Towards a Real Options Analysis of Adaptation to Sea Level Rise around the Lower Waikato River

Report to NIWA

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Infometrics
Economics put simply

Authorship

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The assistance of Paula Holland and Sanjay Wadhwa is much appreciated, along with helpful suggestions from other NIWA personnel. Any remaining errors are solely my responsibility.

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Glossary

Abbreviation	Explanation
AEP	Annual exceedance probability. For example AEP=1% denotes a 1 in 100 year event. Statistically this means that over a period of 100 years there is a 63.2% probability of at least one such event and a 36.8% probability of no such event.
Beta distribution	A statistical distribution with a fatter tail than a Normal distribution. It provides scope to constrain the distribution outcomes within plausible bounds and allows skewed distributions.
CBA	Cost benefit analysis: a standard technique used to value streams of costs and benefits of different investment strategies over time using discounting – see Appendix C.
CEA	Cost effectiveness analysis: the same as CBA except that the benefits are identical across all alternative strategies, so they do not need to be measured in monetary values.
Cut-off probability	The risk-neutral probability at which the statistically expected cost from over-investing (spending more or sooner than is required to avoid an adverse outcome) is the same as the statistically expected cost of damage from under-investing or delaying investment to avoid adverse outcome.
ROA	Real options analysis: essentially the same as CBA except that a value is estimated for the option of delaying an investment if delaying could provide more information about likely outcomes. An option value could be negative.

1. Introduction & Summary

This report contributes to NIWA's *Future Coasts Aotearoa* research project, financed by the Endeavour Fund of the Ministry of Business, Innovation and Employment. The full programme title is *Transforming coastal lowland systems threatened by sea-level-rise into prosperous communities*.

The overarching aim of the project is to enhance the evidence base for relative sea level rise risks (exposure, consequences, evolving environmental states, adaptation thresholds, positive/negative feedbacks) by building evaluation tools that are fit for purpose – and incorporating them into a decision-making framework.

Our contribution is to apply Real Options Analysis (ROA, an extended form of cost benefit analysis) to various broadly defined strategies for pro-active adaptation to address the increasing severity of inundation events with an Annual Exceedance Probability of 1% in the context of future sea level rise in the lower Waikato River region. We do not analyse adaptation strategies to address existing or unchanged risk.

The effects of coastal erosion, although clearly significant in this location, are outside the scope of this research. Also excluded is the effect of slowly rising groundwater, although the effect of sea level rise on flood levels is included. Initial modelling of changes in groundwater levels generated estimates that were too coarse for our level of economic analysis.

Comprehensive input data for modelling is scarce, but with extensive sensitivity testing we assess four adaptation strategies:

1. Wetland restoration with estimated monetised values of ecosystem services.
2. Dwellings and buildings elevated.
3. Combination of (1) and (2).
4. Maintain and enhance the stopbanks and drainage system.

Doing nothing means allowing the stopbank and drainage system to deteriorate to such an extent that the flow of the river would eventually be unimpeded. The land, buildings (including dwellings) and infrastructure that are protected by the current stopbanks and drainage system would eventually become not functional, irrelevant or uninhabitable.

In that situation – which may well be the community's objective – restoration of wetlands is the least cost strategy to adapt to relative sea level rise, provided the imputed monetised value of ecosystem services are accurate. A wide uncertainty band means that the full value of anticipated eco-system benefits may not materialise, or it could be better than anticipated. Greater precision is a priority for further research.

Maintaining and enhancing the stopbank and drainage system to protect against a worsening of AEP=1% events up to 2130 is probably the most robust adaptation strategy when error margins on costs and benefits are taken into account. However, it still requires a reasonably high degree of certainty about future sea level rise to be preferable to doing nothing. Delaying a decision could reduce costs.

As a general strategy, elevation of buildings, notably dwellings is unlikely to be an economic strategy as it involves high upfront costs relative to the small reduction in lost assets compared to doing nothing. Nevertheless there are likely to be particular dwellings where elevation would make economic sense – those that are most exposed to future inundation and/or those of high (community) value relative to the cost of elevation. Such micro-level analysis is beyond the ambit of this indicative study.

There may also be non-economic reasons (such as the avoided social costs of dislocation) for preserving dwellings and accompanying infrastructure, but otherwise allowing the river to run freely. Other than including the monetised value of wetland benefits our assessment does not consider the social, cultural or environmental aspects of adverse extreme events associated with climate change and rising sea levels – which are difficult to monetise. This means that more expensive strategies such as elevation could nonetheless be worth pursuing when assessed in a wider context. A multicriteria approach could be a useful contribution to assessing such non-monetised benefits. That might also provide a basis for assessing distributional effects, notably the extent to which the costs of adaptation actions might be linked to those who benefit from the protection thereby provided.

We recognise that analysis frameworks such as CBA and ROA do not adequately capture sociocultural considerations like the effects of attachment to place amongst Māori communities. Such economic assessments may even be inappropriate. All economics can offer is to demonstrate that allowing for sociocultural considerations may not be costless.

There are many more combinations of strategies, their implementation dates and sea level rise scenarios than could be examined here. However, in this preliminary application of ROA we do not have the detailed data or community sanctions to constrain the number of combinations to something that is both manageable and relevant to the community involved.

Feedback from a presentation and discussion of the ROA findings with interested groups is summarised in Appendix E.

2. A Guide to ROA

The emphasis in economic evaluation is on the efficient allocation of resources to meet some desirable social objective. In the context of adaptation to climate change effects that means analysing the cost of protecting the services provided by natural assets and built capital assets such as dwellings and infrastructure (eg roads and pipes), as well as agricultural and forestry operations. In essence the issue is whether the net benefit of protecting an asset exceeds the net benefit of either relocating it, providing some other means to deliver the services it provides, or letting it fail.

Real Options Analysis (ROA), frequently in combination with Dynamic Adaptive Pathways Planning (DAPP) can reveal how robust adaptation strategies are to changes in the timing and severity of risks posed by a climate change hazard such as sea level rise (SLR).

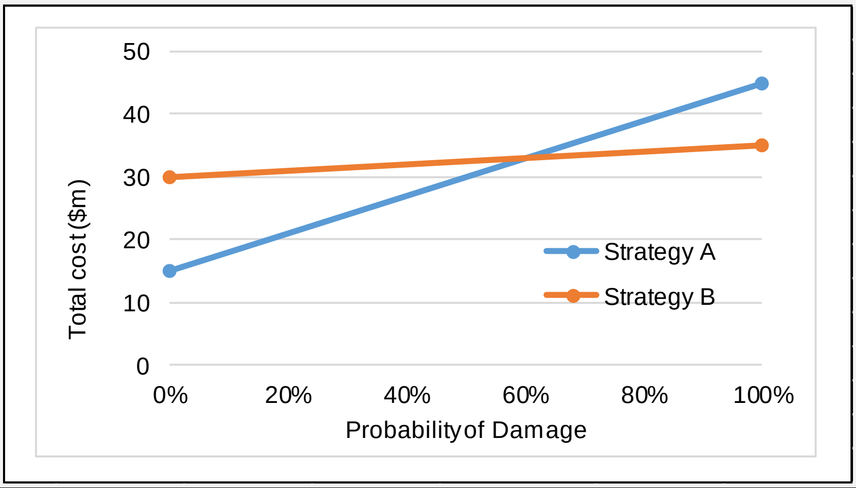
The trade-off is between spending too much too soon (if the hazard turns out to be less serious than initially anticipated) and potentially incurring economic loss if the hazard emerges sooner or more intensely than anticipated. This gives rise to a concept called the cut-off probability – see box below.

The 'Cut-off' probability

In many applications of ROA the analyst is required to stipulate the probability of different future outcomes, with ROA then producing the adaptation strategy with the highest expected net benefit. We reverse the question and ask at what probability do two (or more) investment strategies yield the same expected net benefit? That probability is termed the cut-off probability.

The cut-off probability is not an estimate of the probability of a particular climate change or sea level rise scenario. It is the risk-neutral probability at which the statistically expected cost from over-investing in protection (spending more or sooner than is required for the desired degree of protection) is the same as the statistically expected cost of damage from under-investing or delaying investment in protection.

The following simplified example illustrates the concept. If Strategy A is undertaken and the damage scenario does not eventuate, the expected discounted cost is \$15m, whereas under Strategy B the cost is \$30m - twice as much as is required to provide the desired degree of protection. If, however, the damage scenario does occur, Strategy A is more costly than Strategy B which provides more protection. At a probability of 60% the statistically expected costs are equal. That is the cut-off probability. It is likely to change with different climate change scenarios.



DAPP provides a strategy to reduce the under/over risk by identifying flexible pathways along which short term protective actions (including adaptation) do not compromise further actions in the future. ROA can quantify those pathways by assessing the option value of waiting for more information that could lead to a better decision, frequently relative to a Do Nothing strategy.

Among the costs and benefits that are needed as inputs into ROA/DAPP are the following:

- The economic life of an existing asset, encompassing its current value and operating costs.
- The costs involved in prolonging its economic life.
- The capital and operating costs of adaptation measures (eg stopbanks and pumps).
- The costs of relocating built assets elsewhere (managed retreat).
- The capital and operating costs, and benefits of changing how its services are delivered (eg replacing some reticulated water with rainwater tanks).

However, the question is more complicated than just collecting the above data. The complication is uncertainty, not so much with regard to estimating costs and benefits (though these are not straightforward), but rather with regard to the timing of SLR and thus the timing of investment in adaptation measures. This is why the techniques of DAPP and ROA, rather than just traditional cost benefit analysis (CBA) are required.

The definition of assets may be broad, encompassing natural assets such as wetlands, salt marshes and other riparian vegetation. Restoration or enlargement of these non-built assets could appear on the benefit side of the equation if land currently used for agriculture or buildings becomes unsuitable for such uses. Three approaches to include natural assets or other non-economic benefits in ROA are possible:

1. Application of valuation techniques for non-market and non-use services, such as hedonic pricing, stated preference and revealed preference methods (choice experiments). Such valuations can be directly incorporated into CBA and ROA.

2. If monetary valuations are too dubious, ROA suffers from the same problems as CBA. As with CBA, however, ROA can be used in a manner analogous to cost effectiveness analysis, which identifies the least cost way to achieve a minimum desired outcome. Costs are still expressed in monetary terms, but the benefits are the same across all adaptation options (such as resistance to a given extreme event) or are measured in some other unit. In the health industry for example this might be life-years saved and in the transport industry it might be tonnes of particulate matter from vehicles. Or it could be a score based on multicriteria analysis that assesses a number of non-monetised benefits simultaneously.

3. ROA can reveal the incremental cost of not proceeding with the least net cost strategy when another strategy that has non-monetised benefits is favoured. For example a stopbank may be the least expensive option, but could impede access to the river. If a more expensive option that preserves river access is adopted instead, the difference in costs is an estimate of the minimum value of river access.

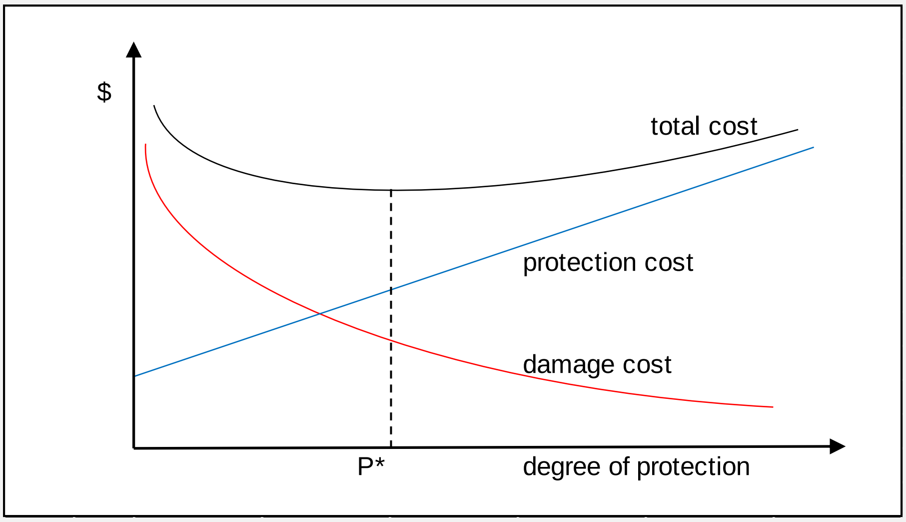
   Even then, however, analysis frameworks such as CBA and ROA may not adequately capture, or even be appropriate for considering sociocultural ethics such as the effects of attachment to place (adaptation that improves the health of the river simultaneously enhancing the wellbeing of the local people) amongst Māori communities (Mahuta et al, 2025, forthcoming).

As economists we can use techniques such as CBA and ROA to evaluate the relative monetised costs and benefits of different adaptation options and pathways, but our role is not to determine which is best, as such a call may involve more than financial metrics. That is a decision for the affected community and those who bear the costs.

A note on residual loss

With the exception of managed retreat, it is highly likely that every adaptation strategy carries some residual risk of loss that cannot practically be avoided. The resources that can be devoted to protective measures are not unlimited. At some point a decision is required about how much residual risk is acceptable, relative to the cost of minimising it further.

The figure below provides an illustration. The blue line represents the cost of a protection pathway. It is smoothly linear merely for convenience. We would expect it to be convex and probably quite jagged owing to the lumpiness of capital expenditure.



The red line expresses the expected cost of damage, again drawn smooth for convenience. The greater the amount spent on protection, the lower the expected damage cost. Expenditure to enhance protection beyond point P* is inefficient, as P* represents the minimum total cost (the most efficient point), at which the marginal cost of protection equals the marginal reduction in damage cost. Thus some residual expected loss remains.

Note that the diagram is merely to illustrate a concept. The positions and slopes of the curves would likely change over time.

3. Analysis of Strategies

Introduction

The area in the lower Waikato River that constitutes the focus of the study is shown in Figure 1. Apart from the Port Waikato township which is located at the southern end of a small triangle of land close to the mouth of the river, the area is sparsely populated. Around 2500 people live in the study area, with an overall population density of less than 20 people per square kilometre. Port Waikato has the highest population concentration.

Figure 1: Lower Waikato (study area outlined in green)

Source: Reeves and Wadhwa (2023)

The land adjacent to the river is generally low-lying (see cover page photograph), although there are many hillocks and much undulating terrain that are not at increasing risk from inundation, but may face other climate-related risks. At the coast there is considerable erosion from storms and high tides, undermining buildings located along the top of the cliff. This will be exacerbated by a rising sea level.[1]

The NZ Sea Rise programme[2] has projections for sea level rise (SLR, including vertical land movement), at the mouth of the river (sites 3060 and 3061), but not at points upstream or on adjacent land. See Figure 2. The projection for SLR at the mouth of the river, at the (fairly extreme) 83rd percentile for RCP 8.5, is for 2.05m by 2130. For the 50th percentile at RCP 7.0 it is 1.38m by 2130.

[1] See for example https://www.waikatotimes.co.nz/nz-news/350352242/sunset-beach-loses-two-metres-overnight-erosion-battle-continues

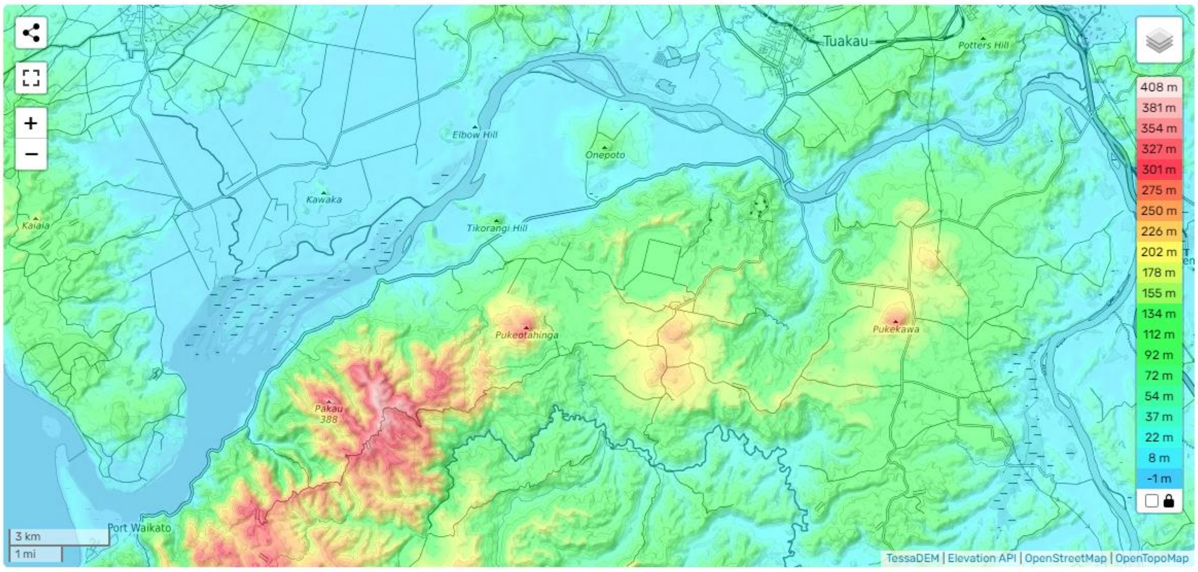
[2] https://searise.takiwa.co

The main hazard (and our focus here) is the joint effect of inundation from extreme events (notably AEP=1%) in the context of the projected gradual rise in mean sea level as it pushes into the lower river basin and estuary, raising the level of the water table.

Low-lying land, including forestry (on the north side of the river with pasture behind), pastoral farming, wetlands and buildings, will be exposed to a greater risk of inundation. Rainfall that might currently be considered as normal would be more likely to lead to flooding, even with the water diversion structures further upstream which reduce river flow downstream.

Excluded is the effect of slowly rising groundwater, although the effect of sea level rise on flood levels is included. Initial modelling of changes in groundwater levels generated estimates that were too coarse for our level of economic analysis. Also the effects of incipient groundwater saturation depend on the type of structure in existence, including how wastewater and potable water are reticulated. Damage functions for slow impact groundwater intrusion are not well defined.

Figure 2: Lower Waikato River Area Elevation



Source: https://en-au.topographic-map.com/map-jn4s/New-Zealand/?popup=-46.80006%2C169.98047&center=-37.30738%2C174.83986&zoom=11

Issues with inundation data

Reeve and Wadhwa (2023) have provided us with data on inundation depths, with and without stopbanks, for various SLR scenarios and extreme event (AEP) frequencies out to 2150, at centroids of property polygons and at a 10m grid of points. The centroid data identifies 1568 properties and the grid data 1532 properties.

The data does not include all stopbanks (see Appendix A), and unfortunately, it also does not account for drainage infrastructure such as tidal gates, culverts, and pumping stations. This means that even with no change in relative sea level, some stopbanks appear to increase the amount of land subject to inundation from extreme events rather than reducing it, due to water retention behind the stopbanks. In reality – and how we model it – the drainage system would mitigate that effect. The grid dataset seems to suffer more from this problem so we use the centroid dataset, but also test the results against the grid dataset.

We cannot link the amount of protection each specific property/asset currently receives to any particular aspect of the drainage system which comprises at least 140 flood gates, pump stations and drainage channels. We therefore assume that in the relevant adaptation strategies, maintaining the stopbanks and drainage system will continue to protect land and assets up to an AEP=1% event. Beyond that either drainage will not be able to cope or stopbanks will be over-topped, or both.

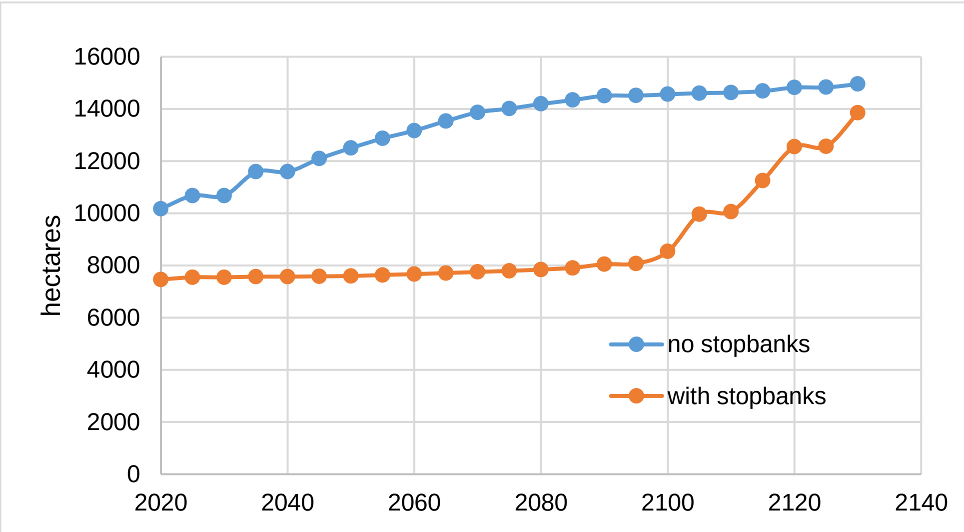
Over a period of 100 years there is a 63.2% probability of at least one such inundation event and a 36.8% probability of no such event.

SLR to time profile

The inundation data from NIWA is not explicitly linked to climate change scenarios, so they have no time dimension. As time is a crucial factor in CBA/ROA we map the NIWA SLR-event scenarios onto three RCP scenarios: RCP 4.5, RCP 7.0 and RCP 8.5,[3] at the 50th percentiles from the projected SLR scenarios given in the NZ Sea Rise programme.

The three RCP scenarios are given initial weights of 45%, 45% and 10% respectively to form a hybrid base case RCP scenario. Note that these are merely statistical weights, not probabilities of any RCP scenario occurring. The end result has an SLR profile that is almost the same as that for the 40th percentile for RCP 7.0. The weights are varied in sensitivity analysis. Figure 3 illustrates the effect of stopbanks on the amount of land that would be inundated under an AEP=1% event for the base case scenario. By 2130 there is not much difference as the stopbanks would be over-topped or breached. The mean inundation depth without stopbank protection is never less than 0.5m and increases over time.

Figure 3: Land Inundation under an AEP=1% event (hybrid base case)



Adaptation Strategies

One general adaptation principle that the community has promoted (and requested by the project team) is allowing the river to flow unimpeded by stopbanks and with no protection against sea level rise and a rising water table. Floodgates, pump stations and drainage channels would all be allowed to deteriorate, but not actively dismantled.

[3] Shared Socioeconomic Pathways (https://www.ipcc.ch/assessment-report/ar6/)

Buildings, notably dwellings could be raised as necessary, wetlands restored and native wetland cropping of some sort might eventually be established in areas where the ground becomes too wet for agriculture. The sequencing of these actions may need to be explored although that may be largely dictated by the rate and pattern of sea level rise.

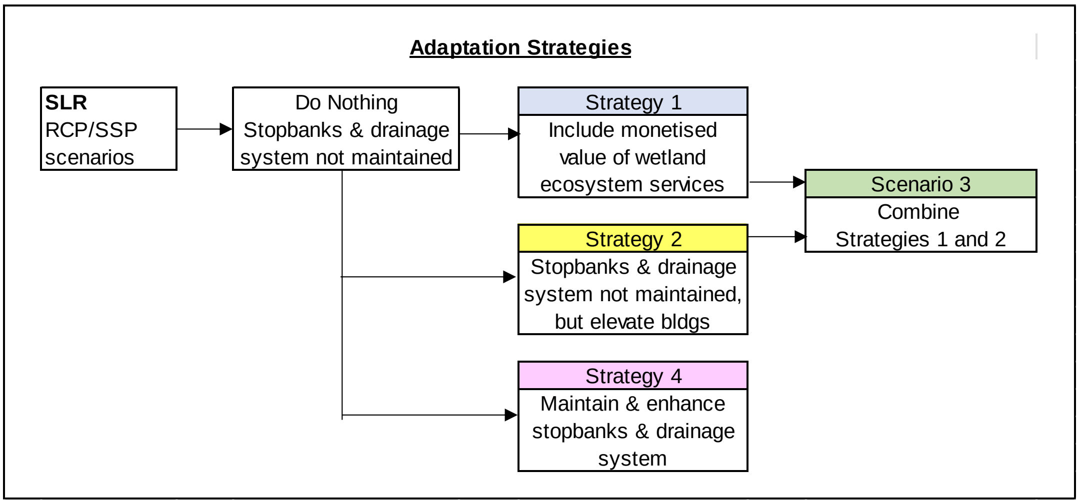
Strategies

The default strategy is No Action. Stopbanks and the drainage system are not maintained and allowed to deteriorate, so land, infrastructure and other assets that are currently or would be protected, are eventually inundated by extreme events, becoming not functional, irrelevant or uninhabitable. Nuisance flooding may lead people to abandon assets before serious inundation occurs.

Four active adaptation strategies are explored. They are illustrated in Figure 4.

1. As in No Action plus the monetised value of wetland benefits. Over time as land is repeatedly inundated, previously drained land will become more water-logged (and perhaps too salty, although a freely flowing river would mitigate salinization) and no longer suitable for agriculture. Wetland restoration is discussed further below.
2. Dwellings and buildings are elevated to maintain the same level of protection that is currently delivered by the stopbank and drainage system up to an AEP=1% event. That is, the strategy addresses increasing risk of loss due to climate change, not to dealing with the current level of risk without climate change.
3. Combination of (1) and (2).
4. Maintain and enhance as necessary the existing stopbanks and drainage system, again so as to keep the risk of economic loss from an AEP=1% event the same as currently exists (2020-25).

Figure 4: Adaptation Strategies



These are all broad strategies that will have varying impacts in specific locations, but our modelling is too high level for such detailed analysis, Similarly we cannot consider micro-level strategies that might solve localised problems over short horizons.

Wetland restoration

We consider the possibility that land which becomes unsuitable for agriculture (notably dairy farming) due to the increasing frequency of inundation from extreme events, is converted to wetlands. There are two possibilities here:

- Passive: The land is passively rewetted, though incurring some costs, as the sea level rises along with the frequency of AEP=1% events.
- Active: Similar to other adaptation strategies such as elevation, wetland restoration requires active investment before a possible AEP=1% event. That means abandoning some dairy land currently in active use. It also means that the benefits of ecosystem services would accrue even if no SLR occurs.

We assume that the timing of conversion is proportional to the expected incremental loss of dairy land as the stopbanks deteriorate over the period to 2130. This implies an average conversion rate of about 4ha per annum.[4]

Arguably even without the exacerbating risk of AEP=1% events, currently exposed dairy land could be converted to wetlands. Indeed there may well be other land that is also suitable for wetland restoration, or there may be a desire to accelerate restoration well in advance of the loss of agricultural land. However, such actions are beyond the ambit of this project as they are not strategies to explicitly respond to the increasing risk of loss from adverse events.

To our knowledge there is no study that identifies the specific types of benefits that might be generated by restored wetlands in the lower Waikato River study area, nor even which types of vegetation or paludiculture might be suitable – sorghum, harakeke (flax) or raupo (cattail) for example. Hence we use the recent work by Yang and Stewart-Sinclair (2024). This lists eighteen types of ecosystem services provided by peatlands and wetlands such as moderating extreme events, regulation of water flows and providing recreational opportunities. Their combined annualised benefit stream is estimated at over US$340,600/ha, although that value arises because of some implausibly high values for the maintenance of life cycles. Some further caveats should also be noted:

- It is not entirely clear that (in the original studies) the underlying components have been consistently calculated with regard to parameters such as the discount rate and the time horizon.
- The monetised values are not strictly additive as there is some double counting of types of services.
- We do not know which types of ecosystem benefits are relevant to the study area, though moderation of extreme events is a top contender.

Given these reservations we assume a tentative illustrative value of NZ$27,100/ha/year, being an arbitrary half of the USD value (after scaling back the outlying values for maintenance of life cycles), converted to NZD.

The cost of wetland restoration is adapted from a study of peatland restoration in Germany by Willenbockel (2024). We assume an initial investment cost of $15,000/ha, with ongoing

[4] The precise conditions under which this would occur depend on many factors such as the degree, duration and depth of waterlogging and salinity, the type of grass, other vegetation and grazing. See Nichols (2024).

costs of $200/ha per year. For modelling purposes it is assumed that there is a lag of 10 years between restoration and the delivery of any ecosystem services, although Willenbockel uses eight years.

Note that rewetting of drained wetlands is not the same as constructing completely new wetlands, which would have much higher costs. For example Matthews et al (2024) estimate that the cost of constructing wetlands systems (designed to reduce agricultural sediment and nutrient loads) on a flat and accessible site is $126,000/ha, with $4040/ha for annual operational costs. Both are central estimates that have accompanying error margins. Such a strategy may be worth analysing with better data.

Aside from potential moderation of extreme events, another possible benefit wetlands restoration is carbon sequestration. Landcare Research (2018) assume sequestration of carbon by restored wetlands at a rate of around 2t CO_2e/ha/yr, although noting that the error margin is wide (±80%) and that the sequestration rate varies over time. Coupled with an average carbon price of say $80/tonne CO_2e, the implied return is $160 per hectare. The ultimate storage of CO_2 would be around 700t CO_2e/ha implying that sequestering could continue for over 300 years.[5]

However, at this stage modelling carbon sequestration by wetlands would be too error-prone. The land needs to rewet naturally as the water table rises and stopbanks are overtopped, and according to Simmonds et al (2023), once restored, a minimum of 55% vegetation cover is needed for the land to become a net carbon sink. Additionally, such sequestration is not included in the New Zealand's Emissions Trading System.

Another benefit from wetlands restoration might be improvements in biodiversity. This is included in the tabulations by Yang and Stewart-Sinclair, although for New Zealand the monetary value of biodiversity could potentially be covered in a proposed biodiversity credits scheme. However, the parameters of the scheme have yet to be decided so any quantitative assessment at this stage seems too speculative. [6]

In sensitivity testing below we look at the effects of assuming a different monetised return from wetland ecosystem services.

Other assumptions

The analysis requires a considerable amount of data that is not available, although more may become available in due course. In the meantime we make a number of assumptions:

1. With regard to the protection provided by the existing stopbank and drainage system, we note that its current assets (flood gates, pump stations, drainage channels and stopbanks) are aging, but generally still effective. We estimate that on average their market value in 2020 was about 73% of the replacement value, albeit with wide variability and cases where market (depreciated) value is deemed equal to replacement value. Commensurate with our inability to link protection of specific properties to specific components of the drainage system, we assume that the system's average level of service can be maintained without significant maintenance until its value has depreciated by 33% of base year replacement value. This occurs within the next few years. After that it needs to be maintained to prevent any further decline in its level of service – for the relevant adaptation strategies.

[5] See also https://niwa.co.nz/news/muddy-sinks
[6] https://environment.govt.nz/what-government-is-doing/areas-of-work/biodiversity/biodiversity-credits-an-incentive-to-support-conservation-efforts/

2. Any expansion or enhancement of stopbanks and drainage that is needed to cope with an AEP=1% event is assumed to have the same real annualised resource cost per hectare protected as currently applies.

3. If the system is not maintained, the loss value of currently protected land, buildings and infrastructure will vary directly with the deterioration of the stopbank/drainage system and the rate of sea level rise.

4. All infrastructure that is on land protected by the stopbanks and drainage system is also thereby protected. This includes (apart from the drainage system itself) roads and access paths, and driveways to dwellings.

5. Due to a lack of information we ignore the velocity and duration of inundation events. Changes in salinity and temperature in the river channel are also not modelled.

6. The NIWA modelling has focused solely on sea level rise and Waikato River floods from extreme events. It does not address rain-on-grid effects, which could lead to increased nuisance flooding as sea levels rise. For example, sea level rise will reduce the drainage efficiency of gated culverts and change the 'drainage window' worsening flooding behind stopbanks during rain-related event (Waddington et al, 2022).

Appendix B has more details on costs and values.

Results

The adaptation strategies are essentially independent. There is one action – elevation, to preserve dwellings, one action – wetland restoration to help replace agriculture, and one action – enhancement of the stopbank and drainage system, to protect land and assets. Each adaptation action is technically separate from the others. Hence we initially use ROA to determine cut-off probabilities and then explore the effect of changing the timing of one of the strategies – the value of the option to delay.

A discussed in Section 2 the cut-off probability is the probability of the assumed hybrid RCP/SLR scenario eventuating at which the cost of investment in adaptive actions plus any residual expected loss, is equal to the expected loss under a No Action strategy. All costs and losses are discounted at a default 3% pa, with other discount rates tested later. The higher the cut off probability, the higher is the expected total cost plus loss.

To reiterate an earlier point, this not attaching a probability to a specific climate change or SLR scenario. It is determining a probability at which a particular adaptation strategy would be economically justified, for some given SLR scenario. The cut-off probabilities for other SLR scenarios are tested later.

The cut-off probabilities occur where the strategy lines intersect with the No Action line, are summarised in Table 1, which also shows the discounted investment cost and cost plus residual loss for each strategy. Figure 5 illustrates Strategies 1, 2 and 4, relative to No Action.

Strategy 1 (wetland benefits) is essentially No Action (a freely flowing river), but with a monetisation of wetland benefits. It yields a cut-off probability of around 24%, so is an economically viable adaptation strategy – provided of course that the estimated monetised values are indeed realistic. As discussed above, the estimate includes monetised values for many non-market benefits. Any under-estimation would have the effect of raising the cut-off probability.

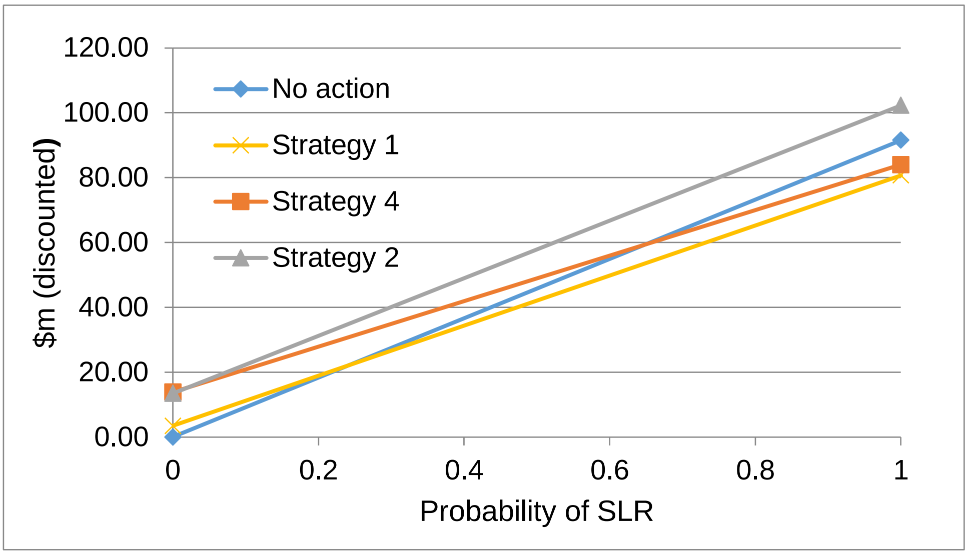
Table 1: Discounted Cost plus Loss and Cut-Off Probabilities

Strategy	At AEP=1%	Cost	Cost + Loss	Rank
No action	--	$0.0m	$91.6m	4
1 Wetlands benefits	24.3%	3.5	80.7	1
2 Building elevation	>100%	13.5	102.3	5
3 Combine 1 and 2	99.2%	16.9	91.4	3
4 Stopbank system enhancement	64.7%	13.9	84.0	2

Strategy 2 differs from No Action simply by elevating dwellings. This produces a cut-off probability over 100%. Although this makes no mathematical sense, practically it means that the investment cost of adaptation – in this case elevation – plus the residual loss (notably of other assets and farm income) is higher than the expected loss from doing nothing.[7] The main reason for this is simply that elevation must occur before an AEP=1% event occurs. However, such an event may not occur, implying a possible waste of resources. In contrast pre-emptive elevation has a definite cost.

This does not mean that the elevation is uneconomic for all dwellings. Exceptions will likely exist for dwellings that are most exposed to future inundation and/or those of high value – commercial or otherwise – relative to the cost of elevation. That requires more detailed modelling.

Figure 5: Investment Cost plus Residual Loss v Probability of SLR



Adding the monetised value of ecosystem services to elevation (Strategy 3) is just sufficient to justify a package of elevation plus wetland restoration, but requires near complete certainty about SLR. However, there is no technical reason for combining these actions.

Enhancing the stopbank and drainage system (Strategy 4) presents a contrasting result with a cut-off probability of around 65%, indicating that if the probability of the benchmark weighted RCP scenario is considered to be more than about two-thirds, Strategy 4 is preferable to No Action.

[7] Indeed WT(2023) point out that, when compared to new-build costs, elevation is competitive only for timber framed dwellings.

Note that as with any cost-benefit analysis based on probabilities of future events, once an event has actually occurred (which could be at any time), any previous analysis would need to be revised as a new baseline would prevail.

Option value

Taking Strategy 4 as an example, is there a value to the option of delaying when it is implemented? Delaying investment lowers its discounted cost. but because the time profile of investment is optimally linked to the expected rate of economic loss from SLR, the gain is less than the increase in the statistically expected loss from the greater exposure to SLR in the short term. Hence this is a riskier strategy, but it is not necessarily a poor choice.

For instance if all investment is delayed by 30 years until 2055 with no action until then (call this Strategy 4a), the cut-off probability increases from 64.7% to 85.9%, so very unlikely to be better than doing nothing. However, Strategies 4 and 4a cross at a probability of 31.3%. Thus if the probability of the (base case) SLR scenario occurring is thought to be less than about a third, Strategy 4a should be pursued in preference to Strategy 4. If SLR turns out to be much less or slower than anticipated (as assessed in 2055), Strategy 4a would be justified. The discounted cost difference is or about 19% or $2.6m

If SLR turns out as anticipated (or worse) Strategy 4 would have been better, with a discounted cost plus residual loss difference of 7% or $5.7m. Indeed, referring back to Table 1, if the probability of the base case SLR scenario occurring is considered to more than 65% Strategy 4 should be pursued in preference not only to Strategy 4a, but also in preference to doing nothing.

All of the above analysis is based on risk-neutral probabilities, but communities may not be risk-neutral. Those that are risk averse would likely favour Strategy 4, but Strategy 4a might be attractive to communities willing to take on more risk.

It is no doubt apparent that the number of combinations of strategies, their implementation dates and SLR scenarios is rather large. In this preliminary application of ROA we do not have the detailed data to constrain the number of combinations to something that is both manageable and relevant to the community involved.

In the next section we undertake sensitivity analysis that assesses each adaptation strategy against the No Action strategy. That should provide some guidance on which strategies merit further investigation, including investigating more options to delay, once adaptation strategies have been further developed and refined.[8]

An illustration of option value calculations using a simplified example is presented in Appendix D. The numbers are not related to the study area.

Sensitivity Analysis

There are many assumptions and uncertainties in the above analysis. Standard ones include the discount rate, estimates of asset values and investment costs, and the pace of sea level rise along with adverse event frequency (RCP scenario). Less prominent are the potential returns from wetland cropping and the rate at which stopbanks and the drainage system depreciate – and how that relates to the delivered level of service.

[8] See for example the development of strategies to address coastal hazards in Hawke's Bay; https://www.hbcoast.co.nz/

All of this provides ample scope for sensitivity testing. To do this in a meaningful way we firstly present separate sensitivity tests on the discount rate, the RCP scenario, the grid dataset, and the drainage level of service. The other parameters are then jointly tested using Monte Carlo simulation. Table 2 presents the results of the discrete testing.

Discount rate

With a lower discount rate (1%) the cut-off probability falls for all strategies (although remains above 100% for Strategy 2) except Strategy 4, indicating that if potential losses from SLR are given more weight, less certainty is required about future SLR to justify taking adaptive actions. For Strategy 4 there is very small increase in the cut-off probability, reflecting a delicate balance between the time profile of costs and the time profile of expected residual losses.

A higher discount rate (6%) places less weight on future losses. For Strategies 1 and 3 the cut-off probability is negative, indicating that compared to No Action the payback from wetland restoration is too distant (or too low) to justify the costs, even without any SLR. That is, a higher discount rate renders Strategies 1, 2 and 3 (so all except stopbank enhancement) unviable. See Table 2.

RCP weights (timing of SLR)

Changing the RCP weights is equivalent to altering the timing at which damage from SLR occurs. In the base case the weights on RCP 4.5, RCP 7.0 and RCP 8.5 are 45%, 45% and 10% respectively. Hence we look at two extreme cases; a 100% weight on RCP 8.5 and a 100% weight on RCP 4.5.

Under RCP 8.5 the potential economic loss comes earlier, so the investment to mitigate any losses must also come earlier. The net effect could go either way. In this case the cut-off probabilities fall, except with regard to Strategy 4, and it is still over 100% for Strategy 2. Conversely under the RCP 4.5 the cut-off probabilities move in the opposite direction. Overall though the changes are not large indicating little sensitivity to the pace of SLR.

Drainage system level of service

As discussed above, the system as a whole is currently valued at an average 73% of replacement cost, but presumably able to fulfil its designed level of service (LoS) without significant maintenance costs until it is truly challenged. Our assumption is that by the time the system has depreciated to 67% its LoS would begin to deteriorate and will therefore require some maintenance, but only enough to prevent its value slipping below 67% of replacement value – as a proxy for its adequate LoS.

Clearly the 67% threshold is somewhat arbitrary, even as a system-wide average. Table 2 shows the effect of lowering it to 50%. All strategies, including No Action benefit from a stopbank/drainage system that has a longer life before requiring maintenance. Deferring investment in adaptation lowers its total discounted cost, so the cut-off probability required to justify taking action declines (although for Strategy 2 it is still over 100%). The size of the declines relative to the base case points to the importance of the assumed effectiveness of the drainage system.

A higher threshold could be assessed, but not higher than 73% – the current depreciated value of the stopbank/drainage system. Anything higher would imply that the current LoS is already below its design standard. If that is indeed the case it is an issue to be addressed irrespective of future SLR and thus falls outside the scope of our analysis.

Grid dataset

All of the results so far use the property centroid dataset for estimates of land potentially inundated. The alternative dataset has estimates for a grid of points at 10m intervals. Using the means for each property the cut-off probability for Strategy 4 falls to 54.9%. This reflects the tendency for the property means of SLR based on the grid data to be higher than those obtained from the centroid data, thereby advancing the case for adaptation and thus lowering the cut-off probability. However, for Strategy 1 the cut-off probability turns negative indicating that the accelerated wetland restoration implied by faster SLR brings the opportunity costs forward to such an extent that the net present value is negative – akin to the higher discount rate effect.

Interestingly, as shown in Table 2, the ranking of strategies in all cases with sensible cut-off probabilities is mostly unchanged from that in the base case: Wetland restoration with its estimated monetised benefits ranks top, followed by stopbank & drainage enhancement, then wetland restoration combined with building elevation, and finally elevation on its own.

Table 2: Sensitivity Tests of Cut-Off Values (%)

Strategy	Base case	Discount rate 1%	Discount rate 6%	RCP 8.5	RCP 4.5	Drainage LoS 50%	Grid dataset
1 Wetlands	24.3	5.2	<0	21.8	28.7	15.7	<0
2 Elevation	>100	>100	>100	>100	>100	>100	>100
3 1+2	99.2	29.7	<0	95.9	>100	49.8	<0
4 Stopbanks etc	64.7	64.9	73.0	66.6	63.9	40.8	54.9

Joint analysis

There are other uncertainties in the analysis in addition to those studied above: the potential loss from foregone agriculture, the value of the potential loss of infrastructure and dwellings and the cost of elevating dwellings.

Rather than consider these item by item, we incorporate them into a Monte Carlo sensitivity analysis that also includes the RCP scenarios tested individually above. Values for each variable are randomly drawn from statistical distributions appropriate to each variable; a 4-parameter Beta distribution for SLR under the RCP scenarios, and triangular distributions elsewhere. See Table 3.

Table 3: Monte Carlo Distributions and Parameters

	Distb.	Mean	Minimum	Maximum
RCP, SLR by 2130, mms	Beta	1280	790	2050
Wetland monetised return, $000/ha/yr	Triangular	27,100	13,300	35,500
Agriculture value added, $/ha/yr	Triangular	4200	3600	4900
Value of improvements, $/bldg.	Triangular	204	180	230
Cost of elevation, $/bldg.	Triangular	180	140	230
Value/cost of infrastructure, $m	Triangular	150	120	180

For SLR in 2130 the minimum is the value at the 17th percentile for RCP 4.5, and the maximum is the value at the 83rd percentile for RCP 8.5, from the NZ Sea Rise programme, so more extreme than the scenarios in Table 2. The mean is as per the initial weights for the three RCP scenarios at the 50th percentiles.

For agriculture the minimum and maximum values correspond approximately to milksolids prices of about $6.00/kg and $8.20/kg respectively, compared to the base case decade-average price of about $7.00/kg.

With regard to wetland restoration, as the monetised benefits are much larger than the costs and also more uncertain (and not necessarily correct for the lower Waikato River), only the benefits are included in the sensitivity analysis. We explore a wide range from -50% to +30% of the mean value for benefits. These tests could also be interpreted as retaining the same value per hectare, but changing the number of hectares allocated to restoration, as well as (at the upper end) allowing for some wetland farming.

The discount rate is omitted from this testing as although there are strong economic arguments governing the choice of a discount rate (see Appendix C), the pure rate of time preference, which is a component in the discount rate, is ultimately a value judgement.

The uncertainty in the variables in Table 3 is epistemic uncertainty, which is uncertainty that is attributable to a lack of knowledge. The distribution of values or outcomes is unknown, so can only be approximated on the basis of current knowledge. Better information may emerge with time or with research. That is, the uncertainty is theoretically reducible, although more knowledge does not always reduce uncertainty.[9]

The results for the cut-off probabilities are presented in Table 4, which shows the means, the values at the 5th and 95th percentiles, and the proportions of simulations that result in a cut-of probability less than 100%, for 20,000 draws from the distributions. All cut-off probabilities are set to a maximum of 100% and a minimum of 0% as values outside that range are nonsensical.

For Strategy 4 (stopbank enhancement) the 90% range of cut-off probabilities is fairly narrow and none are over 100%. The cut-off probability for Strategy 1 (wetland benefits) spans a wide range owing to the interaction between the uncertainty about SLR and the monetised value of wetland ecosystem services. This also affects Strategy 3. Strategy 2 (elevation on its own) is uneconomic in all 20,000 simulations. Thus Strategy 4 is the most robust from the perspective of cost and benefit uncertainty.

Table 4: Cut-Off Probabilities (%) from Monte Carlo Analysis*

Strategy	Base	Mean	5th percentile	95th percentile	% of runs ≤100%
1 Wetlands benefits	24.3	18.4	0	91	95
2 Building elevation	>100	100.0	100	100	0
3 Combine 1 and 2	99.2	53.5	0	100	77
4 Stopbank system enhancement	64.7	64.8	58	72	100

* These numbers will change every time the analysis is re-run.

We should reiterate, however, that the foregoing analysis is based entirely on an economics perspective, and even then the discounted total cost plus loss for Strategy 4 is not that different from No Action. There may also be sound non-economic reasons to let the stopbanks and drainage system deteriorate so that the river can flow unimpeded. If

[9] There is another type of uncertainty known as stochastic or aleatory uncertainty, such as applies to the toss of a coin. The uncertainty here is irreducible; no amount of research or waiting for more information will alter the probability distribution.

such strategy is too uncertain to monetise, a multicriteria approach could be a useful contribution to assessing such benefits. See for example Infometrics and PS Consulting (2015).

Distributional Implications

Due to the limited nature of data available for this analysis, the economic assessment of adaptation options is principally based on the estimated effects of adaptation on built assets (buildings, roads etc.) or commercial agricultural assets, with economic impacts aggregated to the study area. By comparison, the distribution of asset ownership – such as who owns the land affected by protection or flooding – is not included in the ROA assessment. Some sub-groups in the community may be more exposed than others and therefore face varying degrees of potential economic loss under different SLR scenarios and adaptation strategies.

Likewise, the question of who should or could pay for adaptation is beyond what ROA can deliver. Consideration of who pays would theoretically provide an opportunity to alleviate the unequal losses from potential inundation if the costs of adaptation are (mostly) imposed on the beneficiaries of the protection it provides, rather than across ratepayers more generally. For example to what extent do the benefits of a freely flowing river constitute a public benefit compared to the mostly private benefit to farmers from enhancing the stopbanks?

As the Hawke's Bay experience illustrates (https://www.hbcoast.co.nz/) it can take many years to reach what a majority of the community considers an equitable allocation of adaptation costs – more or less on a user pays basis. And that is even with much more detailed estimates of costs and losses than are available for the lower Waikato River region.

Overall, distributional effects are a challenge. To progress beyond broad qualitative comments requires a more refined set of adaptation strategies that have evolved from detailed financial estimates and a thorough understanding of how the community sees the trade-offs between monetised and non-monetised costs and benefits, such as might be examined with multicriteria analysis.

Policy implications

This analysis provides quantitative estimates of the potential economic value of investing in different adaptation strategies to address a 1:100 year flood event in the face of SLR uncertainty and climate change. The findings of the analysis reflect what can be achieved with limited data. However, they are insufficient to select a final set of detailed, including spatially detailed adaptation strategies. Rather, the findings should contribute to dialogue about socially appropriate adaptation with relevant interest groups, including the Council. In this respect, a number of issues need to be considered.

- The data for the ROA was incomplete. Information on rising groundwater in the area was not available in a form for this to be included. The inclusion of information on rising groundwater would probably not affect the rank of strategies, but would likely lower the cut-off probabilities somewhat.

- Importantly, incomplete information on the environmental and sociocultural impacts of different adaptation options means that the total contribution of adaptation strategies to economic wellbeing could not be determined, reiterating that the rankings of the strategies provided are preliminary. More research would be helpful.

- The economic value of environmental change arising from adaptation options is mostly excluded from the analysis. As discussed above, allowing the stopbank and drainage system to deteriorate over time could potentially contribute to the re-establishment of wetlands. Although that is included in the modelling, specific benefits such as improvements in biodiversity by supporting freshwater species and improved access to food (as whitebait are not forced to move upstream) are captured only coarsely.

- More emphasis on the economic value of environmental benefits from the restoration strategy could further improve its attractiveness, relative to maintaining or expanding the drainage and stopbank system.

Conclusion

The preceding analysis has looked at adaption strategies to address the increasing inundation risk from climate change, notably the increasing damage caused by AEP=1% events in association with sea level rise. Adaptation strategies to deal with existing or unchanged risk have not been considered.

Although comprehensive and robust input data for quantitative modelling is scarce, we have endeavoured to address this disadvantage with extensive sensitivity testing. Our analysis suggests that:

- Maintaining and enhancing the stopbank and drainage system to protect against a worsening of AEP=1% events up to 2130 is probably the most reliable adaptation strategy, but is not least cost. Also, it still requires a reasonably high degree of certainty about future sea level rise to be preferable to doing nothing. Delaying a decision could reduce costs.

- Doing nothing means allowing the stopbank and drainage system to deteriorate to such an extent that the flow of the river would be unimpeded. The land, buildings (including dwellings) and infrastructure that are protected by the current stopbanks and drainage system would eventually become not functional, irrelevant or uninhabitable.

- In that situation, restoration of wetlands is the least cost strategy provided the imputed monetised value of ecosystem services are accurate, but a wide uncertainty band makes this a riskier strategy, Greater precision is a priority for further research.

- As a general strategy, elevation of buildings, notably dwellings is unlikely to be an economic strategy as it involves high upfront costs relative to the small expected reduction in lost assets compared to doing nothing. Nevertheless there are likely to be particular dwellings where elevation would make economic sense – those that are most exposed to future inundation and/or those of high value relative to the cost of elevation. Such micro-level analysis is beyond the ambit of this study.

However, there may be non-economic reasons (such as the avoided social costs of dislocation) for preserving dwellings and accompanying infrastructure, but otherwise allowing the river to run free. Other than including the monetised value of wetland benefits our assessment does not consider the social, cultural or environmental aspects of adverse extreme events associated with climate change and rising sea levels. Augmenting ROA with other techniques such as multicriteria analysis would enable such effects to be better integrated into a more comprehensive evaluation framework. That might also enable distributional effects to be assessed.

Nevertheless, we recognise that analysis frameworks such as CBA and ROA do not adequately capture sociocultural considerations like the effects of attachment to place amongst Māori communities. Such economic assessments may even be inappropriate. All economics can really offer is to demonstrate that allowing for sociocultural considerations may not be costless.

There are many more combinations of strategies, their implementation dates and sea level rise scenarios than could be examined. However, we do not have the detailed data to constrain the number of combinations to something that is both manageable and relevant to the community involved.

4. Limitations

Although limitations to the foregoing analysis have been noted in various places above, we restate them explicitly here. Essentially there are three types of limitations; data, coverage and methodology, although they are not totally independent.

Data limitations apply to:

- The timing of projections of the rate of SLR and the frequency of adverse inundation events.
- Estimates of the value of production and assets at risk of future SLR and inundation.
- Estimates of the value of eco-system services provided by wetlands.
- Estimates of the costs of different strategies to address future SLR and inundation.
- Imprecise association between the protection each property receives and any particular aspect of the stopbank and drainage system.

Coverage of the analysis excludes the following:

- The effects of slowly rising groundwater and salinisation.
- Distributional effects – potential exposure to loss and to the cost of adaptation, related to land ownership.

Application of the ROA methodology is limited by:

- Adaptation strategies being too broad. Ideally ROA should be preceded by comprehensive community consultation that leads to more refined adaptation strategies.
- However, even then, analysis frameworks such as ROA and CBA do not adequately capture sociocultural considerations. At best they can be useful, at worst they may be inappropriate.

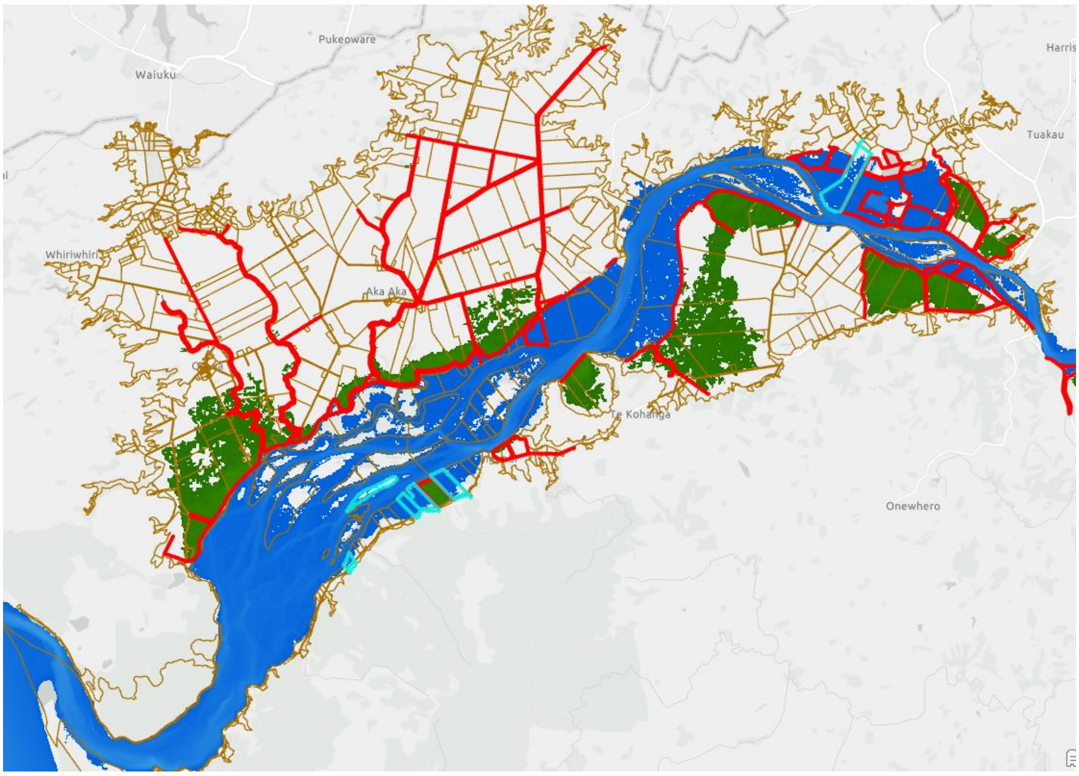
Appendix A: Stopbanks

In the maps below stopbanks are highlighted in red. Green signifies inundation without stopbanks, while blue represents inundation with stopbanks, which of course includes the river. The locations outlined in cyan are examples of situations where stopbanks raise inundation rather than lowering it – by not allowing for the effect of drainage schemes.

Note, however, that not all (minor) stopbanks were incorporated into the NIWA model. For example the stopbank protecting location 4833457 is not included in the modelling – see Map 2.

Overall the modelling shows that the southern side of the river (Maps 1 and 3) experiences more inundation with stopbanks due to the higher water level they retain – again ignoring the effect of the drainage system, which in the modelling we do not ignore.

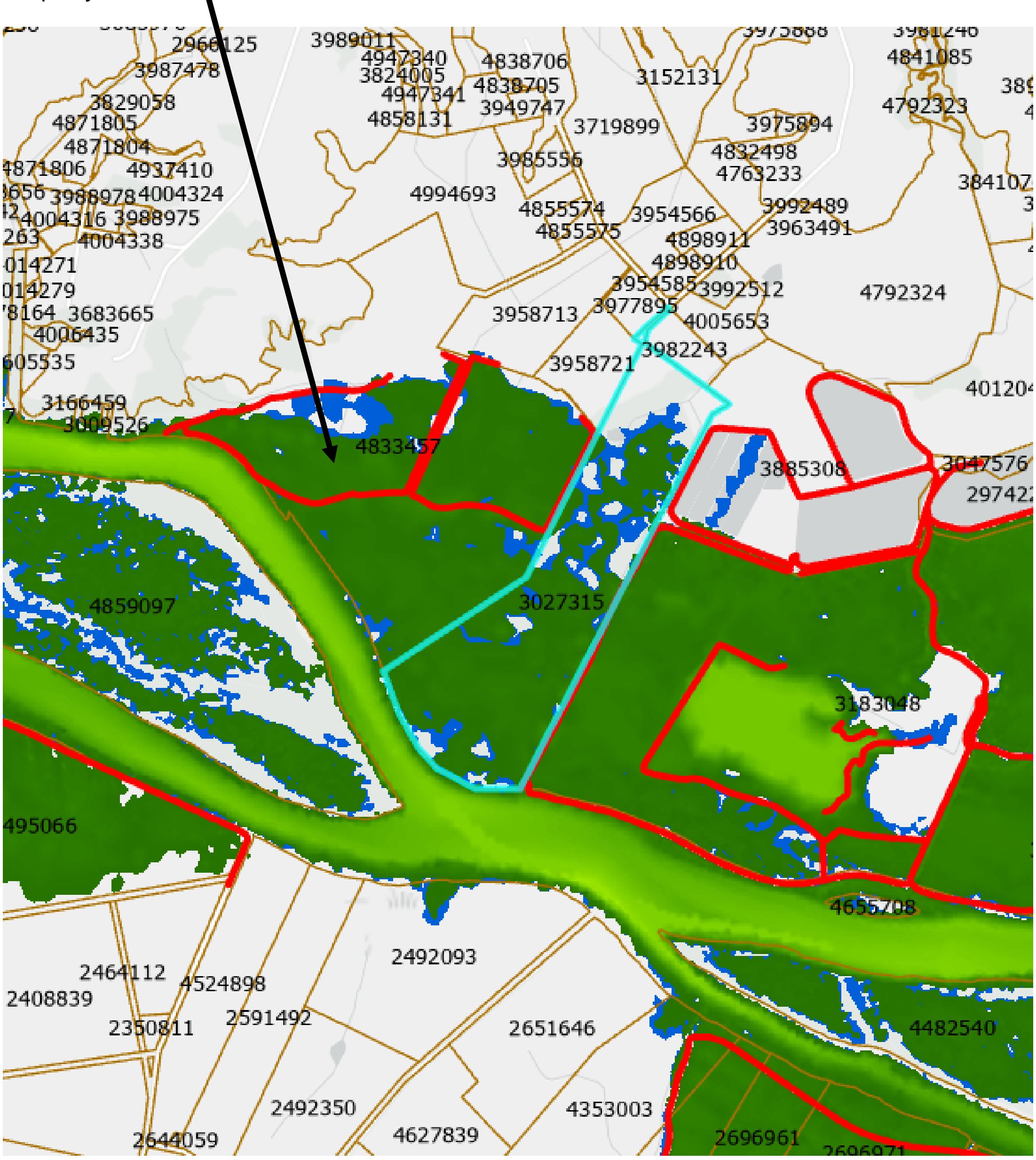
Map 1: Lower Waikato River



Source: Reeves and Wadhwa (2023)

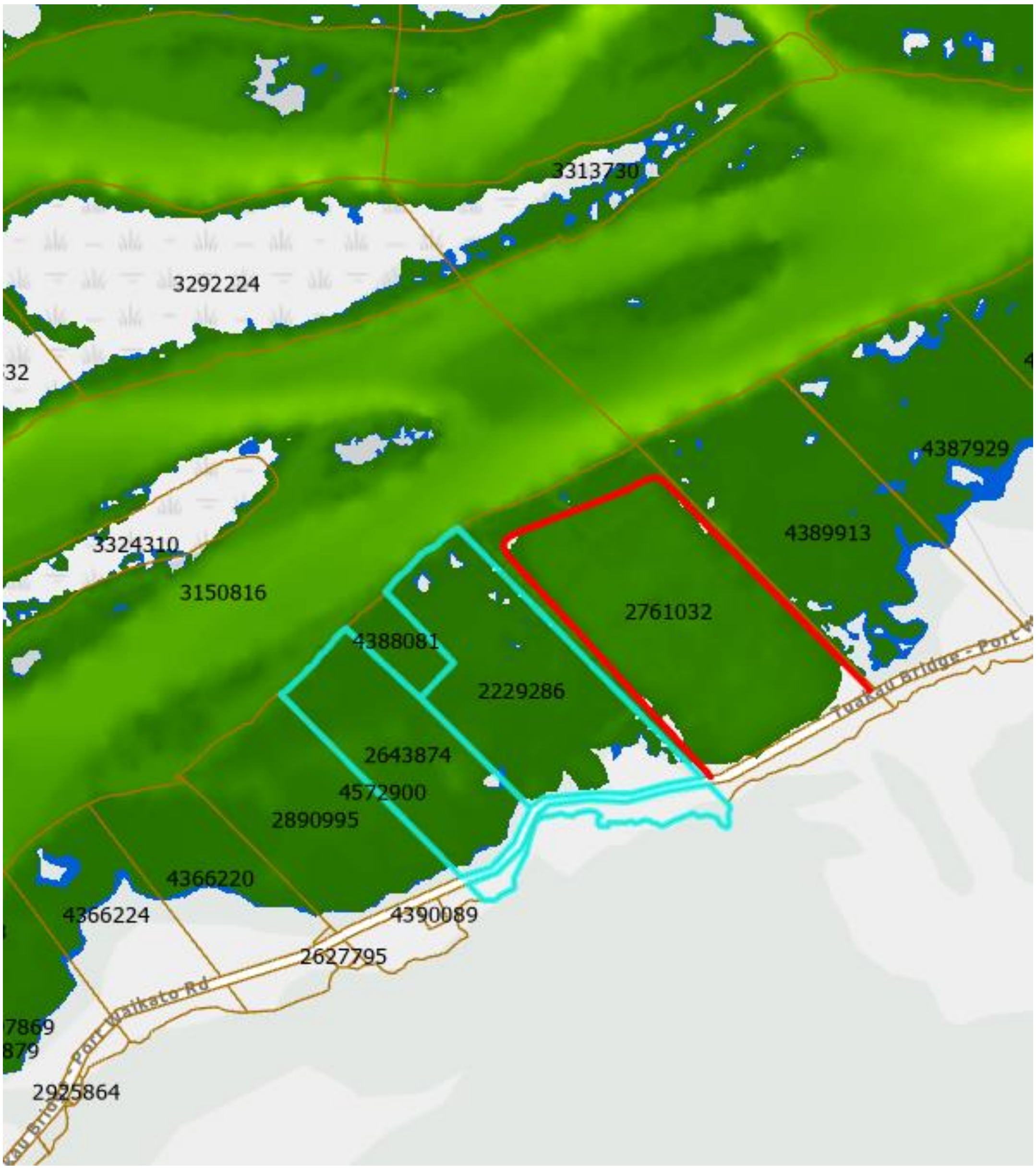
Map 2: North side

Property 4833457



Source: Reeves and Wadhwa (2023)

Map 3: South side



Source: Reeves and Wadhwa (2023)

Appendix B: Default Values and Assumptions

All values and assumptions are open to improvement. Data is from various sources as listed in the Reference section.

Land and Dwellings (2020 approximate)

Item	Value	Unit
Land value	487	$m
Improvements value	99	$m
Total value	586	$m
Cost of raising a dwelling (WT, 2023)	1800	$'000
Max no. dwellings/buildings affected*	482	No.
Total cost of raising	87	$m

* For an AEP=1% event with SLR=160cm.

Pipes*

Item	Value	Unit
Port Waikato storm water	2031	m
Port Waikato water	5866	m
Total length	7897	m
Annual cost per metre over 50 years	50	$/m/yr
Undiscounted value	$19.7	$m

* Reticulated systems are rare outside Port Waikato.

Roads (including driveways)

	Value	Unit
Total length potentially exposed	118	km
Capital cost per km (rural)	1.1	$m/km
Total cost	55.0	$m

Drainage System

There are an estimated 47km of stopbanks and 100km of drains.

Item	Number	Value ($m)
Floodgates	44	4.4
Pump Stations	15	8.7
Stopbanks	18?	24.3
Drains	64	2.5
		40.0

Wetland ecosystem services

Item	Value	Unit
Benefit of ecosystem services	27,100	$/ha
Cost of restoration	15,000	$/ha
Maintenance cost	200	$/ha/yr

Agriculture (dairying)

Item	Value	Unit
Farm area exposed (approx)	1213	ha
Productivity*	1200	kg MS/ha
MS price	7.00	$/kg MS
Income per ha	8400	$/ha
Total	10.2	$m
Value added, say 50%	5.1	$m

* *Dairy Statistics*. Farms in the affected area are mostly dairy.

Value added in dairying of $5m seems reasonably plausible. In 2022 total value added from diary, sheep, beef, cattle and grain farming contributed an estimated $59m to the GDP of the entire north-west Waikato District (SA3). Its area is 1547 km^2 compared to 232 km^2 for the study area.

Appendix C: Discount Rate Theory

There are two fundamental properties of discount rates that are relevant to investment in adaptation to sea level and its related risks:

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. The rate should incorporate a market based risk premium, as set out in the Capital Asset Pricing Model (Treasury, 2008). Treasury's current discount rate for infrastructure projects is currently 5.0%, although it has previously been considerably higher.[10]
2. If the capital cost of the project does not truly represent the opportunity cost of that capital in other uses, a social discount rate is likely to be more appropriate.

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 adaptation to climate change this equivalence is unlikely, especially if property rates or other 'user pays' levies 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 adaptation projects, or at least it should be substantially reduced towards something like the social rate of time preference (SRTP), which is appropriate when the opportunity cost is lower 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

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) 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), who suggests that a reasonable value of the SRTP for New Zealand is around 3.0% - 4.0%.

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

Appendix D: Value of Delay

The example below is purely illustrative. The numbers are not related to the study area.

Once only decision

The matrix below shows discounted total costs (expected economic loss plus the cost of investment in flood protection) for two climate scenarios (simply with and without) and two adaptation strategies. There are four scenario-strategy combinations:

1. No climate change and invest in Strategy A
2. No climate change and invest Strategy B
3. Climate change and invest Strategy A
4. Climate change and invest Strategy B.

Table D1: Discounted Cost plus Loss

Action	No climate change	Climate Change
Strategy A	[1] $110m	[3] $186m
Strategy B	[2] $136m	[4] $154m

The two scenarios on the leading diagonal in Table D1 (1 and 4) are optimal in the sense that a correct decision is made. Scenario 2 is a Type I error with a cost penalty of $26m in over-investment, while Scenario 3 is a Type II error with a loss penalty of $32m from under-investment in flood protection.

For the given climate change scenario and its estimated economic loss, at what point (p) do the statistically expected total discounted costs of Strategies A and B coincide? That is:

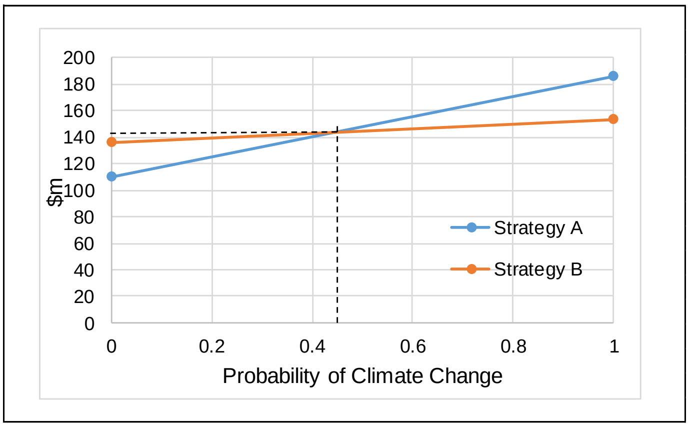
$$E(A) = 110(1-p) + 186p$$

Similarly the expected total discounted cost of Strategy B, E(B) is:

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

These two equations yield the same solution at p=44.1%. So for p in excess of this value Strategy B should be pursued; otherwise Strategy A is preferred. See Figure D1.

Figure D1: Adaptation Strategies



Value of delay

However, the above is all based on the assumption that a decision is made only once to pursue a single strategy at the start of the planning period. When we know or suspect that the risk of SLR and adverse events are changing, is there value in pursuing Strategy A initially and delaying a decision to upgrade to Strategy B until some sort of trigger (such as the number of AEP=10% events, which are less serious, in a given time period) is reached?

For illustrative purposes we assume that Strategy A is implemented at the start of the period and that a review is triggered in 2055, at which point either Strategy B is implemented or nothing extra is done – until the next policy trigger point if there is one. See Figure D2 in which the Do nothing strategy is assumed to expire in the near term, whereas Strategies A and B can continue indefinitely. Likewise for a strategy in which A is adopted initially, with a switch to B at some point in the future.

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

The calculations in Table D2 show that the expected discounted cost of pursuing Strategy A at the start of the planning period and then implementing Strategy B in 2055 is $166m.

Table D2: Expected Loss and Cost of Adaptation Strategies

	No Climate Change				Climate Change					
	Strategy A		Strategy B		Strategy A		Strategy B		Delay: A then B	
	Loss ($m)	Invest ($m)	Loss ($m)	Invest ($m)	Loss ($m)	Invest ($m)	Loss ($m)	Invest ($m)	Loss ($m)	Invest ($m)
2025	3.3	96.3	0.5	142.8	3.3	96.3	0.5	142.8	3.3	96.3
2030	3.3		0.5		5.7		1.1		5.7	
2035	3.3		0.5		8.0		1.6		8.0	
2040	3.3		0.5		10.4		2.2		10.4	
2045	3.3		0.5		12.7		2.7		12.7	
2050	3.3		0.5		15.1		3.3		15.1	
2055	3.3		0.5		17.4		3.8		17.4	66.2
2060	3.3		0.5		19.8		4.4		4.4	
2065	3.3		0.5		22.1		4.9		4.9	
2070	3.3		0.5		24.5		5.5		5.5	
2075	3.3		0.5		26.8		6.0		6.0	
2080	3.3		0.5		29.2		6.6		6.6	
2085	3.3		0.5		31.5		7.1		7.1	
2090	3.3		0.5		33.9		7.7		7.7	
2095	3.3		0.5		36.2		8.2		8.2	
2100	3.3		0.5		38.6		8.8		8.8	
2105	3.3		0.5		40.9		9.3		9.3	
2110	3.3		0.5		43.3		9.9		9.9	
2115	3.3		0.5		43.3		9.9		9.9	
2120	3.3		0.5		43.3		9.9		9.9	
Totals	20.9	89.3	3.5	132.5	96.8	89.5	21.2	132.5	51.9	114.3
discounted		110.2		135.9		186.2		153.6		166.2

Hence the equation we need to solve is:

$$E(\text{delay}) = 110(1-p) + 166p = 154$$

Table D3 shows the expected cost for various values of p in the above equation. At p=77.5% the expected cost of delay at $154m is the same as the expected value of pursuing Strategy B at the start of the period.

Figure D2: Strategy Paths

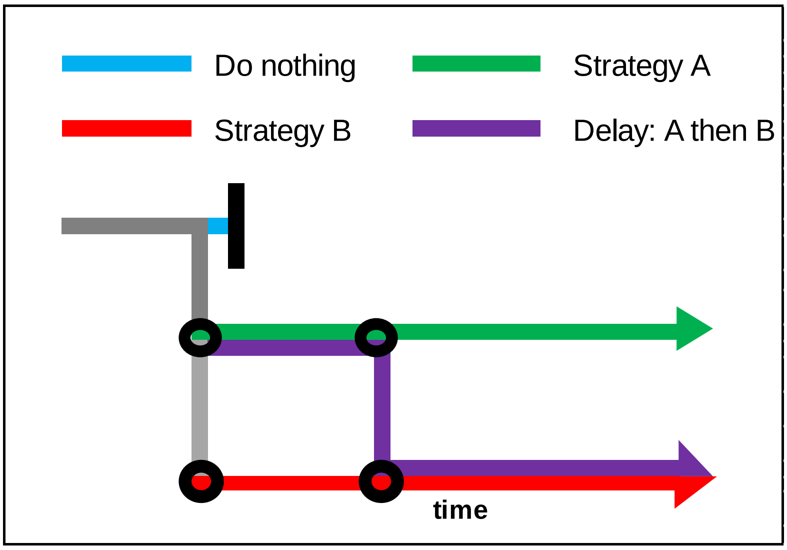


Table D3: Expected Costs under Uncertainty

Probability of climate change	Expected cost with delay ($m)
0.0%	110
20.0%	121
50.0%	138
77.5%	154
80.0%	155
100.0%	166

Therefore if the probability of climate change (given some rate of SLR) is thought to be more than 77.5%, Strategy B 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 usually lead to a more cautious adaptation strategy than relying on standard cost benefit analysis.

Appendix E: Feedback

In October 2024 a presentation and discussion of the ROA findings was held with interested groups. A number of issues (in some cases reiterating those mentioned in the report) :and recommendations for further work were raised:

- Sociocultural and distributional issues, especially important to Māori, need investigation.
- Imperfect economic data.
- Uncertain levels of risk.
- The potential residual cost of flooding in Lower Waikato presently could be higher than currently estimated, so future costs could also be understated.
- Carbon sequestration benefits are not included.
- Non-financial impacts generally are limited.
- Distributional issues are not addressed. In particular the existing drainage system creates harm that is not well recognised in the analysis (such as loss of wetlands, facilitation of salt wedge creep, displacement of water (flooding) to other land, including that of Māori.
- Social benefits of adaptation options are not discussed, for example the social benefit of elevation of dwellings.

It was noted the limitations and exclusions could potentially affect the estimated economic performance of the adaptation strategies that were assessed.

References

Auckland Transport (2017). Board Meeting, 28 March 2017, Agenda item no. 11.3

Infometrics and PS Consulting (2015). Flood protection: option flexibility and its value – Hutt River city centre upgrade river corridor options report. Report Prepared for Greater Wellington Regional Council.

Koru Environmental Consultants Ltd (2017). Summary of life cycle costs for wastewater infrastructure solutions, for Greater Wellington Regional Council.

Landcare Research (2019). The potential use of sphagnum moss to improve river health and as an economically and ecologically sustainable crop. Prepared for West Coast Regional Council.

Mahuta, R., van Schravendijk-Goodman, C., Holland, P., Harrison, S., Rolleston-Gabel, T., Johnson, D., Yang, W., Blackett, P., Connolly, J., Kerridge, D., Manukau, T., Rika-Heke, M., Te Ao, B., Te Ao, P. and Flavell, K. (2025) Measuring climate change impacts on Indigenous sociocultural wellbeing: case study of Te Puuaha o Waikato. *Coastal Transformations*. New Zealand Coastal Society. March.

Manaaki Whenua Landcare Research (2018). *Carbon sequestration potential of non-ETS land on farms*. Prepared for: Ministry for Primary Industries.

Matthews, Y. S., Holland, P., Matheson, F. E., Craggs, R. J., & Tanner, C. C. (2024). Evaluating the Cost-Effectiveness of Green Infrastructure for Mitigating Diffuse Agricultural Contaminant Losses. *Land*, *13*(6), 748.

Ministry for the Environment (2023). Developing a Carbon Removals Strategy. https://environment.govt.nz/assets/publications/developing-a-carbon-removals-strategy-cab-paper-and-mins.pdf

Nichols, S. (2024). Impact of waterlogging on growth of perennial ryegrass. AgResearch report to NIWA.

NIWA (2023). Lower Waikato Asset Exposure Summary.

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

Reeve, G and Wadhwa, S. 2023 (unpublished data from the Maaku anoo – Building our own house within a climate change environment" project, a collaboration between NIWA, Te Whakakitenga o Waikato and Swampfrog Environmental Ltd, funded by the Vision Mātauranga Capability Fund of the New Zealand Ministry for Business, Innovation and Employment, contract C01X2021).

Simmonds, K., L. Ferris, D. Austin, M. Madison & H. Emond (2022). *The Humble Wetland – A Carbon Superhero?* Paper presented at Water New Zealand Conference & Expo. https://www.waternz.org.nz/Attachment?Action=Download&Attachment_id=5202

Stern, N. et al (2006). The Economic of Climate Change. HM Treasury.

Treasury (2008). Public Sector Discount Rates for Cost Benefit Analysis.

Waddington, K., Khojasteh, D., Marshall, L., Rayner, D., & Glamore, W. (2022). Quantifying the effects of sea level rise on estuarine drainage systems. *Water Resources Research*, *58*(6), e2021WR031405. https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2021WR031405

Waikato District Council (2018). Onewhero Water Supply: Water Safety Plan. https://www.waikatodistrict.govt.nz/docs/default-source/services-and-facilities/water/water-supply/water-safety-plans/wdc-final-onewhero-wsp-2018.pdf?sfvrsn=7df180c9_4

Waikato district data on water infrastructure and inundation: https://data.waikatodistrict.govt.nz/data/?q=water

https://coastalinundation.waikatoregion.govt.nz/

Waikato Regional Council (2019). Land Drainage Management Plan, Waikato Regional Council Policy Series 2019/14

Willenbockel, D. (2024). Peatland restoration in Germany: A dynamic general equilibrium analysis. *Ecological Economics*, *220*, 108187.

WT Ltd (2023). Indicative cost estimates to raise existing residential and non-residential Properties, for NIWA

Yang, W., Holland, P., Qu, Z., Tanner, C. (2024). Dynamic Economic Valuation of Coastal Wetland Restoration: A Nature-Based Solution for Climate and Biodiversity. Unpublished report at NIWA.