.

[9] Op cit.

Firstly the MCA scores are not discounted as they are relative, not absolute. They are also particular to the individuals and group undertaking the MCA analysis. A different group may produce different results.

Secondly we assume that when Option 2C is delayed, the MCA score for Option 5A applies up to and including 2050 (allowing up to five years for construction) and that the MCA for Option 2C applies thereafter. Again, as the scores are relative there is no overall decline in the MCA scores to reflect the risk of climate change raising the likelihood of a breach.

The value of the MCA at 3.19 corresponds to 35 years (up to 2050) of the Option 5A benefit and 65 years of the Option 2C benefit. This markdown to the full benefit of Option 2C is worth the cost saving achieved under deferral, but not if the probability of climate change effects on flood frequency and magnitude gets too high; namely over 88.9% in this case.

Why is this probability higher than the 77.5% derived in the previous section? Conceptually the difference could be in either direction. Relevant factors are:

1. How the rate at which the rising expected cost of the damage from climate change (in the 77.5%) compares with the deferred benefit from Option 2C – as measured by the undiscounted MCA score. The quicker the increase in the expected cost of the damage from climate change effects, the lower the associated cut-off probability.

1. The VfM calculation includes benefits such as traffic flows and river access that are additional to the reduction in potential economic loss from investing in flood protection. These benefits do not depend on climate effects so there is less reason for delay.

2. Even if no benefits other than flood protection were included in the MCA, there is no guarantee that the relative dollar values of economic loss between the options would align with the relative scores of an MCA evaluation.

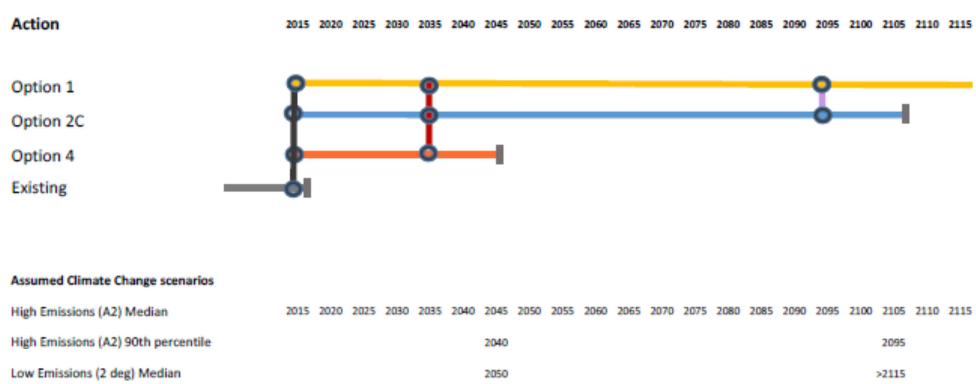
The MCA methodology may be more subjective, but with errors in the estimates of cost and loss, the VfM result is not necessarily inferior. Both results should be considered by decision makers. Nevertheless two questions arise:

1. How robust are the results of the MCA?

2. Are the incremental investment cost differences between various flexible pathways commensurate with the MCA point differences so as to allow meaningful comparisons of value for money?

Appendix B: Adaptive Pathways

Hutt River City Centre Upgrade Project - Adaptation Pathways Map



Path Actions	Relative Costs	Target Effects	Side Effects		
			Social Impacts	Transport	Ecology Environmental
[yellow arrow]	0	++++	- - - -	+++	++++
[blue arrow]	++++	++++	- - -	++++	+++
[orange arrow]	++++	0	0	++	+
[blue arrow] [yellow arrow]	0	++++	- - - -	++++	++++
[orange arrow] [blue arrow]	++++	++	- -	++++	+++
[orange arrow] [blue arrow] [yellow arrow]	++	++	- - - -	++++	++++
[orange arrow] [yellow arrow]	++	++	- - - -	+++	++++

Adaptation Pathways Map (draft)
'Use by Date' Review Date approx. 10 years before the 'Use by Date'
The 'Use by Dates' shown on the map have been assessed on the basis of three potential climate change scenarios. The scale below the map shows the 'review dates' and 'use by dates' for each scenario.

The panel to the right of the pathways diagram provides summary measures for each option. More favourable (i.e. cheaper) construction costs and better flood protection that meets design standards over at least 100 years, are indicated by more plus (+) signs under Relative Costs and Target Effects respectively. The last three columns show qualitative ratings for social costs (mostly related to property purchase), transport effects and ecological/environmental effects. These are not directly addressed in this report, but they are incorporated into the multi-criteria analysis.