Infometrics

Real Options Analysis of Strategies to Manage Coastal Hazard Risks: Southern Units J-L

for Hawke's Bay Regional Council

November 2017

Contents

1. Executive Summary

The Hawke's Bay Regional Council (HBRC), Napier City Council (NCC) and Hastings District Council (HDC) have convened a Technical Advisory Group (TAG) to develop strategies for adapting to coastal hazard risks caused by climate change.

Infometrics was requested by the TAG to look at whether the use of Real Options Analysis (ROA) would provide worthwhile insight into the development of those strategies. ROA is an expanded version of cost-benefit analysis that assesses whether there is value in waiting for more information before an expensive and possibly irreversible investment is undertaken, and whether an alternative investment might suffice in the meantime.

In the case of an increasing risk of coastal inundation for example, is it better for a community to retreat inland in the very near future (which is effective, but expensive), or is it better to construct some form of coastal defence that provides protection from most inundation scenarios for the next 20-30 years, and perhaps for much longer if the effects of climate change end up being less severe than anticipated?

The ROA provides the councils with a costing assessment that enables decision making that can be flexibly implemented over time as the climate changes and as its impacts increase. This ensures that decisions taken today do not create further risks which are costly to reverse in the future, and that a range of options have been assessed for their ability to meet community objectives over time.

The ROA complements Multi-Criteria Decision Analysis and the application of the Dynamic Adaptive Policy Pathways framework.

Broadly, the results demonstrate that a flexible investment strategy, enabling a change of course in the future, is more likely to deliver a lower cost outcome than pursuing a single option. The main results for each unit are presented below.

Unit L: Clifton

For Unit L: Clifton, our results show that if the probability of the type and extent of climate change considered by the TAG (from Tonkin & Taylor) is more than about 60%, the best option is to construct a sea wall that provides sufficient protection until around 2045. For a probability of less than 60% it is better not to pursue any of the options presented.

Come 2045 it is likely, but not certain that the sea wall will need to be enhanced. It is also possible that enhancement will not be required or that no enhancement whatsoever will provide the requisite level of protection. In that case retreat would be the only option. At present though, that option is too expensive relative to the what is currently known about the risk of damage.

Unit K: Haumoana

For Unit K:Haumoana the least cost choice, based on current estimates of protection costs and potential losses, is to adopt the 'retreat the line' option immediately if the probability of climate change (of the type analysed by Tonkin & Taylor) is more than about 42%. Otherwise it is better to do nothing. However, retreat the line has little flexibility. For an additional expected discounted cost of around $2m, the best choice is to begin with control structures and beach renourishment as this leaves open the options of enhanced control structures, partial retreat or even full retreat at a later date.

Unit K: Te Awanga

The situation for Te-Awanga is very similar to that for Haumoana. A lower probability of (T&T scenario) climate change is required to justify investing in any protective measure, but 'retreat the line' again has the lowest expected cost. A more flexible pathway is to begin with control structures and beach renourishment, retaining the possibility of retreating later.

Unit J: Clive / East Clive

The results for Clive provide a very clear message: retain the status quo (essentially do nothing) for the next 25-30 years, after which beach renourishment and control structures constitute the best protective strategy – least investment cost plus expected loss, and most flexible. In the longer term a sea wall or retreat the line may be required.

A stand-alone summary page for all of the southern units follows.

Summary of Results

Summary of ROA Results

	Least expected cost	Highest MCDA	Best value for money	Most flexible	Cost premium
Unit J: East Clive	Q+C+C	Q+C+L	Q+C+C	Q+C+C / Q+C+S	na $1.4m
Unit K: Te Awanga	L	C+C+C	C+C+C	C+C+C / C+C+L	$1.8m, $2.2m
Unit K: Haumoana	L	C+C+M	C+C+C	C+C+C / C+C+L	$1.3m, $2.1m
Unit L: Clifton	S+S+S	S+S+M	S+S+M	S+S+S / S+S+M	na $1.2m

Q: Status quo, R: Renourishment of the beach, C: Control structures such as groynes and breakwaters, with renourishment, S: Sea wall, M: Managed retreat, L: Retreat the Line

Notes

1. All future values are discounted (base rate is 3%). Investment costs for protection options use Tonkin & Taylor's 'medium' estimates. The values of assets lost under retreat options are treated as protection costs. There is no allowance for the possibility that assets might be replaced with cheaper structures. All pathways provide protection up to at least a 1% AEP scenario.

2. If there is no climate change adverse events that cause damage would be rare, so we assume that the 0.5% AEP scenario applies. If there is climate change, but no investment in protection, losses would be frequent, so we take the sum of the 0.5%, 1% and 10% AEP scenarios. Although both situations are unlikely they are useful for analytical purposes.

3. The least cost options may change under different assumptions about discount rates, values of potentially lost assets, protection costs or climate scenarios. In general the conclusion are robust to changes in assumptions. although a lower discount rate (which implies greater weight on the welfare of future generations) tends to strengthen the case for moving to managed retreat sooner rather than later. Owing to a lack of data we have not considered climate change scenarios other than the one used by Tonkin & Taylor.

4. Although for analytical purposes we assume review dates and transition periods in 2040-45 and 2070-75, in practice these dates may change. It is expected that a number of well-defined trigger points will be decided in advance. Examples could include a frequency or intensity threshold for extreme events, or a given change in mean sea level. It is understood that the *Edge* National Science Challenge is involved in this process.

5. Finally we stress that our analysis is based purely on economic costs and avoided losses. Other than though the MCDA results it does not consider the social, cultural or environmental aspects of coastal hazard risks associated with climate change.

2. Unit L: Clifton

We begin with Unit L and so present more detail on the methodology than we include for the other units.

Objective

We wish to ascertain the probability of climate change (of the type and extent used by Tonkin & Taylor)[1] occurring that determines:

- When doing something to deal with the adverse effects of climate change is better than doing nothing.
- If something is done, what is the best combination and timing of options?

Assumptions

A number of assumptions, especially around costs and losses are required for the analysis. They may need updating as more information becomes available.

1. Values of economic loss are shown below (from the data that underlies Figures 7.7 and 7.10 in T&T report). To avoid possible double counting we take the maximum loss from erosion or inundation, rather than adding them.

Table 1: Max (Inundation Loss or Erosion Loss)

AEP	2015	2065	2120
0.095	2.8	3.7	8.5
0.010	2.9	5.5	10.2
0.005	3.4	6.1	11.4

2. Each protection choice except managed retreat provides protection up to the AEP=0.01 level of residual risk/loss, up to the date at which protection needs to be enhanced.
3. With managed retreat there is no residual risk and thus no possibility of residual loss.
4. The 33% likelihood of occurrence for erosion is approximately consistent with an AEP=0.01 for inundation.
5. If there is no climate change and little or no protection is undertaken, losses would follow the AEP=0.005 scenario – a sort of 'business as usual'.
6. If there is climate change (of the type used in the Tonkin & Taylor report, which we will refer to as the T&T scenario) and no protection is undertaken, losses will follow the full loss profile above.

[1] Tonkin and Taylor (2016). *Hawke Bay Coastal Strategy, Coastal Risk Assessment*. Prepared for Hawke's Bay Regional Council.

7. The costs for each protection pathway are set out in Table 2. All costs except for managed retreat are from T&T. A more detailed split between capital costs and maintenance costs is provided in Appendix A.

8. For managed retreat the cost is assumed to be 100% of assets at risk ($11.4m), with no further loss after retreat. We classify this as an investment cost rather than as a residual loss, as one can think of it as approximately the cost of replacing existing assets with assets of the same age and quality.

Table 2: Pathway Costs (Medium, $m)

		ST	MT	LT	Total
Pathway 1	R+M+M	7.125	11.4	0.000	18.525
Pathway 2	C+C+M	6.250	3.893	11.4	21.543
Pathway 3	C+C+C	6.250	3.893	9.400	19.543
Pathway 4	C+C+S	6.250	3.893	9.575	19.718
Pathway 5	S+S+M	5.225	0.713	11.4	17.338
Pathway 6	S+S+S	5.225	0.713	4.825	10.763

R: Renourishment of the beach

C: Renourishment and Control structures such as groynes

S: Sea wall or revetment

M: Managed retreat

9. It is assumed that each pathway protects against both erosion loss and inundation loss.

10. Following Tonkin & Taylor it is assumed that the protection measures (including retreat where relevant) are undertaken in the 5-year periods ending 2025, 2045 and 2075 (presumably before a previous measure becomes ineffective). For example under Pathway 2 beach renourishment can no longer protect against an AEP=0.01 event by 2045, so there is managed retreat between 2040 and 2045.

11. The discount rate is 3%. See Appendix B.

Results: Fixed Pathways

We look first at the six fixed pathways established by the TAG. In participle these pathways are predetermined in the sense that once a particular pathway has been selected it is unlikely to be changed. Consequently the only question of interest is under what probability of climate change (T&T scenario) occurring is it better to adopt each pathway rather than doing nothing. Table 3 shows the cut-off probabilities.

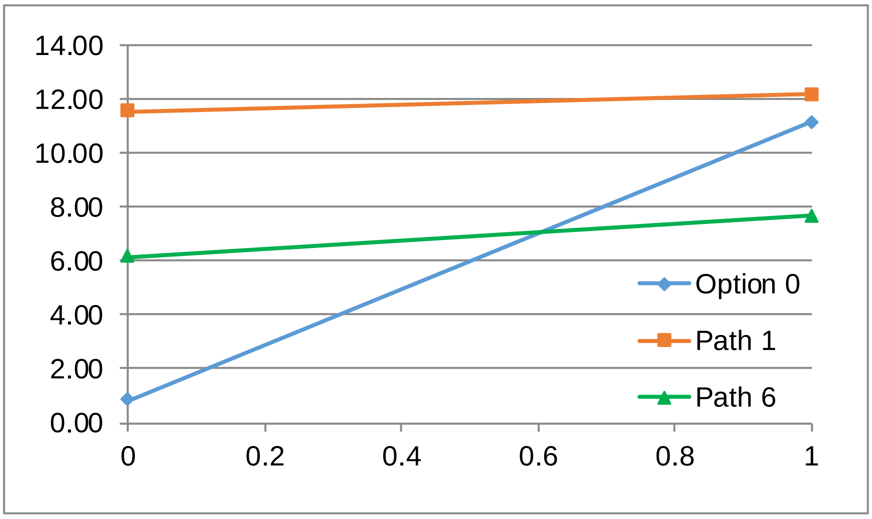
If the prospect of (T&T scenario) climate change is low, taking action to mitigate its effects is likely to be a waste of resources. Better to do nothing – denote this as Option 0. (Strictly speaking, existing measures would presumably continue to apply to deal with historic risks). The situation is illustrated in Figure 1. If nothing is done (blue line) and climate change occurs, the expected loss is around $11m. If Path 6 is adopted and climate change does not occur, the expected loss is about $6m.

Table 3: Pathway Cut-off Probabilities

	Pathway	Cut-off Probability	PV(cost +loss) $m
1	R+M+M	>100%	12.20
2	C+C+M	92.7%	10.47
3	C+C+C	82.5%	9.60
4	C+C+S	90.3%	10.29
5	S+S+M	74.8%	8.83
6	S+S+S	60.4%	7.65

Real Options Analysis (ROA) tells us that if we assess the probability of (T&T scenario) climate change as being at least 60%, Path 6 should be adopted. Paths 2-5 are preferred to doing nothing with higher probabilities of (T&T scenario) climate change, but it takes a probability of over 100% for Path 1 (renourishment in the short term and then retreat) to be preferred, Clearly this is nonsensical, as illustrated by the orange line being everywhere above the other lines.

Figure 1: Paths 1 and 6 versus Do Nothing



Given all six pathways lead to a satisfactory outcome with regard to protection (by definition), the choice of which to adopt comes down to two considerations:

1. Which has the lowest discounted total cost – investment plus statistical residual loss – if (T&T scenario) climate change occurs?

2. Which requires the lowest probability of (T&T scenario) climate change to justify doing something rather than nothing?

Path 6 has both the lowest total expected cost and requires the lowest probability of (T&T scenario) climate change occurring to be preferred over doing nothing. So that is best choice.

However, confining the choices to the above six predetermined pathways with no transition between pathways, although understandable from a communication perspective, means that ROA is not being used to assess flexibility. For example there may be circumstances under which initial renourishment should be followed by sea wall construction. That particular permutation is not available in the six pathways identified above.

A more common approach within the framework of real options analysis is to define the protection options (beach renourishment, sea wall, retreat etc) and allow for transition between them to define the pathways.

Flexible Pathways

The six pathways considered above contain four generic options:

1. Renourishment of the beach (R),
2. Control structures such groynes and breakwaters, with renourishment (C),
3. Sea wall (S),
4. Managed retreat (M).

The options and possible pathways are shown in Figure 2. Excluding some obviously silly permutations, there would seem to be 16 plausible pathways, as listed in Table 4. They are numbered 7-22 to distinguish them from the original six (which are shown in parentheses).

Because seawalls and control structures require augmenting or renewing at various stages (as shown in Table 2) the options shown in Table 4 may contain a (T) to denote a transition cost. For example S(T) means that a sea wall is built after some other structure. Here the transition cost is assumed to be equal to the short term plus the medium term cost of a sea wall, from Table 2.

Note also that if M is undertaken it is assumed to occur only once and is irreversible.

Figure 2: Pathways Map

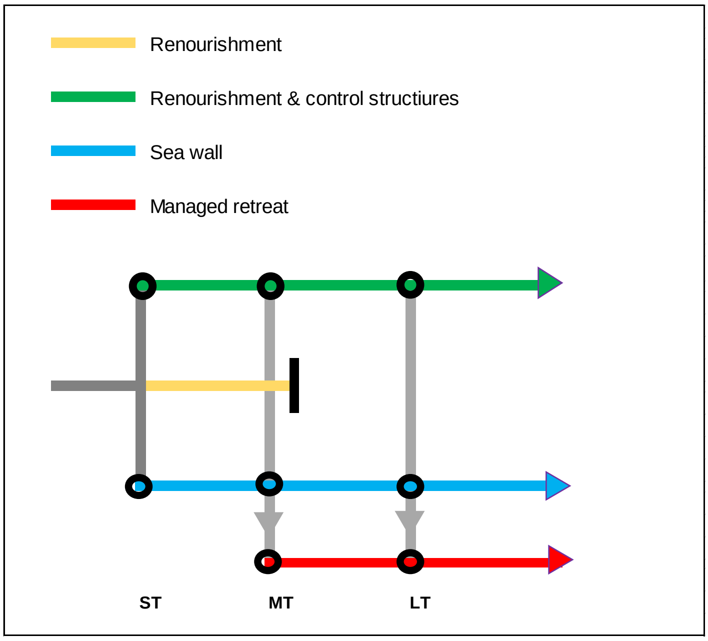


Table 4: Full Set of Plausible Pathways

Option	ST	MT	LT	Discounted Investment Cost	Discounted Cost + Loss	End state	Cut-off probability cf end state
7	R	C(T)	C	9.80	11.29	C	No soln
8	R	C(T)	S	10.49	11.97	S	No soln
9	R	C(T)	M	11.10	12.16	M	31%
10	R	S	M	10.74	11.84	M	60%
11	R	S	S	9.18	10.67	S	No soln
12 (1)	R	M	(M)	11.57	12.20	M	<0%
13 (3)	C	C	C	8.11	9.60	C	NA
14 (4)	C	C	S	8.80	10.29	S	No soln
15 (2)	C	C	M	9.37	10.47	M	>100%
16	C	S(T)	S	9.02	10.51	S	No soln
17	C	S(T)	M	10.58	11.68	M	74%
18	C	M	(M)	11.41	12.04	M	<0%
19 (6)	S	S	S	6.17	7.65	S	NA
20 (5)	S	S	M	7.72	8.83	M	>100%
21	S	M	(M)	10.91	11.54	M	78%
22	M	(M)	(M)	11.40	11.40	M	NA

Under the six fixed pathways the decision on which to adopt meant answering two questions:

1. What probability of (T&T scenario) climate change justifies adopting any of the six pathways, rather than doing nothing?
2. If one of the six is adopted, which should it be?

With greater pathway flexibility we now have a third question:

3. Given that something will be done, are there circumstances that would justify moving more quickly to a long term permanent solution rather than keeping options open?

Hence we first group the above pathways according to the nature of their ultimate solution; control structures (C), sea wall (S) or managed retreat (M).

Consider the case where C is the end point; only Paths 7 and 13 (=3) qualify. The analysis reveals that Path 7 is never preferable to Path 13 (the cost curves are parallel). That is, if C is the end point there is no probability of (T&T scenario) climate change that would justify beginning with option R and moving to C later.

A similar result applies if S (sea wall) is the endpoint. Five paths are in this group (8, 11, 14, 16 and 19), but there is no probability of (T&T scenario) climate change that would justify adopting any of Paths 8, 11, 14 or 16 in preference to embarking on the full sea wall Path 19 from the start.

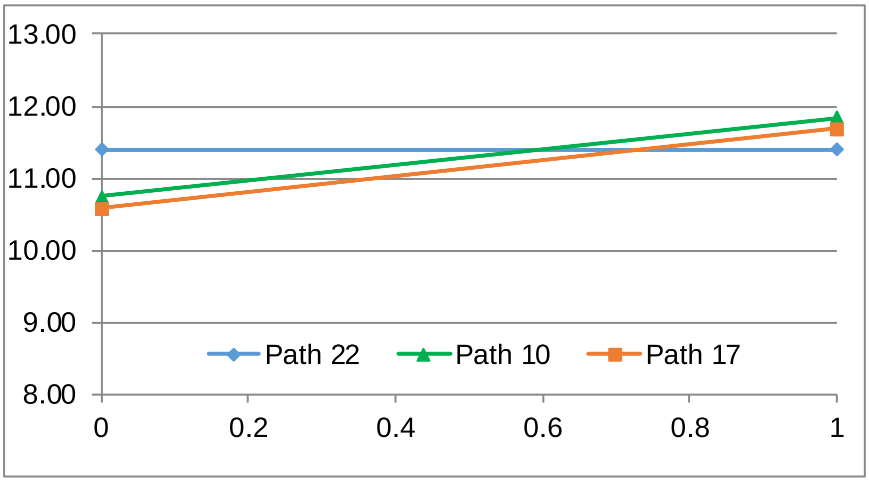
In contrast if M (managed retreat) is the endpoint:

- Paths 15 (=2) and 20 (=5) are always preferred to Path 22 (straight to M).

- Paths 9, 10, 17 and 21 are preferred to Path 22 if the probability of (T&T scenario) climate change is positive but less than 100%. For Path 10 for example the cut-off probability is 60%.
- Paths 12 (=1) and 18 are never preferred to Path 22.

It is worth considering in a bit more depth what these results actually mean. Figure 3 illustrates Path 22 (blue, straight to managed retreat), Path 10 (green, renourishment in the short term, then a sea wall and then managed retreat) and Path 17 (orange, renourishment and control structures, followed by sea wall and then managed retreat).

Figure 3: Paths 10, 17 and 22



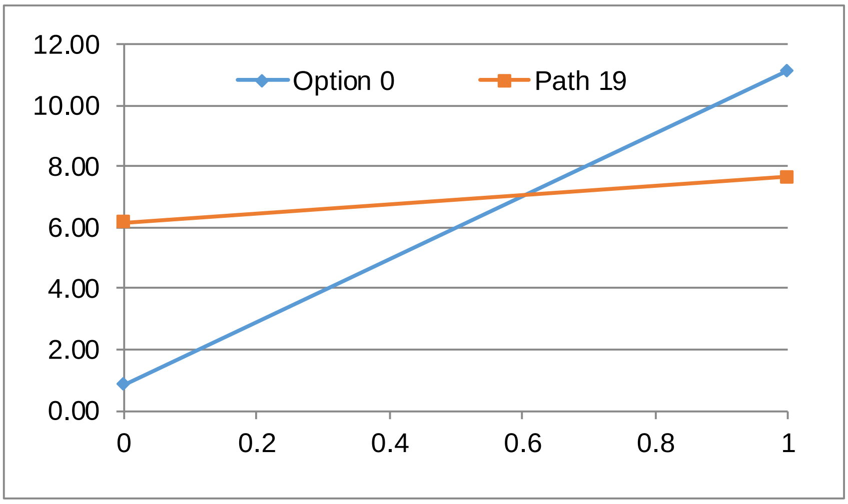
In Figure 3 all pathways share the same end outcome (M). If the probability of (T&T scenario) climate change is less than about 60% Path 10 is better than Path 22. For a probability above 60% Path 22 is preferred to Path 10. However, a number of other pathways that end with M are preferred to Path 22. For example Path 17 (orange line in Figure 3) is always below Paths 10 and 22 and thus always preferable.

What then is the best pathway to adopt initially? Options C, S and M all lead to acceptable outcomes in the long term, so the choice comes down to three considerations:

1. Which has the lowest discounted total cost (investment plus residual loss) if (T&T scenario) climate change occurs?
2. Which requires the most plausible probability of (T&T scenario) climate change to justify adopting it?
3. Which options retain flexibility?

Path 19 (=6) has the lowest discounted total cost at $7.65m. Its end point is a sea wall (S) and there is no probability of (T&T scenario) climate change that justifies embarking on some other option (such as R or C) to begin with – based on current knowledge. And we know from above that if the probability of (T&T scenario) climate change is greater than about 60%, Path 19 (= Path 6) is also better than going nothing. None of the other pathways have a lower cut-off probability.

Figure 4: Path 19 (= Path 6) v Doing Nothing



Path 20 (=5) has the next lowest total discounted cost ($8.83m) and is preferred to doing nothing if the probability of (T&T scenario) climate change greater than 75% (Table 3). Thus Paths 19 and 20 are reasonably close from an analytical perspective. The key difference between them is that Path 20 ends with managed retreat whereas under Path 19 a sea wall is adequate, albeit with a 1% AEP residual risk.

In summary then:

> If the probability of (T&T scenario) climate change is at least around 60%, the first stage sea wall should be built. Given what we know at present about future climate change this action has the lowest statistically expected cost, balancing the likelihood of having to enhance the sea wall later or even retreating, against the possibility that no further action will be required. At around 2040 these options should be re-evaluated.

However, these results are still provisional. In the next section we test the results against:

- Alternative damage scenarios
- When protection measures are undertaken
- Estimates of costs and losses
- Discount rate.

Sensitivity Tests

At this stage we do not have enough information to test alternative climate change scenarios. However, changing investment costs and losses could produce similar results.

Each sensitivity test is performed in isolation, but with more comprehensive distributions of the uncertainty around costs and loses a Monte Carlo procedure could be used to analyse different scenarios simultaneously.

Discount rate

The assumed rate of 3% is more like a social rate of time preference than a commercial discount rate. We look at two other discount rates; a higher rate of 6% (as used by Treasury for these types of projects), and a lower rate of 1.5% which has been used for analysing very long term climate change problems.

With a discount rate of 6% the difference in discounted total costs between Path 19 (=6) and 20 (=5) narrows to less than $0.3m, still in favour of Path 19, but both require the probability of (T&T scenario) climate change to be more than 100% to be preferable to doing nothing.

With a discount rate of 1.5% Path 19 still has the lowest cost, but Path 22 (straight to managed retreat) is now next lowest – the difference is $1.0m. Path 19 requires a probability of (T&T scenario) climate change of only 35% to be preferred to doing nothing whereas Path 22 requires 49%.

The qualitative message from these results is that the more weight one attaches to the economic welfare of future generations, the more the optimal path tends towards managed retreat sooner rather than later, depending of course on whether the probability of (T&T scenario) climate change is seen as more likely than not.

Investment Costs

The two tables below are analogous to Table 2 and represent Tonkin & Taylor's estimates of low and high bounds for the costs of the various protection measures, excluding the costs of managed retreat which are held constant.

Table 5: Investment Costs, High Scenario

	Pathway	ST	MT	LT	Total
1	R+M+M	9.563	11.400	0.000	20.963
2	C+C+M	8.150	4.950	11.400	24.500
3	C+C+C	8.150	4.950	11.900	25.000
4	C+C+S	8.150	4.950	12.000	25.100
5	S+S+M	6.600	0.900	11.400	18.900
6	S+S+S	6.600	0.900	6.000	13.500

Under high investment costs Path 19 still prevails with a discounted total cost advantage of $0.9m over Path 20. The cut-off probabilities relative to doing nothing are 79% and 90% respectively. All of the other paths have cut-off probabilities of more than 100%.

Table 6: Investment Costs, Low Scenario

	Pathway	ST	MT	LT	Total
1	R+M+M	4.688	11.400	0.000	16.088
2	C+C+M	4.350	2.835	11.400	18.585
3	C+C+C	4.350	2.835	6.900	14.085
4	C+C+S	4.350	2.835	7.150	14.335
5	S+S+M	3.850	0.525	11.400	15.775
6	S+S+S	3.850	0.525	3.650	8.025

Under low investment costs Path 19 again prevails with a discounted total cost advantage of $1.4m over Path 20. The cut-off probabilities relative to doing nothing are 42% and 60% respectively,

In essence the relative results are robust to changes in investment costs (excluding the cost of managed retreat which we look at below), but the higher the investment costs the greater the probability of (T&T scenario) climate change that is required to justify taking any action.

All losses higher by 25%

If all loses are higher by 25% (including the cost of managed retreat) Path 19 still has the lowest cost, with a $1.7m advantage over Path 20. The cut-off probabilities to justify taking action relative to doing nothing are 46% and 63% respectively. As expected the greater the potential loss, the lower the probability of (T&T scenario) climate change that is required to take defensive action.

We can infer that lower potential losses would have the opposite effect.

Third Investment Phase

In the base case the third investment period takes place during the five year period ending in 2075. Here we push this out by 15 years to 2090, implicitly assuming that whatever protection is in place in 2075 will last another decade with the same level of maintenance. (An alternative scenario might be that implementation delays lead to a decade of increased exposure to damage). Managed retreat is also deferred by 15 years where relevant.

As before Path 19 is still the best bet, followed by Path 20. The difference in discounted total costs is $0.6m. The cut-off probabilities to justify taking action are 58% and 66% respectively, so slightly lower than in the base case.

This may seem counterintuitive. The logic is that deferring a cost (in this case enhancing protection or deferring retreat) lowers the discounted value of that cost. Thus the hurdle to justify incurring those costs is also lower. That hurdle is the probability of (T&T scenario) climate change.

Managed Retreat in 2120-2125

The above analysis extends to the five year period ending in 2125, which risks carrying the implicit assumption that no significant additional coastal hazard risk arises after that date. In practice such an assumption is seldom required as the present value of the cost of managed retreat more than a century into the future will in most cases be so low as to not affect the main conclusions. Also, in the interests of maintaining flexible pathways there is usually no need to adopt a retreat policy for many decades.

Nevertheless it is worth checking whether the main conclusions are indeed robust to adopting managed retreat in 2125. Recall that Path 19 (S,S,S) has the least expected discounted cost, followed by Path 20 (S,S,M). The cost difference in the base case scenario is $1.2m. This falls to $0.7m if Path 19 effectively becomes (S,S,S,M), so the original conclusion stands. The result does highlight, however, that the two paths are very close from a cost perspective, so the best strategy is still to build a seawall first and then progressively re-evaluate the case for managed retreat thereafter.

Value for Money

The Multi-Criteria Decision Analysis (MCDA) undertaken by the TAG provides a weighted average score for each of the initial six pathways against seven criteria. All of the criteria relate to some form of benefit that the pathways deliver. There is no reference to the costs of the various adaptation measures.

The ROA approach, being based on cost-benefit analysis, encompasses costs and benefits, but the benefits are strictly economic. Cultural and environment benefits for example are not included. It is useful therefore to compare the wider ambit of benefits captured in the MCDA score with the economic costs of securing those benefits – referred to as the investment costs. As noted before this includes the cost of managed retreat.

Table 7 summarises the MCDA scores and the investment costs (from Table 4), and divides the latter by the former to produce a sort of efficiency or inverted Value for Money measure; the dollars on of investment required per MCDA point.

Table 7: Value for Money

Pathway		MCDA Score	Discounted Invest Cost ($m)	VFM ($'000/point)
1	R+M+M	67	11.57	173
2	C+C+M	59	9.37	159
3	C+C+C	52	8.11	156
4	C+C+S	43	8.80	205
5	S+S+M	70	7.72	110
6	S+S+S	49	6.17	126

Path 5 has easily the lowest cost per MCDA point and so represents the best VFM. It has the highest MCDA score and the second lowest discounted investment cost. Path 6 which the ROA analysis suggests is the best choice, has the second lowest cost per point even though its MCDA score is low. Preferring Path 5 to Path 6 carries a cost premium of $1.55m.

Fortunately Paths 5 and 6 differ only in the long term (after 2075), with Path 5 going to managed retreat while Path 6 continues with a sea wall. So there is no real need to choose between them at the present point in time. Flexibility is possible.

In contrast the pathway with the second highest MCDA score is Path 1, but its high cost implies that is poor value for money. More importantly, Path 1 is fundamentally different to Paths 5 and 6. It starts with renourishment and then moves to managed retreat around 2045. It is much less flexible and carries a higher risk of incurring costs that could turn out to be unnecessary. As discussed above, the case for early managed retreat depends on both a low discount rate and a very high probability of (T&T) climate change. Expressed less mathematically, Path 1 might be chosen if the community is very risk averse and is happy to pay for greater certainty.

3. Unit K: Haumoana

Fixed Pathways

We look first at the six fixed pathways established by the TAG. The question of interest is under what probability of climate change (T&T scenario) occurring is it better to adopt each pathway rather than doing nothing. Table 8 shows the cut-off probabilities and the discounted investment costs plus residual expected losses.

Table 8: Pathway Cut-off Probabilities

Pathway		Cut-off Probability	PV(cost +loss) $m
1	R+M+M	137.0%	42.81
2	C+C+M	85.4%	28.46
3	C+C+L	49.7%	19.59
4	C+C+C	45.7%	18.77
5	C+C+S	60.4%	22.46
6	S+S+S	62.3%	22.92

The five protection options are:

1. Renourishment of the beach (denote this as R),
2. Control structures such as groynes and breakwaters, with renourishment (C),
3. Sea wall (S),
4. Managed retreat (M),
5. Retreat the line (L). It is estimated that 19.5% of the asset values at risk in Haumoana are on the seaward side of the line.

If the prospect of (T&T scenario) climate change is low, taking action to mitigate its effects is likely to be a waste of resources. Better to do nothing. Given that some defensive action is undertaken Path 4 is least cost, closely followed by Path 3 which differs only in the long term when option L 'retreat the line' is adopted. Thus beginning with control structures and renourishment is the best strategy – lowest expected cost and most flexible.

Flexible Pathways

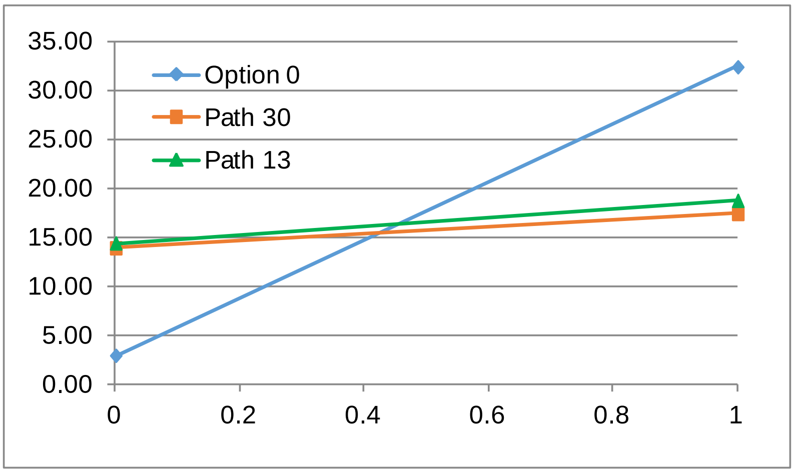
With the five generic protection options there are many more than six pathways or permutations although some are clearly not worth investigating. We identify 28 plausible pathways, as listed in Table 9. They are numbered 7-34 to distinguish them from the original six (which are shown in parentheses). A suffix (T) indicates a transition cost.

Of the original six pathways, Path 4 (=Path 13) is the least cost choice, but with the expanded set of pathways Path 30 (straight to L 'retreat the line') is more than $1m cheaper – in terms of discounted costs plus expected loss. It requires a probability of (T&T scenario) climate change to be 42.3% before being preferred to doing nothing. This is only slightly lower than the corresponding probability for Path 4 of 45.7%. Figure 5 illustrates.

Table 9: Plausible Pathways for Haumoana

Option	ST	MT	LT	Discounted Investment Cost	Discounted Cost + Loss	End state	Cut-off probability cf end state
7	R	C(T)	C	16.79	21.13	C	No soln
8	R	C(T)	S	20.48	24.82	S	No soln
9	R	C(T)	M	28.26	30.82	M	>100%
10	R	S(T)	M	30.23	32.79	M	>100%
11	R	S(T)	S	19.48	23.82	S	No soln
12 (1)	R	M	(M)	41.58	42.81	M	>100%
13 (4)	C	C	C	14.43	18.77	C	NA
14 (5)	C	C	S	18.11	22.46	S	All
15 (2)	C	C	M	25.90	28.46	M	>100%
16	C	S(T)	S	21.94	26.29	S	No soln
17	C	S(T)	M	32.69	35.25	M	>100%
18	C	M	(M)	44.04	45.27	M	>100%
19 (6)	S	S	S	18.57	22.92	S	NA
20	S	S	M	29.32	31.88	M	>100%
21	S	M	(M)	47.77	49.00	M	>100%
22	M	(M)	(M)	63.62	63.62	M	NA
23 (3)	C	C	L	15.59	19.59	L	<0%
24	R	C(T)	L	17.96	21.95	L	<0%
25	C	S(T)	L	22.38	26.38	L	<0%
26	R	L	(L)	16.25	19.99	L	<0%
27	C	L	(L)	18.71	22.45	L	<0%
28	S	S	L	19.01	23.01	L	<0%
29	S	(L)	(L)	22.44	26.18	L	<0%
30	L	(L)	(L)	13.93	17.42	L	NA
31	R	L	M	26.79	29.09	M	>100%
32	C	L	M	29.25	31.55	M	>100%
33	S	L	M	32.98	35.28	M	>100%
34	L	M	(M)	39.81	40.81	M	>100%

Figure 5: Paths 30 and 13 (=4) v Doing Nothing



The closeness of these two pathways leads to two important points:

1. The relative value of assets at risk on the two sides of the 'retreat the line' is a crucial parameter in the ROA calculations – refer sensitivity testing below. If Path 30 is to be seriously considered it would be worth examining the expected loss values more closely. This leads to the second point.

2. Is the community even amenable to adopting 'retreat the line' sooner rather than later? If not Path 3 (=23) or Path 4 (=13) are possibilities, but they incur a cost premium over Path 30.

Some other interesting results that emerge from the ROA of the expanded set are:

- Of all the pathways the end with L, none are preferred to adopting L immediately.
- In contrast, of all the pathways that end in M, all are preferred to adopting M immediately.
- Of the five pathways that end in a sea wall, only Path 5 (=Path 14; C,C,S) is better than beginning with and staying with sea walls (Path 6=Path 19).
- Of the two pathways that end in C, it is better to begin with and stay with control structures (Path 4=Path 13).
- However, all pathways that end in S and most than end in M are inferior to those ending in C or L, and for those two end points the best pathways are Paths 4 (=13) and Path 30 respectively.

In summary then:

> If the probability of (T&T scenario) climate change is considered to be 42% or more, the best choice is to go straight to 'retreat the line', but if this is not desirable, whether for non-economic reasons or to maintain flexibility, the next best choice is to construct control structures to begin with, which admits the possibility of moving to 'retreat the line' at a later date. Based on current knowledge, however, there is a cost premium attached to this choice.

Value for Money

Table 10 takes the MCDA scores for the original six pathways and divides them into the investment costs to produce a measure of 'value for money'.

Table 10: Value for Money

Pathway		MCDA Score	Discounted Invest Cost ($m)	VFM ($'000/point)
1	R+M+M	61	41.58	682
2	C+C+M	72	25.90	360
3	C+C+L	61	15.59	256
4	C+C+C	62	14.43	233
5	C+C+S	50	18.11	362
6	S+S+S	46	18.57	404

The pathway with the lowest investment cost per MCDA point is Path 4, followed by Path 3. They come out ahead of Path 2 which has the highest MCDA score, but is also high cost.

Path 3 has a much lower MCDA score than Path 2, which differs only in the long term by adopting a partial retreat (retreat the line) rather than the full retreat in Path 2. This may reflect the community's doubt that 'retreat the line' provides adequate long term protection – we explore this further below. Taken at face value this ranking would suggest that Path 30 (immediate adoption of 'retreat the line') would not score highly in the MCDA framework. If true the best choice – at additional cost – is to begin with control structures and renourishment, as this as provides maximum flexibility by leaving open the options of enhanced control structures, partial retreat or indeed full retreat at a later date. Thus the conclusion from the previous section stands.

Sensitivity Tests

The list of potential sensitivity tests is much larger than we can realistically expect to fulfil. Based on the result above and on the more comprehensive sensitivity tests examined for Unit L, we look at two alternative discount rates (1.5% and 6%), and at raising the value of the loss on the seaward side of the 'retreat the line' option by 25%. The results are summarised in Table 11.

Table 11: Sensitivity Tests

	Pathway Choice		Cut-off v Do Nothing	
	1st	2nd	1st	2nd
Base Case	30	4	42.3%	45.7%
Discount rate 6.0%	Do nothing	7	--	>100%
Discount rate 1.5%	30	4	13.4%	21.7%
Seaward side loss of option L up 25%	4	3	45.7%	52.0%

With a 6% discount rate the best choice is to do nothing. So little weight is placed on future losses (or indeed future generations) that the largely upfront costs of protection are not justified. As this is unlikely to be acceptable to the community the next best choice, at an additional expected cost of $1.3m is Path 7 (R+C+C); essentially doing as little as possible.

With a 1.5% discount rate the preference order is the same as for the base case, but much lower probabilities of (T&T scenario) climate change are required to justify taking protective action. More weight on future losses lowers the probability (of these losses) that is required to justify taking action. However, the difference in total expected costs between these two choices increases from $1.4m in the base case to $6.3m. With a lower discount rate the value of distant residual losses increase by more than the investment costs, and Path 4 (C+C+C) has higher residual losses than Path 30.

This observation bring us to the third sensitivity test – raising the value of loss for assets on the seaward side of 'the line' under option L by 25%, with a corresponding reduction on the leeward side. The change is sufficient to make Path 4 the least cost choice followed by Path 3 (C+C+L), with a difference in total expected costs of $1.4m. Path 30 becomes the third lowest cost, but is only $0.2m more than Path 3.

Given the greater flexibility of Paths 3 and 4 and the relative uncertainty about the distribution of potential losses either side of the option L line, the case for beginning with control structures and beach renourishment is strengthened.

Retreat in 2120-2125

As for Unit L the question arises as whether retreat might be needed after 2120. There are two scenarios; either full managed retreat (option M) is required, including for pathways that currently end in retreat the line (option L), or that option L will be sufficient. However, there is much uncertainty beyond 2120, and a likelihood that other factors such as ground water levels rather than coastal erosion or inundation might necessitate full managed retreat. Hence we do not consider scenarios where option L is a final solution. There is also a conceptual problem with this scenario which is that any pathways that end in M (such as Paths 1 and 2) would logically become redundant, which is counter to the initial six pathways that the TAG proposed.

Hence we add M to all of the pathways that do not already end in M or L, and we add the cost of retreat landward of the option L line (effectively M less L) to pathways that currently end in L.

Table 12 shows only the three pathways with the lowest discounted expected total cost, in the base case and with option M added to Path 4 in 2125, and M-L added to Paths 3 and 30 in 2125. There are no cheaper pathways. That is, that even if adopting option M by 2125 is required, there is no advantage to adopting option M sooner than might be necessary.

Amongst the three cheapest pathways the rank order is unchanged from the base case, even though full retreat adds relatively more cost to Path 4. Thus from a strictly economic perspective Path 30 is still the preferred pathway, but given the substantial cost uncertainty and VFM results it seems sensible to retain the flexibility of beginning with control structures and beach renourishment. Also as Paths 3, 4 and 30 all have higher costs if full retreat is envisaged over 2120-2125, they require a higher probability of (T&T scenario) climate change occurring before implementing them is justified, further reinforcing the case for not adopting irreversible and expensive options at this stage.

Table 12: Full Managed Retreat in 2125

Pathway		Base Case		Full Retreat in 2125	
		$m	Cut-off Probability	$m	Cut-off Probability
Path 3	C, C, L … + (M-L)	19.59	49.7%	21.95	59.0%
Path 4	C, C, C … + M	18.77	45.7%	21.71	57.4%
Path 30	L, (L), (L) … + (M-L)	17.42	42.3%	19.79	51.4%

4. Unit K: Te Awanga

Fixed Pathways

We look first at the six fixed pathways established by the TAG. The question of interest is under what probability of climate change (T&T scenario) occurring is it better to adopt each pathway rather than doing nothing. Table 13 shows the cut-off probabilities and the discounted investment costs plus residual expected losses.

Table 13: Pathway Cut-off Probabilities

Pathway		Cut-off Probability	PV(cost +loss) $m
1	R+L+M	41.8%	24.15
2	C+C+L	20.4%	17.08
3	C+C+C	18.9%	16.77
4	C+C+S	23.4%	18.48
5	R+S+L	28.1%	20.00
6	S+S+S	23.9%	18.67

The five protection options are:

1. Renourishment of the beach (denote this as R),
2. Control structures such as groynes and breakwaters, with renourishment (C),
3. Sea wall (S),
4. Managed retreat (M),
5. Retreat the line (L). It is estimated that 18.5% of the asset values at risk in Te Awanga are on the seaward side of the line.

Path 3 has a slightly lower expected cost than Path 2, with cut-off probabilities of about 19% and 20% respectively. That is if the expected probability of (T&T scenario) climate change is less than 19%, it is better to do nothing.

Overall the costs are closer than is the case for other areas. To maintain flexibility any of Paths 2-4 are a good choice.

Flexible Pathways

With the five generic protection options there are many more than six pathways or permutations although some are trivial and not worth investigating. We identify 28 plausible pathways, as listed in Table 14. They are numbered 7-34 to distinguish them from the original six (which are shown in parentheses). A suffix (T) indicates a transition cost.

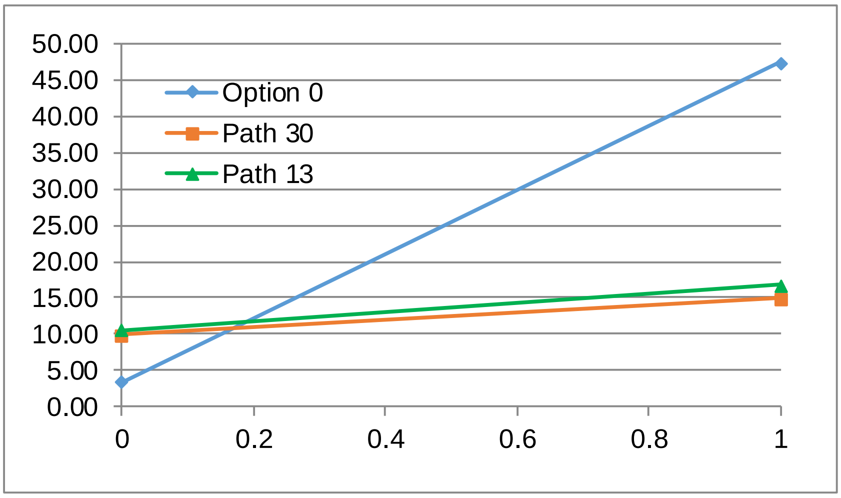
With the expanded set of pathways Path 30 (straight to L ‘retreat the line’) has the lowest expected cost, being about $1.8m cheaper than Path 3 (=13). It requires a probability of (T&T scenario) climate change of only 16.6% before being preferred to doing nothing.

As for Haumoana, if the community is not amenable to early adoption of 'retreat the line' the next best choices are Path 3 (=13) or Path 2 (=23) are possibilities, but they incur a cost premium over Path 30.

Table 14: Plausible Pathways for Te Awanga

Option	ST	MT	LT	Discounted Investment Cost	Discounted Cost + Loss	End state	Cut-off probability cf end state
7	R	C(T)	C	13.03	19.20	C	No soln
8	R	C(T)	S	14.74	20.91	S	No soln
9	R	C(T)	M	21.19	25.59	M	>100%
10	R	S(T)	M	21.68	26.08	M	>100%
11	R	S(T)	S	15.31	21.48	S	No soln
12	R	M	(M)	30.99	33.17	M	>100%
13 (3)	C	C	C	10.60	16.77	C	NA
14 (4)	C	C	S3(T)	12.31	18.48	S	All
15	C	C	M	18.76	23.16	M	>100%
16	C	S(T)	S	15.95	22.12	S	No soln
17	C	S(T)	M	22.33	26.73	M	>100%
18	C	M	(M)	31.63	33.82	M	>100%
19 (6)	S	S	S	12.50	18.67	S	NA
20	S	S	M	18.88	23.28	M	>100%
21	S	M	(M)	32.38	34.57	M	>100%
22	M	(M)	(M)	46.18	46.18	M	NA
23 (2)	C	C	L	11.24	17.08	L	<0%
24	R	C(T)	L	13.67	19.51	L	<0%
25	C	S(T)	L	14.80	20.64	L	<0%
26 (5)	R	S(T)	L	14.16	20.00	L	<0%
27	C	L	(L)	13.15	18.58	L	<0%
28	S	S	L	11.35	17.19	L	<0%
29	S	(L)	(L)	13.90	19.33	L	<0%
30	L	(L)	(L)	9.91	14.94	L	NA
31 (1)	R	L	M	20.16	24.15	M	>100%
32	C	L	M	20.88	24.87	M	>100%
33	S	L	M	21.63	25.62	M	>100%
34	L	M	(M)	28.90	30.68	M	>100%

Figure 6: Paths 30 and 3 (=13) v Doing Nothing



Some other interesting results that emerge from the ROA of the expanded set are:

- Of all the pathways the end with L, none are preferred to adopting L immediately.
- In contrast, of all the pathways that end in M, all are preferred to adopting M immediately.
- Of the five pathways that end in a sea wall, only Path 4 (=Path 14; C,C,S) is better than beginning with and staying with sea walls (Path 19=Path 6).
- Of the two pathways that end in C, it is better to begin with and stay with control structures (Path 13=Path 4).
- However, all pathways that end in M and most than end in S, are inferior to those ending in C or L, and for those two end points the best pathways are Paths 3 (=13) and Path 30 respectively.

In summary the results echo those for Haumoana, but with a lower probability of (T&T scenario) climate change to justify taking action:

> If the probability of (T&T scenario) climate change is considered to be at least 17%, the best choice is to go straight to 'retreat the line', but if this is not desirable (for non-economic reasons) the next best choice is to construct control structures to begin with, which provides the flexibility to move to 'retreat the line' at a later date. Based on current knowledge, however, there is an expected cost premium attached to this choice.

Value for Money

Table 15 takes the MCDA scores for the original six pathways and divides them into the investment costs to produce a measure of 'value for money'. The pathway with the lowest investment cost per MCDA point is Path 3, which also has the highest MCDA score. Thus there is a clear 'win' to Path 3 (=13). Path 2 (=23) has the next highest MCDA score and also the next lowest cost per point.

Therefore beginning with control structures and renourishment is the best starting point. This retains the flexibility to continue with that protection method or eventually move to 'retreat the line'. To reiterate though, this flexibility does come at a price compared to immediately adopting 'retreat the line'.

Table 15 Value for Money

	Pathway	MCDA Score	Discounted Invest Cost ($m)	VFM ($'000/point)
1	R+L+M	50	20.16	403
2	C+C+L	58	11.24	194
3	C+C+C	62	10.60	171
4	C+C+S	53	12.31	232
5	R+S+L	43	14.16	329
6	S+S+S	43	12.50	291

Sensitivity Tests

As before the list of potential sensitivity tests is much larger than we can realistically expect to fulfil. Based on the result above and on the sensitivity tests examined for Unit L, we look at two alternative discount rates (1.5% and 6%), and raising the value of the loss on the seaward side of the 'retreat the line' option by 25%. The results are summarised in Table 16.

Table 16: Sensitivity Tests

	Pathway Choice		Cut-off v Do Nothing	
	1st	2nd	1st	2nd
Base Case	30	3	16.6%	18.9%
Discount rate 6.0%	3	2	46.9%	48.2%
Discount rate 1.5%	30	28	4.1%	9.4%
Seaward side loss of option L up 25%	3	30	18.9%	21.9%

With a 6% discount rate Path 3 (C, C, C) moves into first place, followed by Path 2 (C, C, L). Adopting 'retreat the line' (Path 30) becomes unattractive. In contrast, with a 1.5% Path 30 is preferred, followed by Path 28 (S, S, L). In essence then, with a low discount rate the entire approach changes from a debate between control structures and 'retreat the line' to one between sea walls and 'retreat the line'. As before, placing more weight on the welfare of future generations justifies taking on greater costs sooner.

Raising the value of loss for assets on the seaward side of 'the line' under option L by 25%, with a corresponding reduction on the leeward side, is just sufficient to swap the base case results. Path 3 is the least cost followed by Path 30, with a difference in total expected costs of $0.1m.

Given the greater flexibility of Path 3 and the relative uncertainty about the distribution of potential losses either side of the option L line, the case for beginning with control structures and beach renourishment is strengthened.

Retreat in 2120-2125

As for Haumoana the issue arises as to what happens after 2120.

Table 17 shows only the three pathways with the lowest discounted expected total cost, in the base case and with option M added to Path 3 in 2125, and M-L added to Paths 2 and 30 in 2125. The results are similar those for Haumoana:

- There are no cheaper pathways, so no case for earlier adoption of retreat.
- Going straight to option L is still the least cost pathway.
- But Path 2 (C,C,L) just edges out Path 3 (C,C,C) when retreat over the period 2120-2125 is added.
- All pathways require a higher probability of (T&T scenario) climate change to be justified.

Overall then beginning with control structures and beach renourishment still seems to be the best choice.

Table 17: Full Managed Retreat in 2125

Pathway		Base Case		Full Retreat in 2125	
		$m	Cut-off Probability	$m	Cut-off Probability
Path 2	C, C, L … + (M-L)	17.08	20.4%	18.82	25.0%
Path 3	C, C, C … + M	16.77	18.9%	18.90	24.6%
Path 30	L, (L), (L) … + (M-L)	14.94	16.6%	16.68	21.1%

5. Unit J: East Clive (Clive)

East Clive presents a rather different story to Units K and L as all of the four TAG pathways begin with the status quo in the short term (that is until about 2045). With regard to the other units this is similar to the ‘do nothing’ option – justified only if the probability of (T&T scenario) climate change is low. Strictly speaking, however, it is not the probability of climate change that is the issue. Rather it is the expected loss associated with a particular climate change scenario that matters. This is the situation in East Clive. The value of the assets at risk in the short term amounts to only $0.3m-$0.4m, but is much higher in the medium and long terms.

Pathways

The protection options are:

1. Status quo (Q),
2. Control structures such as groynes and breakwaters, with renourishment (C),
3. Sea wall (S),
4. Retreat the line (L). It is estimated that 73% of the asset values at risk in Unit J are on the seaward side of the line.

The status quo (option Q) has low investment and maintenance costs, but there is still a small statistically expected loss – the value of the assets at risk multiplied by the probability of an adverse event. To be consistent with the other scenarios we assume AEP=1% although arguably a lower value could be appropriate here.

The first four pathways shown in Table 18 were established by the TAG. Path 2 has a negative cut-off probability of (T&T scenario) climate change to justify pursuing it. In other words there is no case for delaying adopting the status quo! Even the other pathways require only low probabilities to be justified.

In terms of expected costs Paths 1 and 2 which involve control structures are preferred to Paths 3 and 4 respectively, which involve a sea wall.

Table 18: Pathway Cut-off Probabilities

Pathway		Cut-off Probability v do nothing	PV(cost +loss) $m	Cut-off Probability v end state
1	Q+C+L	34.7%	40.78	>100%
2	Q+C+C	<0%	18.61	NA
3	Q+S+L	38.2%	43.25	>100%
4	Q+S+S	3.0%	21.77	--
5	Q+L+L	81.0%	72.75	>100%
6	L+L+L	>100%	133.79	--
7	Q+C+S(T)	0.3%	19.98	No soln

It is assumed that adhering to option Q into the medium term and beyond will not provide adequate protection (that is to the AEP=1% standard) so we do not look at such options. There is also no point in looking at earlier adoption of options C or S as both would raise costs with no change in benefits. The only question that seems worth asking is: Is an earlier move to 'retreat the line' a viable option? Although this raises costs it also reduces expected losses. Paths 5 and 6 explore this question.

Of all the pathways that end in L, Path 6 has the highest expected total cost and requires a probability of (T&T scenario) climate change that exceeds 100% for it to be preferred to Paths 1, 3 and 5, which is nonsensical. In effect then, Path 6 is not viable. Nor is Path 5. Path 7 which transitions from C to S in the long term is cheaper than adopting S in the medium term (Path 4), implying that beginning with Path 2 is the best strategy – lowest cost and retaining flexibility.

Value for Money

Table 19 takes the MCDA scores for the original four pathways and divides them into the investment costs to produce a measure of 'value for money'. Path 1 has the highest MCDA score, but it's small margin over Path 2 is easily offset by the much lower cost pf the latter, meaning that Path 2 emerges as the best value for money.

Hence there is a strong rationale for beginning with the status quo and moving to control structures in the medium term, maintaining the flexibility to continue with enhanced control structures or adopting 'retreat the line' in the long term.

Table 19 Value for Money

Pathway		MCDA Score	Discounted Invest Cost ($m)	VFM ($'000/point)
1	Q+C+L	78	31.41	403
2	Q+C+C	76	5.74	76
3	Q+S+L	62	33.88	546
4	Q+S+S	50	8.91	178

Sensitivity Tests

We confine the sensitivity tests to those that could alter the hierarchy of the pathways; two alternative discount rates (1.5% and 6%), and raising the value of the loss on the seaward side of the 'retreat the line' option by 25%. The results are summarised in Table 20 and show that the preference order is actually very robust. It is best to begin with (Q+C+C) which leaves open the possibility of changing to (Q+C+S) or even (Q+C+L) at a later date.

This does, however, raise the same issue as with the other units, namely that ending with C or S may not provide sufficient protection beyond 2120. Hence we look at scenarios where 'retreat the line' (L) is added to Paths 2, 4 and 7. Note that in contrast to units K and L, full managed retreat (M) is not explored here as it is not an option within the initial set of four pathways.

The increase in costs for Paths 2, 4 and 7 is not enough to make other pathways more attractive. Thus the above conclusion stands. That is, remain with the status quo in the short term, with a likelihood (given what is known currently) of building control structures and beach renourishment in the medium term. Beyond that it may be possible to continue with control structures, but the sea wall and retreat option should not be ruled out.

Table 20: Sensitivity Tests

	Pathway Choice		Cut-off v Do Nothing	
	1st	2nd	1st	2nd
Base Case	2	7	<0%	3.0%
Discount rate 6.0%	2	7	2.5%	3.9%
Discount rate 1.5%	2	7	<0%	<0%
Seaward side loss of option L up 25%	2	7	<0%	0.3%
Add option L to paths 2, 4, 7	2	7	7.2%	9.3%

Appendix A: Protection Costs for Unit L

Table A1 is derived from Tonkin & Taylor. It provides a split of capital costs and maintenance costs (medium estimates) for the six pathways considered by the TAG. The costs of managed retreat are not included.

Table A1: Investment Costs ($m)

Year	Path 1	Path 2	Path 3	Path 4	Path 5	Path 6
0	1.650	3.655	3.655	3.655	4.750	4.750
5	1.369	0.649	0.649	0.649	0.119	0.119
10	1.369	0.649	0.649	0.649	0.119	0.119
15	1.369	0.649	0.649	0.649	0.119	0.119
20	1.369	0.649	0.649	0.649	0.119	0.119
25	11.4.000	0.649	0.649	0.649	0.119	0.119
30	0.000	0.649	0.649	0.649	0.119	0.119
35	0.000	0.649	0.649	0.649	0.119	0.119
40	0.000	0.649	0.649	0.649	0.119	0.119
45	0.000	0.649	0.649	0.649	0.119	0.119
50	0.000	0.649	0.649	0.649	0.119	0.119
55	0.000	11.400	1.525	7.738	11.400	2.988
60	0.000	0.000	0.788	0.184	0.000	0.184
65	0.000	0.000	0.788	0.184	0.000	0.184
70	0.000	0.000	0.788	0.184	0.000	0.184
75	0.000	0.000	0.788	0.184	0.000	0.184
80	0.000	0.000	0.788	0.184	0.000	0.184
85	0.000	0.000	0.788	0.184	0.000	0.184
90	0.000	0.000	0.788	0.184	0.000	0.184
95	0.000	0.000	0.788	0.184	0.000	0.184
100	0.000	0.000	0.788	0.184	0.000	0.184
105	0.000	0.000	0.788	0.184	0.000	0.184
Total*	18.525	21.543	19.543	19.718	17.338	10.763

* Undiscounted

	Action
Pathway 1	R+M+M
Pathway 2	C+C+M
Pathway 3	C+C+C
Pathway 4	C+R+S
Pathway 5	S+S+M
Pathway 6	S+S+S

Appendix B: Discount Rate Theory

There are two fundamental properties of discount rates that are relevant to investment in protection from floods and erosion:

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).[2] Treasury's current standard discount rate for infrastructure projects is 6.0%.[3]

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 or erosion 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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[2] Treasury (2008): Public Sector Discount Rates for Cost Benefit Analysis.

[3] 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)[4] in connection with climate change.

There is much debate on the values of these variables, but the arguments are well beyond the ambit of this paper. The interested reader is referred to Parker (2009).[5] Parker suggests that a reasonable value of the SRTP for New Zealand is around 3.0% - 4.0%.

We adopt 3% as the default rate in our analysis as the coastal protection scenarios under investigation span over 100 years. Indeed following Stern a lower rate could be justified when dealing with climate change so we analyse the scenarios with a rate of 1.5% as well. The Treasury rate of 6% is also tested.

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

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