Introduction

Stationarity, which assumes the probabilistic characteristics of hazard extremes and risk can be extrapolated from observational records, is now an ill-suited for dealing with the continually changing risks we face, the inherent deep uncertainties and any downstream tipping points [1].

Driven by rising sea level, ongoing change in risk is unequivocally the new norm for coastal environments. This includes the growing inland reach of coastal processes, such as salinization, groundwater rise, and flood hazards affected by climate change and sea-level rise (Figure 1). As rates of sea-level rise accelerate, adaptation will need to occur at a faster pace and/or a larger scale.

Figure 1: Ohiwa Harbour brimful during a high perigean-spring (king) tide on a sunny day: 1-Feb-2014 [Credit: R Bell]

Consequently, a different approach to risk or impact assessments and risk treatment must explicitly include the: i) increasing rate of change in risk over time; ii) interlinkages and feedbacks within the system including cascading impacts [3]; iii) compounding of coastal and freshwater hazards e.g., flooding; and iv) deepening uncertainties stemming from multiple possible coastal-climate futures, but where the direction of travel is certain.

Being explicit about planning and/or design timeframes is now a critical component of risk/impact analysis [4], when considering adaptation, whether using nominal or policy-driven timeframes (thereby artificially closing off ongoing changes in risk) or taking a realistic view of the permanence of the built environment and land-use decisions. Even short-term or incremental adaptation can lead to path dependency to a particular course of action or maladaptation down the track as climate-related risks unfold [5].

For managing the rising coastal risk and what to do about it (adaptation), risk and impact assessments and the evaluation and treatment of risk, can generally categorized into specialist but often disparate activities (and for which I have had personal involvement):

1. national or regional climate-change risk assessments and adaptation plans [e.g., 6];
2. resource-management plans, policy statements, consenting and risk reduction under the existing Resource Management Act 2001 (RMA) and future reforms [7];
3. design, upgrades or asset maintenance for infrastructure or lifeline utility services at national level or local government e.g., 30-year infrastructure management plans;
4. civil defence and emergency management (CDEM) group plans and the National Disaster Resilience Strategy; and
5. climate-related disclosures of exposure to short-, to long-term risks and opportunities that climate change presents for financial and insurance entities and businesses.

Ongoing, foreseeable, climate-related risks are and will be keenly felt in coastal environments on the back of the rise in mean sea level already in A-NZ (0.2 m since early 1900s [1]) and sea-level rise continuing for centuries, with emissions reduction only slowing the rate of rise [1, 2, 8]. As an example of the urgency to address coastal risk exposure, the first national climate-change risk assessment completed last year [6], identified impacts related to coasts and coastal lowlands as a component in 9 of the top 10 prioritized climate risks to address.

So how can we address time-varying and uncertain climate-driven risks in the non-stationary era we now face?

The problem space

Conventional practice in risk or impact analysis usually adopts the *consequences* × *likelihood* construct for risk, summarizing the analysis with heat maps that identify the combinations that potentially pose the highest risk. This provides a consistent basis for comparing different natural hazards, but it often disadvantages emergent climate-risks that so far barely register on the short-term priority list for risk treatment. This framing reinforces a static approach, or at the most fits around a planning or design timeframe dictated by the policy, standard or planning process at hand e.g., 5-10 years (Long Term Plans, CDEM Group Plans),

30 years (Infrastructure Management Plans, consents) and 100 years for coastal hazard-risk assessments. *Likelihood* poses the biggest challenge to nail down with a continually rising risk, particularly from sea-level rise and its downstream impacts and implications.

For instance, coastal flooding (Figure 1) will become increasingly more frequent over the next few decades on the back of a rising mean sea level [1, 9], so likelihood will quickly blow out over coming decades to be virtually certain (despite the uncertainties about how quickly we get to that state). Alternatively, the MfE coastal guidance [8] recommends focusing on the time-varying *consequences* and associated adaptation thresholds, rather than trying to second-guess what future climate scenario to use or worse, assign a probability to a specific climate scenario (which is not supported by any peer-reviewed literature).

Seemingly, we have lost sight of the high-level definition of risk in the ISO 91000 risk management standard, being "*the effect of uncertainty on objectives*". Embracing the inherent uncertainties associated with different possible coastal-climate futures, the intersection between the rising hazard exposure and community or stakeholder objectives at *adaptation thresholds* (the intolerable conditions we don't want to see happen or loss of a key value), forms a more open-ended and adaptive approach that are informed by risk or impact assessments.

The solution space

Starting with a set of scenarios, the adaptation pathways approach, as recommended in ISO14090 standard for climate change adaptation [10], provides a flexible solution and engagement space to devise alternative pathways that perform across a range of possible futures. The pathways (comprising short-term actions and long-term options) can then be stress-tested against the scenarios, using results from risk or impact assessments, to determine the effectiveness, flexibility and robustness of options and the possible time bounds on their "shelf life" before a switch must be made to the next option or stage in a sequence. One such approach is Dynamic Adaptive Pathways Planning or DAPP, which has been embedded in the national coastal guidance published in 2017 by the Ministry for the Environment [8]. Financial and business climate-risk assessments also use a stress-testing approach using a range of future scenarios [e.g., 11].

DAPP for a vulnerable community or infrastructure network is typically visualised in a pathway map analogous to a decision tree or a "metro map" (Figure 2). It depicts different routes to achieve a destination (objective or level of service), including switches to an alternative option before an "end-of-line" adaptation threshold (vertical bar) is reached [8, 9, 11]. DAPP embraces deepening uncertainty by focusing on decision making over time that is scenario neutral (i.e., does not rely on a choice of a design or most-likely scenario). The essence is proactive and dynamic planning of alternate pathways of investment decisions that together achieve agreed objectives over long planning timeframes, responding to how the near-future conditions are unfolding [6, 8]. The preference for certain pathways over others will depend on the trade-offs between their costs (including cost of delay), side-effects and benefits, and the expected shelf-life of options.

As with any adaptive management approach, DAPP relies on monitoring indicators of change against early signals and triggers (decision points). By allowing for sufficient implementation lead time in defining the trigger, a timely switch to the next option or pathway can avoid the pre-

agreed *adaptation threshold* for the relevant receptor or system. These thresholds are primarily informed by risk and impact assessments on what level of hazard exposure would mean objectives or levels of service are no longer being met [5, 8, 10, 12] This bottom-up approach working with a threshold (could be adaptation or a water quality limit), which is independent of scenarios or time initially, contrasts with the prevailing top-down "predict-then-act" approach of assessing potential risk using a preferred, most-likely, best-estimate or worst-case scenario and adopting its associated timeline for treating risk, planning, consenting or engineering design.

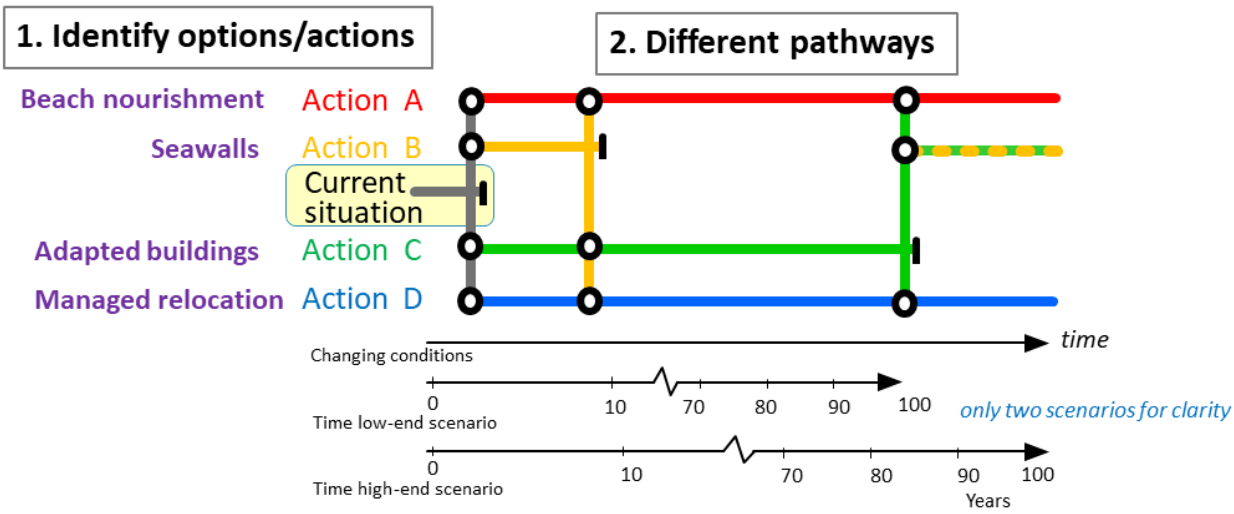

Figure 2: Example dynamic adaptive pathways planning metro map, with adaptation thresholds [8].

Adaptation pathways, incorporating an adaptive approach, provide three key benefits after [13]:

- **Flexibility:** Adaptation pathways such as DAPP explicitly embrace uncertainty and change. Uncertainties can also include societal, cultural, economic, political, environmental, and technological change, as well as climate change and sea-level rise. Monitoring early signals and triggers and regular reviews are a necessary adjunct to DAPP for timely switching to the next option or another pathway. For low-lying coastal areas, this may necessitate pathways that pre-emptively plan for the end goal of managed retreat, through a portfolio of short-term actions and sequences [9, 12].
- **Cost-effectiveness:** Because DAPP considers multiple pathways or integrated portfolios of actions/options [12] for timely adaptation, it helps reduce the risk of over- or underinvesting in adaptation or being unprepared to inform the response after a major hazard event. Planning alternatives over a long period allows relevant agencies to spread or defer large capital costs for future projects over time and allow efficient planning and funding of projects [13].
- **Transparency and more certainty in decision-making:** Because triggers and adaptation thresholds are set ahead of time (but can be adaptive over time as well), pathways allow for transparently integrating climate adaptation considerations into existing decision-making processes, including spatial planning, to support implementation. The ability to collaboratively engage and plan alternatives over a long

period also provides some certainty for communities and stakeholders on the way forward along a preferred pathway – but with flexibility to switch pathways when needed.

New role for risk and impact assessments

Successful and cost-effective adaptation in coastal lowlands over the 21st century and beyond, will need to be adaptive (flexible) and agile, responding to monitoring the ongoing changes within a backdrop of continuing deep uncertainty.

A shift is needed for risk and impact assessments, from assuming stationarity within a conventional "predict-then act" paradigm, to using scenario analysis and adaptive pathways (e.g., DAPP) covering a range of possible futures.

Longer, rather than nominal or "required policy" planning timeframes, are necessary to avoid path dependency (i.e., "picking a winner at the outset") or future maladaptation. The challenge is how do we enable and realize an adaptive paradigm?

The reform process underway on our resource management system, including statutes for spatial planning, and adaptation to climate change (to enable managed retreat), provides an opportunity for a national conversation and a reset towards adaptive planning in our coastal lowlands, as seas continue to rise.

References

[1] Bell, R.G. (2021). How will our coasts and estuaries change with sea-level rise? Implications for communities and infrastructure. *In*: Hon. Helen Clark (ed.), *Climate Aotearoa: What's happening & what we can do about it*. p. 61-92. Allen and Unwin Publishers, Australia.

[2] Oppenheimer, M. et al. (2019). Sea level rise and implications for low-lying islands, coasts and communities. *In*: Pörtner, H.-O. et al. (eds.), *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate*. https://www.ipcc.ch/srocc/

[2] Arias, P.A. et al. (2021). Technical Summary. *In*: Climate Change 2021: The Physical Science Basis. Contribution of Working Group 1 to the 6th Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press. In Press.

[3] Lawrence, J.; Blackett, P.; Cradock-Henry, N.A. (2020). Cascading climate change impacts and implications. *Climate Risk Management 29*: 100234. [Open Access]

[4] Logan, T.M.; Aven, T.; Guikema, S.; Flage, R. (2021). The role of time in risk and risk analysis: implications for resilience, sustainability, and management. *Risk Analysis*. https://doi.org/10.1111/risa.13733

[5] Lawrence, J.; Boston, J.; Bell, R.G.; Olufson, S.; Kool, R.; Hardcastle, M.; Stroombergen, A. (2020). Implementing pre-emptive managed retreat: Constraints and novel insights. *Current Climate Change Reports 6(3)*: 66-80, Springer. [Open Access]

[6] MfE (2020). *National Climate Change Risk Assessment for New Zealand: Main Report – –*

Arotakenga Tūraru mō te Huringa Āhuarangi o Āotearoa: Pūrongo whakatōpū. Prepared by a consortium led by AECOM, including Tonkin + Taylor Ltd, NIWA and Latitude and several independent contractors. Ministry for the Environment Publication ME 1506, Wellington, 133 p.

[7] Grace, E.; France-Hudson, B.; Kilvington, M. (2020). Reducing risk under the RMA. *Build 177*: 71-72, April/May. https://www.buildmagazine.org.nz/articles/show/reducing-risk-under-the-rma

[8] MfE (2017). *Coastal hazards and climate change: Guidance for local government*. Bell, R.G.; Lawrence, J.; Allan, S.; Blackett, P.; Stephens, S.A. (Eds.), Ministry for the Environment Publication No. ME 1292. 284 p + Appendices.

[9] Stephens, S.A.; Bell, R.G.; Lawrence, J. (2018). Developing signals to trigger adaptation to sea-level rise. *Environmental Research Letters 13(10)*: 104004, 11 p. [Open Access]

[10] ISO (2019). *Adaptation to climate change – Principles, requirements, and guidelines*. ISO 14090:2019(E), International Organization for Standardization, 28 pp.

[11] Task Force on Climate-related Financial Disclosures (2020). Guidance on scenario analysis for non-financial companies. October, 131 p.

[12] Kool, R., Lawrence, J., Drews, M. and Bell, R. (2020), Preparing for sea-level rise through adaptive managed retreat of a New Zealand stormwater and wastewater network. *Infrastructures 5(11)*: Paper 92, 19 p. [Open Access]

[13] Kay, R.; Messerschmidt, M.; Marks, M.; Liu, J. (2021). Ramping-up climate adaptation through a “pathways” approach. ICF International article. https://www.icf.com/insights/environment/climate-adaptation-pathways-approach