DECISION-MAKING IN OUR UNCERTAIN WORLD: WHICH, WHEN AND HOW

PATRICK CURRAN

PROF. ANITA WREFORD

DR TOM LOGAN

Changing with our climate

START ADAPTATION PLANNING TODAY

CONTENTS

GLOSSARY

Action	Something that can be implemented designed to address some planning goal.
Adaptation	The process of adjustment to actual or expected climate change and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In some natural systems, human intervention may facilitate adjustment to the expected climate and its effects (IPCC 2014)
Adaptive Capacity	The ability to respond to hazards.
Computer Assisted Reasoning	The use of computers to simulate plans across large ensembles of futures.
Dynamic Adaptive Plan	A plan that, as new information becomes available, the next step can be selected from a range of predefined actions.
Option	The right, but not the obligation, to take some action, at some cost, over some time frame (may be limited or not)
Plan	A proposal outlining what action(s) are to be implemented to achieve some goal
Protective Adaptive Plan	A plan where, as new information becomes available, a predefined next step can be implemented
Risk	The consequences (positive and negative) and associated uncertainties (Aven et al. 2018).
Robustness	The insensitivity of the performance of a plan for a range of futures.
Satisficing	A decision-making strategy that aims for plans to be "good enough" rather than optimal
Sector	A subsystem of the system being adapted i.e. distinct adaptation areas or infrastructure types.
Serious Games	Games that exist to support people to understand and explore challenges and are not specifically designed for entertainment purposes.
Static plan	A plan whose current form is unchanging even when new information comes to light.

WHO IS THIS DOCUMENT FOR?

This guidance is for planners and decision-makers in local and central government, businesses, infrastructure management, and other sectors who are making decisions now for a future that is highly uncertain. In this document, we introduce and describe methods that can be used for making decisions despite uncertainty, and identify which methods can help answer different types of questions. Where they are available, we provide examples from different sectors including land-use planning, infrastructure management, and coastal adaptation.

The focus of this document is on approaches to support decision-making under uncertainty primarily for adaptation to climate change.

We divided the decision-making approaches in this document into two categories (although some approaches could address aspects of both): creation approaches and analysis approaches. Creation approaches create plans that can then be analysed by analysis approaches to help decision-makers in their final selection of a plan. A full decision-making under uncertainty process will use at least one approach from each section. This ensures robustness is built into the plans and accounted for in the final selection of a plan. We have also created an Approach Selection Key to help planners and decision-makers select the best set of approaches for their situation.

Creation approaches

- Dynamic Adaptive Policy Pathways (DAPP)
- Multi Risk Dynamic Adaptive Policy Pathways (DAPP-MR)
- Adaptive Planning

Analysis approaches

- Computer Assisted Reasoning
  - Robust Decision Making (RDM)
  - Engineered Options Analysis (EOA)
- Scenario Planning
- Real Options Analysis (ROA)

INTRODUCTION

Long-term decision-making and planning must now, more than ever, incorporate uncertainty. Many factors can interact with climate change to make planning and decision-making even more challenging, including geopolitical dynamics, population shifts, economic shocks and social change. In the past, decisions were often made assuming one future state of the world. Many traditional investment appraisal tools such as Cost-Benefit Analysis (CBA) rely on this assumption and are no longer as appropriate in a highly uncertain future. We are able to calculate the financial costs, that occur now, but calculating the benefits of adaptation to climate change is more complicated because we are not sure how the climate will change, when those changes will occur, and how large they will be. Comparing these uncertain benefits to the certain costs may lead to decisions that are known as “maladaptive” – where they have unintended negative effects and may potentially lead to increased future risk.

However, changing the way we make decisions is difficult, as our systems and regulations have developed around assuming that we can predict the future. Trying to include uncertainty can be daunting, but there are tools and techniques available to develop robust plans despite uncertainty. This document aims to provide an introduction to some of these.

Although we often refer to “uncertainty” quite generally, it comes about from a range of different sources. In the context of climate change, uncertainty comes from:

1. Future greenhouse gas emissions - these determine the rate, timing and size of the impacts from climate change, and depend on how effective global efforts to reduce emissions will be. The Representative Concentration Pathways (RCPs) allow these futures to be explored;

2. Climate models and impact models – there may be limitations in how well climate models represent the earth system (e.g. dynamic ice sheet processes) or their interactions and feedbacks (e.g. climate–carbon cycle feedbacks). The ways in which the environment or social systems are represented may also be limited;

3. Measurement errors and/or data processing – these may result from imperfect observational instruments (e.g. rain gauges) or algorithms for estimating surface temperature based on satellite data;

4. Socio-economic, demographic, political and technological changes determine how the changes in climate actually affect people and places. These socio-economic changes have been integrated with emission scenarios to create Shared Socioeconomic Pathways (SSPs).

The respective contribution of each of these sources to total uncertainty depends on the timescale and the spatial scale. Over a long period of time emissions uncertainty dominates the total uncertainty.

It's important to remember that each layer of analysis adds more uncertainty, and downscaling climate projections to higher levels of resolution can lead to a false sense of precision. Some authors have referred to "cascading uncertainty" (Wilby and Dessai 2010), where global models are downscaled to regional projections, then potentially used to inform impact models (e.g. hydrological models), which may then be used to drive biophysical (e.g. crop growth) models, and perhaps then an economic analysis may be carried out. Each layer adds further uncertainty. But this doesn't mean we should give up! It just means we need to be careful about how we use the projections, and to make decisions in a way that acknowledges the wide range of possible futures.

Alongside the different sources of uncertainty, there are also different levels of uncertainty based on the precision of our knowledge (Walker, Lempert, and Kwakkel 2013). These levels of uncertainty include:

1. A predictable future is often represented as forecasts or predictions. In practice, a predictable future is very unlikely. However, representing our understanding of the world in this way does have some benefits. Many of our current decision-making approaches rely on forecasts to design and select plans. In some situations, while not accurately representing the range of futures, forecasts can provide valuable insight and may provide enough of a representation of the future for some types of decisions.

2. Another level of uncertainty is a probabilistic representation. This is the most common way to represent uncertainty, often shown as a distribution of possible outcomes around a forecast. This is often a more realistic articulation of possibility, showing the variation inherent in our world.

3. When it's not possible to identify or agree on probabilities, model parameters, or model structure we need to focus on possibility. This level is known as Deep Uncertainty. Deep Uncertainty means most traditional decision-making methods are no longer suitable, so different approaches need to be used. Drawing on existing methods from other disciplines, a range of approaches have been developed to create and assess plans to be adequate over a range of futures rather than optimised to one predicted future.

In this document, we review a selected range of approaches available for decision-makers who need to make decisions in an uncertain future. We provide examples and outline the pros and cons of each approach. The goal is to support decision-makers in choosing the most appropriate approach for their context. The approaches in this document have been presented in a basic form and can be adapted as required and integrated into an iterative decision-making process with stakeholder engagement throughout.

THE DECISION-MAKING PROCESS

We suggest following a generic decision-making process to frame the problem and explore different approaches, as set out here (adapted from Marchau et al. (2019):

1. Frame the analysis
   - Identify the problem
   - Identify the objectives of the plan and the values of the community
   - Identify relevant uncertainties
2. Create plans
   - Decision-makers, analysts, planners, and the community identify and design potential actions.
   - Choose the appropriate decision-making approach(es)
   - Integrate adaptation options into potential plans
3. Explore
   - Analyse how plans perform under different uncertain futures
4. Choose
   - Trade-off analysis of the plans
5. Implement
   - Communicate the outcomes of the decision-making process
   - Monitor as required

Step one and the development of actions in step two can be completed using the "XLRM" framework: a series of questions to aid in problem scoping (Table 1).

Table 1 - XLRM framework, with questions to aid in completion (Lempert, Popper, and Bankes 2003)

UNCERTAIN FACTORS (X)	ACTIONS/INTERVENTIONS/POLICY LEVERS (L)
» What are the uncertain factors outside of the control of decision-makers, that may affect outcomes? » What is the plausible range of these uncertainties? » What information is needed to define these ranges, do best estimates exist? » What level of uncertainty are you facing?	» What actions can be implemented to address today's/the near future conditions? » What type of actions can address changing future conditions?
RELATIONSHIPS (R)	**PERFORMANCE METRICS (M)**
» How might Levers and Uncertainties affect goals/ performance metrics? These relationships should be built into any modelling that is done.	» What characteristic(s) of system performance is important to you? » What are the measures and indicators we should use to evaluate these characteristics? » What are the acceptable levels and limits of the measures and indicators to be achieved? » What is the information needed to define these acceptable limits?

APPROACH SELECTION KEY

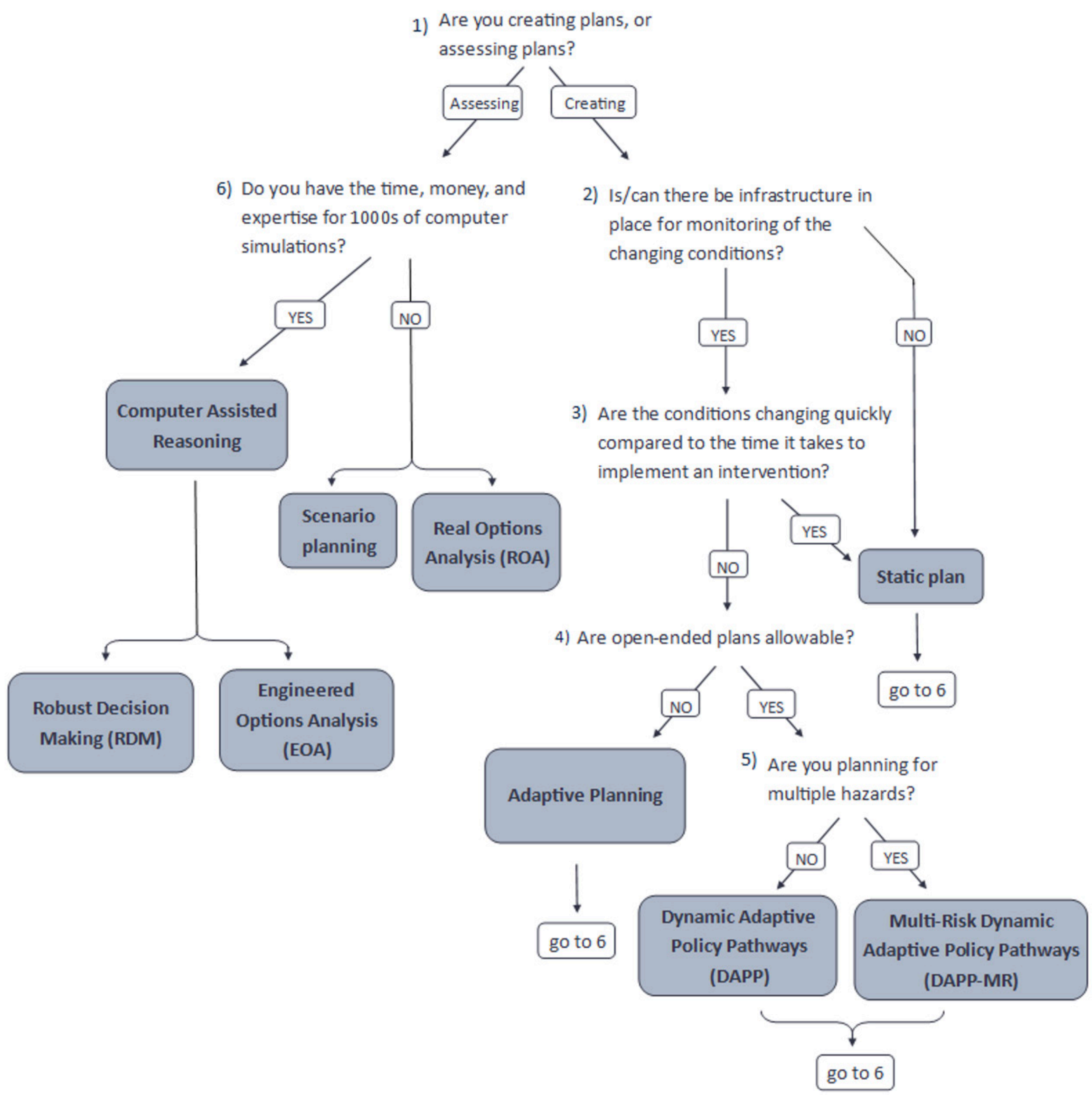

Figure 2 – Decision Approach Tree used for identifying the best approach(es) for a task (Curran, Wreford, and Logan 2023)

We have designed an Approach Selection Key (Figure 2) to help decision-makers choose the most appropriate approach(es) for their task. Decision makers can work through the tree to identify what creation and analysis approaches are best suited for their situation. Each step in the tree is based on the characteristics of the approaches.

Open-ended plans (question 4) are plans that do not have a predefined sequence of actions, instead, they select the best action for the situation as required.

The rest of this document summarises the selected approaches. For more information, decision-makers can consult the additional resources to which this text refers.

We also note that not all decisions require these types of tools. For adaptations that don't have such long lifetimes, a standard CBA may still be appropriate. In other situations, private decision-makers may choose to invest in adaptations that suit their own risk-preferences – for example, a risk-averse individual may assume a high-emissions scenario in a standard CBA and risk "over-investing" in adaptation, while others may assume a lower-emissions future, risking damage and having to pay more for adaptation later. For most publicly funded situations, it will be important to make decisions that are robust to uncertainty and as economically efficient as possible, which is where these tools will become increasingly important.

APPROACHES FOR DECISION-MAKING UNDER UNCERTAINTY

DYNAMIC ADAPTIVE POLICY PATHWAYS (DAPP)

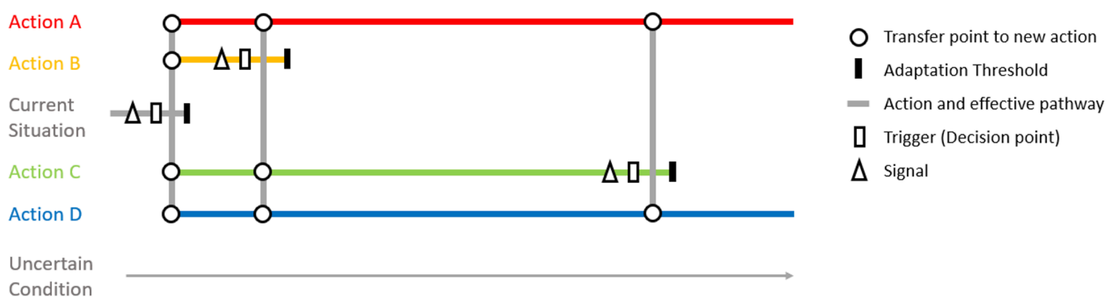

Figure 3 – A generic DAPP "metro map" showing how actions can be switched between as required (adapted Lawrence et al. 2020)

WHAT IS DAPP?

The goal of these approaches is to create a plan that is successful regardless of the uncertain condition (e.g. environmental or economic) it may face. Dynamic Adaptive Policy Pathways (DAPP) seeks to accomplish this by developing a portfolio of actions that can be switched between as necessary, based on their suitability for the current conditions. Having a prespecified portfolio of plans speeds up decision-making but also allows for the selection of a plan that fits the values, needs and fiscal capabilities of the community at that time. A prespecified pathway (a sequence of actions) is less desirable as it limits the adaptive capability of the plan. Instead, actions should be selected as required, based on the observed conditions. This means that only short- to medium-term requirements are implemented, and over-adaptation and path dependence is avoided by keeping options open.

This portfolio of plans is often displayed in a "metro map" diagram (Figure 3) showing actions as lines that terminate when that action is no longer suitable for the current condition: an adaptation threshold. Ideally, before this threshold is reached, a new action has been implemented, ensuring that the plan is functioning under these new conditions. To ensure there is sufficient time to implement the next action, signals and triggers are identified, which indicate when an action may be nearing the end of its design capacity. Signals are predefined conditions that indicate that the decision process for shifting to a new action needs to begin. Similarly, triggers are predefined conditions that occur after signals, that indicate when decisions are required to ensure enough lead time to implement the next step in the plan.

As an example, consider a coastal area that would be intolerably affected by 0.8m of sea level rise, without any action taken. A sea level rise of 0.8m is therefore the adaptation threshold and action is needed before this occurs. Based on the possible actions identified and the time they take to implement, a decision is needed by 0.5m of sea level rise in order for the subsequent action to be in place by 0.8m. Therefore, 0.5m is the trigger. Finally, sufficient time is needed to identify and decide which action will be taken. Therefore, a signal that starts this process needs to be chosen (e.g. 0.2m). Additionally, disruptive events (shocks i.e. extreme weather events) provide opportunities to update and reassess plans as part of the recovery, and as such could also be treated as signals.

IDEAL CONDITIONS AND USERS

The DAPP process works well when there is a single deeply uncertain condition that is changing over time. The alternative actions need to be implementable quickly enough so that the conditions do not outpace this implementation. Given that the next step is unknown (meaning it is an "open-ended" plan), users must be comfortable with uncertainty about what the next action is and when it will be implemented.

The primary users of this approach would be asset managers or strategic planners. Often these plans will be developed through engagement with the community, iwi, and other experts. The output is used by integrating the selected near-term action and associated signals and triggers into organisational plans and strategies.

HOW TO USE THIS APPROACH

These steps have been adapted from Haasnoot et al (2013) and form the basis of the Coastal Hazard and Climate Change Guidance (Ministry for the Environment 2017).

1. Identify potential actions
   a. A preliminary list of actions can be compiled through engagement with local experts, iwi, and the wider community. Efforts should be made to get a diverse range of opinions and actions. (Combinations of actions should be considered as independent actions, e.g. beach nourishment in combination with coastal armouring may extend the viability of an action).
   b. Identify the conditions at which each action becomes unsuitable or unfit for purpose. These are the adaptation thresholds/tipping points (e.g. [x] meters of sea level rise)
   c. For each action, determine the possible subsequent actions and the time it would take to switch between them, i.e. implementation/lead time. Use the longest of these times to inform the trigger.
   d. For each of these triggers, signal points need to be determined. This needs to provide enough time to enable engagement, analysis, and other activities before deciding on the next action.
   e. The lead time and decision time need to be translated into conditions that can be monitored as we don't know the timing of the threshold and therefore cannot simply project these timings backwards. A conservative approach would be using worst case climate scenarios to determine the change in uncertain condition (e.g. change in sea level) corresponding to the lead and decision times. Alternate methods for signals and triggers can be found here: (Stephens, Bell, and Lawrence 2018; Lawrence et al. 2020).
2. Design Pathways
   a. Sketch out/generate the "metro map":
      - The uncertain condition (e.g. sea level rise) should be drawn as a horizontal line (like an x-axis of a figure).
      - Above this, draw out a horizontal line for each action, terminating at their adaptation threshold.
      - Mark each action's trigger point.
      - Mark each action's signal.
      - Connect actions to their possible subsequent actions using vertical lines between the trigger and threshold
   b. The result is a series of connected actions, and each possible combination of these is a pathway (i.e. the different ways to trace your way through the metro map).
   c. For simplicity, it is possible to use a table to present different pathway combinations (Figure 4).

Pathway	Short term	→	Medium term	→	Long term
PW 1	Renourishment	→	Managed Retreat	→	Managed Retreat
PW 2	Renourishment + Control Structures	→	Renourishment + Control Structures	→	Managed Retreat
PW 3	Renourishment + Control Structures	→	Renourishment + Control Structures	→	Renourishment + Control Structures
PW 4	Renourishment + Control Structures	→	Renourishment + Control Structures	→	Sea wall
PW 5	Sea wall	→	Sea wall	→	Managed Retreat
PW 6	Sea wall	→	Sea wall	→	Sea wall

Figure 4 - Tables showing simplified adaptation pathways for Clifton (Bendall and Mitchell Daysh Ltd 2018)

3. Evaluate Pathways
   a. Scorecards (often semi-qualitative) are often used to evaluate pathways showing costs, benefits, and co-benefits (Figure 5).
   b. Additionally, analysis approaches, including Real Options Analysis, Robust Decision Making, Engineered Options Analysis, and Scenario Planning can be used to evaluate pathways.

Figure 5 – Example of a DAPP qualitative scorecard (Lawrence et al. 2019)

4. Design Adaptive Plan
    a. Using this information, decisions are needed to choose the initial action and identify the possible subsequent actions.
    b. Design a monitoring plan based on the identified signals and triggers.
5. Implement plan

EXAMPLE: HUTT RIVER CITY CENTRE UPGRADE PROJECT:

One example of DAPP implementation in New Zealand is the Hutt River City Centre Upgrade Project (HRCCUP) undertaken by the Greater Wellington Regional Council, Hutt City Council, and Waka Kotahi (NZTA). This plan aims to adapt the river and surrounding area for the uncertain effects of climate change on river flows and flooding.

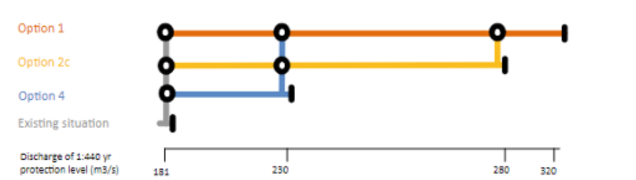

Figure 6 - Pathway map for HRCCUP (Lawrence et al. 2019)

The project developed an initial list of possible actions, then shortlisted three, based on the feasibility. These three actions formed six possible pathways. These pathways were evaluated using Real Options Analysis and multi-criteria analysis (Figure 5) (Infometrics and PS Consulting 2015). Option 1 was determined to be too costly in the short-term, so options 2c and 4 were presented to the community (Lawrence et al. 2019). It was decided to implement option 2c with a review in 10 years or when a signal/trigger has been met, whatever is earlier. Potential triggers include the level of service falling, a change in rainfall intensities, or the coping capabilities of those affected by repeated flood events.

PROS AND CONS OF DAPP

DAPP has the following strengths:

- Designed for deeply uncertain situations through flexibility.
- Identifies sequences of actions to help avoid path dependence.
- While specialist tools exist, the DAPP process can scale to the time and resources available.
    - The minimum you need is a pen and paper to brainstorm and draft pathways.
    - The drawings can facilitate discussion and community engagement.

DAPP also has the following weaknesses:

- Difficult to implement in situations with multiple hazards
    - DAPP-MR is available for instances of multiple hazards, with the same driver of uncertainty.
- Currently no way to ensure that future decision-makers adhere to the plan.
- Existing legislation does not support planning without specified actions and end points (open-ended planning). This may make funding difficult.
- Open-ended style planning may be difficult to communicate to communities and developers.
- As this is a new technique, initial buy-in may be difficult to achieve. This is sometimes solved by using Serious Games.
- DAPP is best suited when the uncertain condition is monotonic (i.e. it either never decreases or never increases).
- Infrastructure to monitor plans could present another cost.
- Adaptive planning is more expensive than static planning and if trigger points are not met then it could be seen as a waste of money.

CONCLUSIONS

DAPP provides planners with a way to create dynamic adaptive plans that are robust to many different futures. The National Adaptation Plan action 3.7.3 indicates that DAPP guidance for central and local government will be available within the next two years. The Ministry of the Environment released the Coastal Hazards and Climate Change Guidance for Local Government in 2017 which provides documentation on the implementation of DAPP in New Zealand. This document has informed many of the coastal adaptation programs currently underway around New Zealand (The Head of Lake Wakatipu Natural Hazards adaptation programme, Clifton to Tangoio Coastal Hazards Strategy, CCC Coastal Hazards Adaptation Program).

The open-ended nature of the approach has been poorly executed in practice. Often a single pathway is selected in advance, which reduces the robustness of the plan. If an open-ended plan is unsuitable, then another style of planning should be used.

ADDITIONAL RESOURCES

MfE guidance for Coastal Hazards and Climate Change (2017) https://environment.govt.nz/assets/Publications/Files/coastal-hazards-guide-final.pdf

Dynamic Adaptive Policy Pathways (DAPP): From Theory to Practice (Lawrence et al. 2019)

MULTI-RISK DYNAMIC ADAPTIVE POLICY PATHWAYS (DAPP-MR)

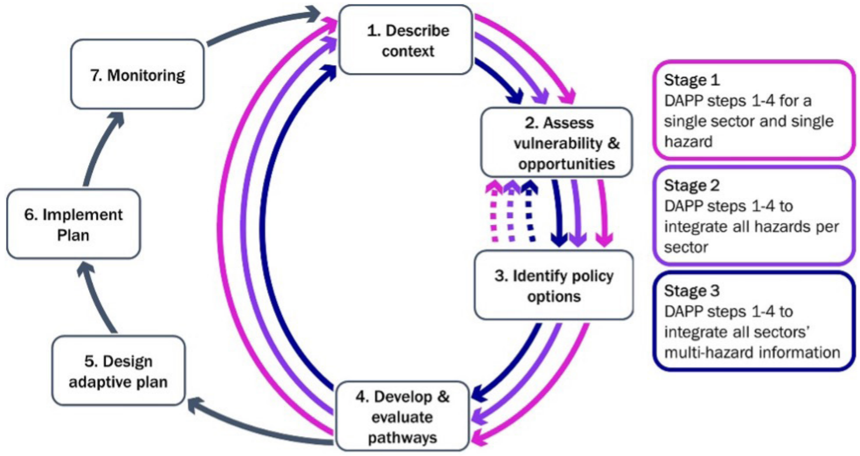

Figure 7 - DAPP-MR framework showing how steps iterate across uncertainties and sectors (Schlumberger et al. 2022)

DESCRIPTION

Multi-Risk Dynamic Adaptive Policy Pathways (DAPP-MR) is a modification of Dynamic Adaptive Policy Pathways that allows for the creation of dynamic adaptive plans in the face of multiple hazards across a range of sectors. In this case, a sector could be a community or asset type. The DAPP-MR approach involves iteratively creating pathways (combinations of actions) for each hazard in each sector, at each step identifying where pathways may influence each other, and identifying synergies and trade-offs. The initial actions can then leverage these synergies across all hazards and sectors while avoiding trade-offs.

IDEAL CONDITIONS AND USERS

DAPP-MR is useful when making plans for multiple, continuously changing (generally monotonic), hazards (that develop along the same uncertain condition). The alternative actions need to be actionable with sufficient time so that the conditions do not outpace implementation. Given that the next step is unknown (meaning it is an "open-ended" plan), users must be comfortable with uncertainty about what the next action is and when it will be implemented.

The primary users would be specialised asset managers or strategic planners. The metro-map outputs can be highly complex so an intermediary translation step may be required for engagement with the community, iwi, other experts, and when in discussion with policymakers. The output is used by integrating the selected near-term action and associated signals and triggers into organisational plans and strategies.

HOW TO USE THIS APPROACH

1. Identify the range of sectors (a subsystem of the system being adapted i.e. distinct neighbourhoods/areas or infrastructure assets) and hazards.
2. Identify actions for a single sector and single hazard.
    a. A preliminary list of actions can be compiled through engagement with local experts, iwi, and the wider community. Efforts should be made to get a diverse range of opinions and actions. Combinations of actions should be considered as independent actions, e.g. beach nourishment in combination with coastal armouring may extend the viability of an individual action.
    b. Identify the conditions at which each action becomes unsuitable or unfit for purpose. These are the adaptation thresholds.
    c. For each action, determine the possible subsequent actions and the time it would take to switch between them, i.e. implementation/lead time. Use the longest of these times to inform the trigger.
    d. For each of these triggers, signal points need to be determined. This needs to provide enough time to enable engagement, analysis, and other activities before deciding on the next action.
    e. The lead time and decision time need to be translated into conditions that can be monitored as we don't know the timing of the threshold and therefore

cannot simply project these timings backwards. A conservative approach would be using worst case climate scenarios to determine the change in uncertain condition (e.g. change in sea level) corresponding to the lead and decision times. Alternate methods for signals and triggers can be found here: (Stephens, Bell, and Lawrence 2018; Lawrence et al. 2020).

3. Design the single-sector single-hazard pathway.

   a. The uncertain condition (e.g. sea level rise) should be drawn as a horizontal line (like an x-axis of a figure).

   b. Above this, draw out a horizontal line for each action, terminating at their adaptation threshold.

   c. Mark each action's trigger point.

   d. Mark each action's signal.

   e. Connect actions to their possible subsequent actions using vertical lines that originate between the trigger and threshold.

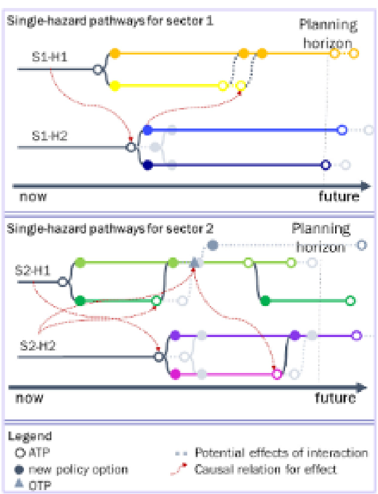

Figure 8 - Single hazard pathways for each sector showing the influence between actions (Schlumberger et al. 2022).

4. Repeat steps 2-3 for each hazard in the sector, completing the influence table/pathways.

   a. Each time a new set of pathways is created, the synergies and trade-offs between other pathways need to be identified. This can be done in an influence table as in Table 2; the boxed section displays the multi-hazard influences from a single sector. These influences should also be shown on metro maps with arrows and shifting the starting points of the actions (Figure 8).

   b. To guide the identification of influences:

      - Look for any opportunity tipping points (the point where a specific action becomes feasible or attractive) that arise from actions from the implementation of other pathways.
      - Remove any actions that fail when accounting for other hazards.
      - Add actions that may arise from the combination of other actions.

5. Repeat steps 2-4 for each sector building out the influence table/pathway.

   a. Each time a sector is completed, the synergies and trade-offs need to be identified. This can be done in an influence table as in Table 2. Again, this should also be displayed on the metro map as in Figure 9.

   b. To guide the identification of influences:

      - Identify any opportunity tipping points that arise from actions from other pathways being implemented.
      - Remove any actions that fail when accounting for other sectors.
      - Add actions that may arise from the combination of other actions.

Table 2 - Tabularised interactions of hazards and sectors (Schlumberger et al. 2022)

			S1				S2			
			H1		H2		H1		H2	
			A	B	C	D	E	F	G	H
		A		0	0	0	0	0	0	0
	H1	B			B benefits from C	0	E benefits from B	0	0	0
		C				0	0	0	0	0
S1	H2	D					D impeded by E	0	0	0
		E						0	0	0
	H1	F							0	0
		G								0
S2	H2	H								

Zero represents no interaction between the policy options.

6. Evaluate pathways.

   a. Pathways can be evaluated using a qualitative scorecard as in Figure 9. These scorecards have information on the cost of a pathway and the direct benefits displayed by hazard and sector. This can help identify how different communities feel about the possible actions and allows for selection based on diverse views.

b. Analysis approaches such as Robust Decision Making, Engineered Options Analysis, Scenario Planning and Real Options Analysis could be used to provide additional insights into each pathway.

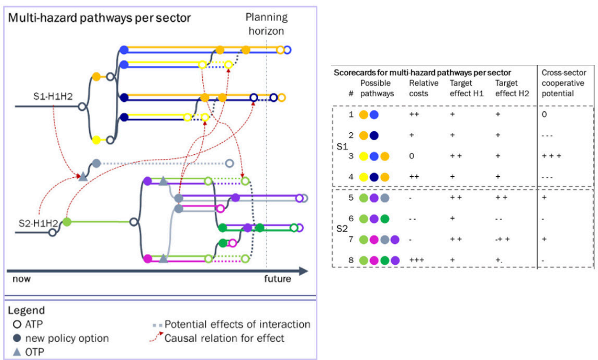

Figure 9 - Multi-hazard pathways showing interactions between sectors and qualitative score card (Schlumberger et al. 2022)

7. Design Adaptive Plan.

a. Using this information, decisions are now needed to choose the initial action and identify possible subsequent actions.

b. Design a monitoring plan based on identified signals and triggers.

8. Implement plan.

EXAMPLES

DAPP-MR was first proposed in October 2022 by Schlumberger in the paper Proposing DAPP-MR as a disaster risk management pathways framework for complex, dynamic multi-risk. At the time of publication DAPP-MR has not been implemented.

PROS AND CONS OF DAPP-MR

DAPP-MR has the following strengths:

- DAPP-MR seeks to account for multiple hazards.
- Treats the problem as a system, looking for synergies and trade-offs.
- Supports identifying and avoiding path dependence.
- The dynamic nature of the subsequent plan allows for decisions to be made alongside the community of the time.

DAPP-MR has the following weaknesses:

- DAPP-MR does not handle cases where there are different uncertain drivers (e.g. sea level rise and increased severity of storms).
- The final output needs to be simplified for stakeholders and decision-makers as complex multi-sector/hazard metro maps may be overwhelming.
- Existing legislation does not support this type of open-ended planning style. This may make funding difficult.
- Open-ended style planning may make it difficult to communicate with communities and developers.
- By not specifying the next action, signals and triggers may be ignored in the future.
- No way to ensure that future decision-makers adhere to the plan.
- Process is still new and has never been put into practice before. There may be unforeseen difficulties that need to be resolved.
- Significant investment may be needed and if the conditions aren't met the plan wouldn't be implemented and could be considered a waste of resources.

CONCLUSIONS

The problems facing planners today are complex multi-risk scenarios. DAPP-MR provides a way to address this while still using a pathways approach. This does come at the expense of increased complexity in the output. There may be a need for an intermediary step, to translate the complex plans to the public and decision-makers.

As this is a new approach there are very few resources to aid in the creation and DAPP-MR approach. The implementation is similar to the Dynamic Adaptive Policy Pathways approach and there is a growing body of research and examples to aid in this.

ADDITIONAL RESOURCES

Schlumberger (2022) Proposing DAPP-MR as a disaster risk management pathways framework for complex, dynamic multi-risk

ADAPTIVE PLANNING

DESCRIPTION

Adaptive Planning creates a robust plan by predetermining actions that address vulnerabilities arising from uncertain conditions. Predetermining the actions has the advantage that the next steps in the plan are known but are flexible to uncertain conditions. This means there is less uncertainty in what decision-makers will do in the future, which is helpful when other people rely on these plans (i.e. people purchasing or developing properties). This is different to pathways approaches where the plans are open-ended, providing more flexibility to the plan at the expense of certainty.

Adaptive Planning can be built on existing plans, increasing their robustness, and avoiding having to start from scratch. This fits well with New Zealand's planning system where long-term plans are created for 10-year periods and reviewed every three years.

IDEAL CONDITIONS AND USERS

Adaptive Planning is useful when creating a plan under any number of deeply uncertain conditions. The main users would be strategic planners and decision-makers during the design and implementation of plans. As the actions have been prespecified it may be easier to implement and communicate the next actions in the long-term or spatial plans if trigger points are well-defined (compared to Dynamic Adaptive Policy Pathways and Multi-Risk Dynamic Adaptive Policy Pathways).

HOW TO USE THIS APPROACH

There are four steps to Adaptive Planning (Walker, Marchau, and Kwakkel 2019):

1. Assemble the initial plan.
    a. An initial plan is required. This could be the current plan/systems in place, a new plan designed to address today's conditions/certain future conditions, or an adaptive plan that sequences actions (essentially a prespecified DAPP pathway).
2. Increase the robustness of the initial plan.
    a. Identify the conditions/circumstances where the initial plan performs poorly. To identify these situations, scenario discovery as part of Robust Decision Making can be used. Alternatively, Assumption Based Planning can be used to identify the "load-bearing assumptions," i.e. the assumptions that, if false, would result in failure.
    b. Identified weaknesses can then be addressed by increasing robustness through updating the initial plan with several static actions:
        - Shaping actions try to force a specific future state into one the plan works well in.
        - Mitigating actions aim to reduce the adverse impacts of very likely events e.g. stopping future development in flood-prone areas.
        - Hedging actions may have some initial costs but will reduce downsides in the event of a poor outcome e.g. insurance.
        - Seizing actions take advantage of very likely events e.g. purchasing land in new developments to enable future land swaps.
        - Exploiting actions take advantage of unlikely events.
    c. Identified weaknesses can also be addressed through adaptive actions (actions triggered by future conditions):
        - Corrective actions are adjustments to the plan after implementation e.g. raising minimum floor heights at [x] meters of relative sea level rise.
        - Defensive actions are designed to avoid failure and are only implemented once the initial plan is in place, relying on monitoring conditions to trigger activation.
        - Capitalising actions take advantage of opportunities to improve the plan.
        - Reassessment occurs when the plan is no longer fit for purpose due to a change in the underlying conditions or goals and an entirely new plan is required. This will generally be in a post-disaster situation.
    d. An actions table can be used to show the vulnerability and the action that will be implemented to address it as in Table 3.

3. Create a monitoring system.

a. A monitoring system is established that looks for triggers to implement an action.

b. An extra column can be added to the actions table (e.g. similarly to Table 3) to show the trigger points for each adaptive action.

4. Implement the plan.

EXAMPLES: SEA LEVEL RISE ILLUSTRATIVE EXAMPLE (RAHMAN, WALKER, AND MARCHAU 2008)

This illustrative example was prepared for the Board of the Netherlands Ministry of Transport and Water and investigates how the Netherlands could "be safe against flooding, while remaining an attractive place to live, to reside and work, for recreation and investment."

The initial plan is to raise coastal protection to ten times more than its current safety requirements (intermediary safety requirements) and produce a study that looks for a balance between protection and avoiding disruption to the economy and environment (updated safety requirements).

Table 3 (vulnerabilities column) shows the conditions required for the basic plan to succeed. The actions to be implemented to ensure that the conditions are met appear in the last two columns.

Table 3 - The conditions required for success and actions to ensure that they occur (Rahman, Walker, and Marchau 2008).

VULNERABILITIES	MITIGATING/HEDGING	ADAPTIVE ACTIONS AND TRIGGERS
Certain: Currently, there is no way of accumulating coastal defence money over time	Prepare an emergency law to make such savings over time possible (e.g. a 'Delta Fund')	-
Uncertain: The money might not be there when needed to meet the updated safety requirements	Once the 'Delta Fund' is in place, start saving according to the demands of the updated safety requirements	Monitor developments with respect to decision-making on the updated safety requirements. In case the updated safety requirements changes the intermediary safety requirements, undertake corrective action (i.e. increase or decrease the rate of saving)
Uncertain: There might not be enough sand available to create defensive coastal infrastructure	Begin studying alternative ways of providing the required level of coastal protection	Monitor the level of sand available. When it is clear there will not be enough, trigger the use of the best available alternative
Uncertain: There might not be enough sand transport capability	Buy an option on the private provision of sand transport boats, to be used if and when needed	Monitor the difference between the need for sand transport and the availability of boats. If the difference is too small, trigger the use of the private boat option.
Uncertain: The sea level rises faster than expected	Prepare plans for interim flood protection (e.g. station empty oil tankers along the coast)	Monitor changes in the sea level. In case of a faster rise in sea level, implement interim flood protection.
Uncertain: A storm surge might occur	• Provide the public with insurance against this eventuality • Prepare food preparation and response plans	Monitor storm surge possibilities. In case of a storm surge, implement flood preparation and/or flood response plans.
Uncertain: The decision-making process on the updated safety requirements takes a long time (e.g. because of multiple and conflicting objectives among the crucial stakeholders)	Prepare emergency 'national flood security law'	Monitor both changes in the sea level and negotiations on the updated safety requirements. In case of a trigger (rise in sea level while discussions are in a stalemate), implement the national flood security law and begin increasing the safety level of the dikes.

Finally, the initial plan and the mitigating/hedging actions are implemented. A monitoring system is developed so adaptive actions can be triggered when necessary.

PROS AND CONS OF ADAPTIVE PLANNING

Adaptive Planning has the following strengths:

- A prespecified series of actions allows for more certainty in what will be done.
- Implementation into Long Term Plans may be easier than Dynamic Adaptive Policy Pathways and Multi-Risk Dynamic Adaptive Policy Pathways due to the next step(s) being prespecified.
    - This has implications for funding as it is easier to secure funds when you can say how they will be used.
- The final output is relatively easy to understand.
- Adaptive Planning handles multiple uncertainties (at a range of levels) well. Care is needed in communicating the level of uncertainty for each vulnerability to decision-makers.

Adaptive Planning has the following weaknesses:

- As subsequent actions are predefined there is a drop in robustness as plans can't react if conditions change beyond what is planned for. To counter this, plans may need to be more conservative (over-adapting).
- Decisions for the community are made far in advance, however, communities are not static so there is potential for change in community values.
- Adaptive planning is more expensive than static planning and if trigger points are not met then it could be seen as a waste of money.
- Each uncertainty is treated as independent; there is no formal system in place to look for synergies and trade-offs between actions.

CONCLUSIONS

Adaptive Planning bridges the gap between Dynamic Adaptive Policy Pathways and current static planning practices. While Adaptive Planning may not be as robust as Dynamic Adaptive Policy Pathways or Multi-Risk Dynamic Adaptive Policy Pathways it may be easier to implement. The outputs are easy to understand and provide certainty about the next steps of the plan; this should increase community buy-in and make securing funding more likely.

The assembly of the initial plan does not require a change in current practice, and while having adaptive plans is ideal, traditional static plans would also work (and would be easier) for this process. This means that Adaptive Planning can easily be integrated into current planning procedures by identifying vulnerabilities and actions that may need to be undertaken to address them. This process may provide a stepping stone for agencies to embrace uncertainty in their planning.

The process can very easily be expanded to a fully dynamic adaptive process by providing a portfolio of actions for each vulnerability. This needs to be combined with signals to start the decision-making process. In this case, the actions table would include the signal, trigger and a list of possible actions. The list of actions could also be represented as a metro map (like DAPP) for each vulnerability.

ADDITIONAL RESOURCES

Coping with Uncertainties About Climate Change in Infrastructure Planning – An Adaptive Policymaking Approach. (Rahman, Walker, and Marchau 2008)

COMPUTER ASSISTED REASONING APPROACHES

DESCRIPTION

One way to estimate how an action or plan will perform under uncertain future conditions is to use a computer-based simulation to explore all the potential futures. This is called Computer Assisted Reasoning, where thousands of simulations are used to evaluate the performance/utility of plans where the uncertain conditions are varied. There are two primary Computer Assisted Reasoning approaches; Robust Decision Making and Engineered Options Analysis. These analyses are resource intensive but can provide critical insights into how plans work across the uncertainty space, making them ideal for deeply uncertain situations.

ROBUST DECISION MAKING (RDM)

Robust Decision-Making models how the utility of the plan develops across the uncertainty space. This provides a direct measure of robustness, through identifying the proportion of possible futures that meet some pre-identified criteria. The combinations of uncertainties where the plan(s) is unsatisfactory can be identified through Scenario Discovery. Scenario Discovery uses algorithms such as the Patient Rule Induction Method (PRIM) to identify combinations of uncertainties that are common to weaknesses in the current plans, which can help guide what new actions need to address.

ENGINEERED OPTIONS ANALYSIS (EOA)

Engineered Options Analysis analyses the distribution of possible outcomes. This analysis provides insights into the range of potential outcomes, and enables a comparison between these to identify those that are most robust.

IDEAL CONDITIONS AND USERS

This approach is rigorous and can account for any number of uncertain conditions, regardless of level. However, every additional uncertain variable/condition increases the modelling time exponentially. Computer Assisted Reasoning is only feasible when there is a computational model that is efficient enough to run thousands of times, in the time available, in a process known as exploratory modelling.

The Exploratory Modelling and Analysis (EMA) workbench is a Python package designed to aid exploratory modelling and analysis of the resulting data set (including scenario discovery). It has built-in connections for Netlogo, Vensim, Excel, Simio, and Vadere. Other modelling software may be able to be integrated in a bespoke manner. The EMA workbench aids in the creation of the dataset but the EOA investigation is not built in.

Due to the modelling expertise and computing resources needed, this work may require specialists. The large datasets will need to be analysed before being presented to decision-makers for trade-off analysis.

HOW TO USE THIS APPROACH

Figure 10 - Robust Decision-Making Framework adapted from Popper (2019).

1. Create the plans.
   a. Create using Dynamic Adaptive Policy Pathways, Multi-Risk Dynamic Adaptive Policy Pathways, or Adaptive Planning where possible.
2. Simulate the plan across the uncertainties.
   a. As with any computer assisted reasoning approach, computer models need to be constructed. They should be efficient as they need to be run thousands of times.
   b. Each plan needs to be simulated in as many different combinations of uncertainties as possible given time and financial constraints. Latin hypercube sampling should be used to fully sample the uncertainty space (built into the EMA workbench). Modelling should be systematic with every plan being modelled in the same set of combinations of uncertainties.

3a. RDM: Analyse the vulnerability.

a. Robustness can be directly measured based on what proportion of the futures met the minimum required utility.

b. Scenario discovery can be used during this step to identify where plans may still be vulnerable. The Patient Rule Induction Method (PRIM) is a mathematical technique used to identify a set of uncertainties that bound a large proportion of unsatisfactory scenarios (Hall et al. 2012).

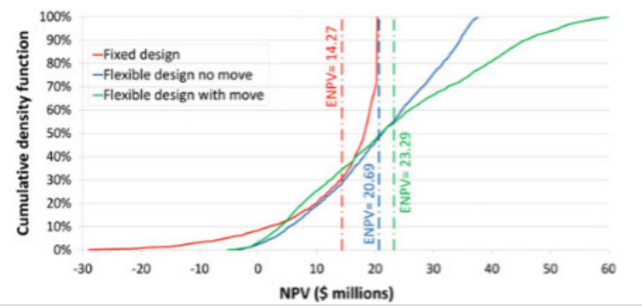

Figure 11 - Utility curves showing the distribution of possible outcomes in a cumulative distribution (Cardin, Ranjbar-Bourani, and de Neufville 2015)

Table 4 - multi-criteria performance metrics of curves in Figure 11 (de Neufville et al. 2019)

Criterion	ENPV value ($ millions)			Improvement (%)	
	Optimum fixed design	Flexible timing	Flexible time + place	Flexible timing	Flexible time + place
Expected NPV	14.27	20.69	**23.29**	45	**63**
Value at Risk, 10%	1.82	**5.40**	3.74	**197**	105
Value at Gain, 90%	20.46	34.54	**45.78**	69	**124**

3b. EOA: Analyse the model distributions

a. Plot utility curves. Order the output data by utility along the x-axis. Data is then spaced equally up from y=0 to y=1. This creates a cumulative distribution (Figure 11).

b. Analyse curves; often done in a table showing the mean, 90th and 10th percentile (Table 4). The curves can be analysed visually by looking at cross-over points, shape, etc.

4. Update plans and re-test the plans.

a. If plans do not meet the robustness requirements, update plans, re-run the model and undertake the vulnerability analysis.

b. If plans do meet minimum requirements, then proceed to step 5.

5. Trade-off analysis.

EXAMPLE (RDM): COASTAL WASTEWATER TREATMENT PLANT ADAPTATION

Multi-Objective Robust Decision Making (MORDM) is currently being used in conjunction with Dynamic Adaptive Policy Pathways and Real Options Analysis to create an adaptation plan for two low-lying coastal wastewater treatment plants (WWTP) in Aotearoa. In this case, RDM will be used to help identify the adaptation thresholds and signals. A computer simulation based on the system model in Figure 12 was used to identify how the WWTP would react under different climate and inflow scenarios.

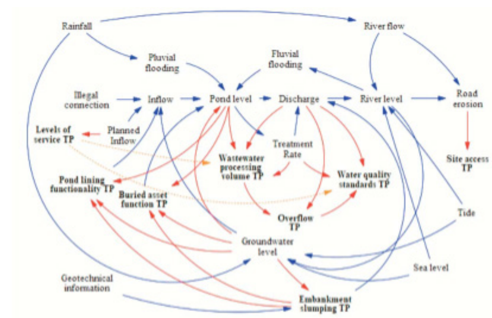

Figure 12 - System Diagram of the Wastewater treatment plant that the RDM model was based on (Allison et al. 2022)

The system model will then be integrated into a cellular automaton model to add hazard and inflow projections, adaptation actions, and performance metrics. MORDM can then be used to assess the proposed plans, removing those that don't meet the performance requirements. Trade-off analysis can then take place, analysing economic viability and other objectives of stakeholders.

EXAMPLE (RDM): ADAPTATION PLANNING IN THE UPPER VIETNAM MEKONG DELTA

The upper Mekong Delta is vulnerable to monsoon flooding, which is expected to worsen with climate change. The monsoon provides essential nutrients for farmers. This case study investigates how inequalities develop given different combinations of climate change scenarios and actions. RDM was used for the adaptation of the flood infrastructure of the Mekong Delta. The flow conditions of the river had large implications on the prosperity of the people living and working in the flood plains.

Initial adaptation options:

- High dykes.
- Low dykes.
- Fertiliser subsidies (make up for the loss of nutrients from reduced flooding).
- Seed upgrades (Crops more resilient to floods).

The initial uncertainties:

- River discharge (Under RCP 4.5 and RCP 8.5).
- Upstream dam construction (5 development scenarios).
- Farming practices (scenarios based on the Mekong Delta plan).
- Drought-induced seasonal productivity gap (a range in productivity drop between 15% and 45%).

By exhaustively combining the adaptation options with Latin hypercube sampling of the uncertainties, 43,200 different scenarios were created. These were simulated through an economic land use model.

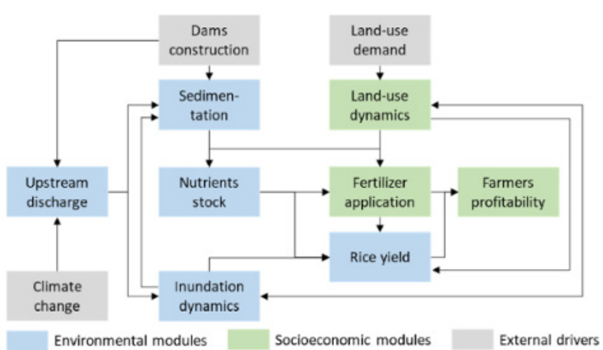

Figure 13 – Economic land use model used for the Mekong Delta RDM study (Jafino et al. 2021)

The outputs of the model simulations were clustered into 18 potential economic scenarios using a clustering algorithm (Figure 14). Clusters that were deemed satisfactory across many different viewpoints were selected. These clusters helped highlight what combination of actions lead to these satisfactory outcomes.

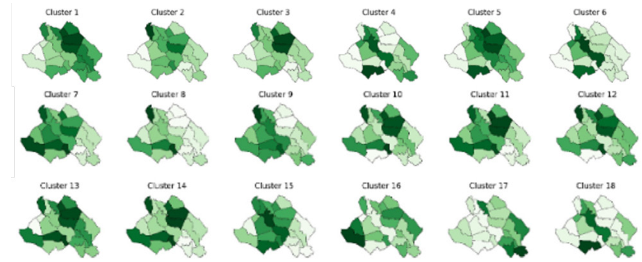

Figure 14 - Clusters of the Mekong Delta economic model outputs ready to be investigated for trade-off analysis. (Jafino et al. 2021)

EXAMPLE (EOA)

A theoretical example of EOA has been undertaken for the replacement of flood-defence and inland water regulation infrastructure in the Netherlands (Smet 2017). Three different pump configurations were analysed using EOA based on a fixed design, a reactive adaptive design and a proactive flexible design with parameters from Table 5. The reactive design has low initial costs, but expansions are more expensive.

Table 5 - Costs of design alternatives (Smet 2017)

DESIGN ALTERNATIVE	CAPITAL COSTS (MILLIONS)	EXPANSION COSTS (MILLIONS)	ANNUAL OPERATION & MAINTENANCE COSTS (MILLIONS)
Fixed Robust design	242.6	n/a	3.6
Reactive Adaptive design	146.2	49.9 for an addition of 50 m3/second	0.006515 *P* (the current pumping capacity)
Proactive Flexible design	172.6	17.5 for an addition of 50 m3/second	*0.006515 P (the current pumping capacity)*

By modelling each of the actions through a combination of two different sea level rise scenarios, four different changes in precipitation patterns, a range of natural variability in daily precipitation, and a range of precipitation canal inflow models. The net present value for each scenario was calculated and plotted in cumulative distributions.

In all cases, the fixed design had the highest costs over its lifecycle. The proactive flexible design dominates in the high SLR scenarios. In the low SLR scenario, the proactive flexible design was cheaper at the 10th and 50th percentile but at the 90th percentile(Figure 15), the reactive Adaptive design becomes cheaper.

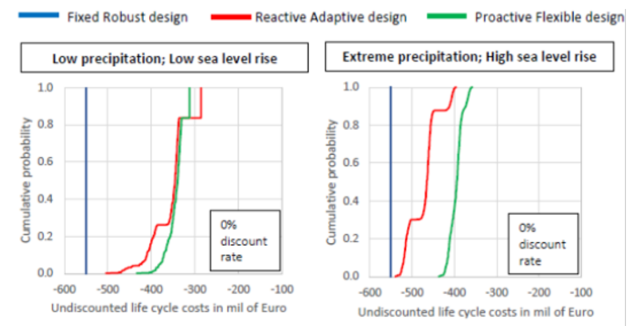

Figure 15 - Cumulative distributions for pump configurations (Smet 2017)

PROS AND CONS OF COMPUTER ASSISTED REASONING

Computer Assisted Reasoning has the following strengths:

- Can identify conditions where vulnerabilities occur, allowing for plans to target the vulnerabilities (RDM).
- If conducting one Computer Aided Reasoning approach, there is very little extra work to undertake the other Computer Aided Reasoning approach. This provides additional insights for decision-makers.
- Various tools exist to aid in the RDM process (Exploratory Modelling and Analysis Workbench, Open MORDM, and Rhodium).
- Provides qualitative results for decision-makers.

Computer Assisted Reasoning has the following weaknesses:

- Reasonable and comprehensive computer models that appropriately reflect the situation and its complexities can be challenging, if not impossible, to develop.
- Models may not exist that are quick enough to fully explore the uncertainty space and can be expensive to produce
- Large datasets need to be distilled down to be useful to decision-makers.
- For EOA, there is no direct comparison of how the plan performs under specific scenarios.

CONCLUSION

Computer Assisted Reasoning provides a direct measure of robustness, which is the aim of DMDU approaches. This measure should only be used to inform decision-makers and a full trade-off analysis between costs and community values needs to be undertaken before a final decision can be made.

Significant resources are required to create and run the thousands of simulations necessary to undertake the analysis. This overhead can be shared using other computer-assisted reasoning approaches to provide additional insights.

RDM can help to identify scenarios (combinations of uncertainties) where plans are vulnerable. This can help with the development of plans to increase robustness. By starting the decision-making process with RDM, initial actions/plans can be designed more efficiently.

ADDITIONAL RESOURCES

EMA Workbench website http://simulation.tbm.tudelft.nl/ema-workbench/contents.html

SCENARIO PLANNING

DESCRIPTION

Scenario planning aims to explore possible futures by using scenarios. Ideally, these scenarios should be sufficiently different to capture the range of uncertainty. Scenarios should be exploratory, not normative or predictive. They should be created by asking "What could happen?". This can be done both internally and/or with the community, iwi, and other experts to get a diverse set of views. Discussions can then take place with the community to to stress test plans in each of the scenarios.

We recommend not using normative or predictive scenarios for the following reasons.

Normative scenarios are used to identify an ideal future scenario and then backcasting is used to identify the actions required to get there. However, this implies too much control over the future than what is likely in these contexts given the substantial number of external drivers. On the other hand, predictive scenarios aim to estimate/predict what will happen. This is unsuitable for highly uncertain conditions. Currently, much of the scenario planning undertaken by local government is predictive, as narratives are created to show what the region may look like under a given plan.

When designing scenarios, they need to be Consistent, Plausible, Distinctive, Relevant, and Challenging (TCFD n.d.).

- Consistent – Scenarios exist to show how uncertainties and systems of interest could interact; each interaction needs to have a strong internal logic.
- Plausible – Scenarios should describe what happened and why it happened.
- Distinctive – Scenarios should not be slight deviations of uncertainties but clear combinations of different uncertainties and timings.
- Relevant – Scenarios need to provide unique insights that relate to the decision being made.
- Challenging – Scenarios should not just be conventional views of the future but explore potential significant changes that alter business-as-usual thinking.

One source of climate scenarios are the IPCC's Shared Socio-economic Pathways (SSPs). These provide organisations with a good starting point for their own scenario-planning process. However, from a monitoring perspective, it is important to identify environmental change (e.g. amount of sea-level rise) in each scenario.

IDEAL CONDITIONS AND USERS

Scenario planning is an analysis approach that creates four-to-six scenarios (anything from storylines to quantitative models) that can be used to assess how plans could work in the future. The scenarios are developed from uncertain conditions and as such this approach works well when there is a low number of deeply uncertain conditions. It may not be feasible to describe the range of possible futures in four-to-six scenarios at higher numbers of deeply uncertain conditions.

The main users of scenario planning are strategic planners and decision-makers. Planners are already using scenario planning to assess plans, but often using predictive or normative methodologies. The creation of exploratory scenarios has been described as an art and a science, and artists and storytellers have previously played a role in the creation of internally consistent scenarios.

HOW TO USE THIS APPROACH

1. Identify the uncertain factors.
   a. Using the XLRM framework as the basis for the decision-making process provides a good starting point for what the scenarios should include.
   b. The factors investigated should be reduced to those that are important to the decision-making process. Having too many factors to account for can result in focusing on uncertainties based on interest rather than importance.
2. Identify interactions in uncertain factors.
   a. Some uncertain factors may be correlated (e.g. sea level rise and temperature change).
   b. Some factors may drive change in other uncertainties (e.g. temperature change affecting primary industries, in turn affecting some communities' fiscal capabilities). Many of these interactions can be identified using the relationships section of the XLRM framework.
3. Produce initial scenarios.

   a. Ask experts and stakeholders "what if questions".

   b. Limit production to 4-6 scenarios (it is impossible to focus on and fully explore large numbers of scenarios). The interactions of uncertain factors often lead to clusters of plausible outcomes.

   c. Test scenarios and iterate if they are not consistent, plausible, distinctive, relevant, or challenging.

4. Write scenarios.

   a. Scenarios should have memorable, neutral titles. This helps in the discussion of how plans work but also avoids biasing scenarios as "good" or "bad" based on what they're called.

   b. There is no set way to write up scenarios. A page of text can be all that is needed to spark conversation when testing plans. Modelling can provide quantitative data and diagrams can provide visual aids for the scenarios.

5. Investigate how plans function under these scenarios.

   a. The output of this process is likely to be a set of qualitative reports on how each plan works under different scenarios.

EXAMPLES: AUCKLAND PLAN 2050

Auckland City Council has created five distinct exploratory scenarios for Auckland Plan 2050:

- Living with nature.
- Safe haven.
- The people's network.
- Whose food bowl?
- Two speed Auckland.

The specifics of these scenarios can be viewed in more detail here: https://www.aucklandcouncil.govt.nz/plans-projects-policies-reports-bylaws/our-plans-strategies/auckland-plan/about-the-auckland-plan/Documents/auckland-plan-future-scenarios.pdf

These scenarios create storylines that show how different climate, economic and social drivers could lead to a very different version of Auckland (and the surrounding regions) in the future. In some scenarios, there have been some assumptions of policy change to fully describe the scenario. This does not undermine their use to investigate how planning decisions may perform in these scenarios unless the plan goes against the assumptions.

PROS AND CONS OF SCENARIO PLANNING

Scenario planning has the following strengths:

- Provides planners with a way to communicate uncertainty to the community and decision-makers.
- Does not require computer simulations, although simulations can be used as an aid.
- No specialist tools required.
- Established process with large amounts of guidance and research available.
- Can be easily adapted to the available resources and requirements.

Scenario Planning has the following weaknesses:

- In situations where there are large numbers of uncertainties, it may be difficult to fully describe the possible futures in just 4-6 scenarios (as recommended).
- Relies on the scenarios being a proxy for the whole uncertainty space.
- If scenarios are not internally consistent users may find it difficult to fully engage, and stakeholder buy-in could be difficult to achieve.

CONCLUSION

Scenario planning has been successfully used under uncertain conditions. Scenario planning can be used regardless of the level of uncertainty and provides a semi-quantitative way to analyse plans under deep uncertainty. It is particularly useful when there are few (1-2) deeply uncertain conditions, although can be used under a higher number of uncertainties through thoughtful development of scenarios. For complex systems, where running thousands of simulations is not feasible, scenario planning, while not perfect, can communicate and investigate plans and decisions with the community and decision-makers.

ADDITIONAL RESOURCES

Scenario Planning for Cities and Regions Managing and Envisioning Uncertain Futures, Robert Goodspeed (2020).

The Use of Scenario Analysis in Disclosure of Climate-related Risks and Opportunities, TCFD, https://www.tcfdhub.org/scenario-analysis/

REAL OPTIONS ANALYSIS (ROA)

DESCRIPTION

Real Options Analysis (ROA) extends the principles of cost-benefit analysis (CBA) to allow for flexibility and learning over time. ROA considers the difference in value that can result from deciding to invest in a project now, delaying the decision, or leaving multiple investment options open for future decision-making based on new information. Originating from financial economics, ROA allows decision-makers the option to make adaptation investments.

ROA can identify when it makes more sense to wait for new information rather than investing immediately, and when factoring flexibility into the design of an adaptation is economically efficient. For example, a flood defence may not be required now, but the option to construct it in future can be retained. Or, a water storage facility could be designed so that it is possible to extend it. Holding a real option delays expensive actions and preserves the flexibility to learn and adapt to change, and is economically defensible.

In the context of climate change, ROA could consider the range of possible climate futures (in New Zealand, this would currently be the four Representation Concentration Pathways [RCPs] and the six General Circulation Models [GCMs]; a total of 24 potential futures). It can then identify the most economically efficient course of action across these contingent events. By placing an explicit value on flexibility and learning over time, ROA makes investments as efficient as possible and adaptable to a range of climate futures, avoiding costly over - or under - investment.

ROA can assist decisions about whether to (for example):

- Invest now.
- Delay investment.
- Invest partially now and retain the option to invest further into the future.
- Abandon a project.

A range of different analytical methods fall under the ROA umbrella, and can also be extended to include several options staged over time in logical sequences (perhaps in conjunction with DAPP, for example). ROA can therefore also be applied in a more general context to investigate the value of new information and cost and flexibility trade-offs in an adaptive plan. Due to sunk costs and future lock-ins, ROA can play a critical role in ensuring investments with a long life-time are as efficient as possible in the context of climate change uncertainty. This explicit incorporation and valuation of uncertainty and new information in the economic appraisal is the added-value that ROA can bring.

IDEAL CONDITIONS AND USERS

ROA is most useful for large, long-lifetime, costly, generally irreversible investments, where there is a risk of over- or under-investment. These are usually infrastructure, such as water storage, coastal defences or wastewater treatment plants. However, as mentioned, it can also have value in conjunction with DAPP to assess several options staged over time.

ROA requires the same type of data as a CBA as well as climate data, but is more technically complicated than CBA.

The main end users and stakeholders for this type of analysis are the investors in the adaptation – it is very much an investment appraisal tool.

HOW TO USE THIS APPROACH

The problem question should be carefully defined. It is important that the options that can be evaluated are suitable for ROA, and that the necessary data is available. Another key consideration is whether the institutional arrangements are capable of managing a decision-sequence over potentially long time periods.

As with CBA, an observable variable explaining the stream of benefits, revenues or cashflow of an investment is required, where changes over time can be described by a stochastic process. For example, in the case of water storage, a variable explaining future water availability under the range of climate futures is necessary, as well as an understanding of the relationship between water availability and quantifiable outcomes, such as milk and/or horticultural yields. Other outcomes can be included if data is available, as with CBA.

The main criticism of ROA is the requirement of an agreed probability of the alternative future states. In the context of climate change and deep uncertainty, this can be problematic. Most studies assume all RCPs are equally likely, or use expert elicitation to agree-on probabilities. The assumption is also that uncertainty will decrease over time as more climate information becomes available. While this is a limitation of ROA, it is still an improvement on approaches that only consider one future.

Several different approaches fall under the ROA name. Possibly the most straightforward ROA application is a binomial decision-tree approach. Further details can be found in (Dittrich et al., 2016, 2019; Lazarow, 2016; Watkiss et al., 2015; Wreford et al., 2020)

EXAMPLES

To date, the practical implementation of a ROA study is limited in New Zealand. A hypothetical analysis was carried out for agricultural water storage, where analysts calculated the size of a reservoir/s required to meet crop and pasture needs to maintain current production under 24 different water availability scenarios for the future.

The size of the reservoir was chosen for the current time period based on the net present value of the reservoir between now and 2040, for the range of scenarios (24 RCP/GCM combinations), including an allowance in the design for an extension in 2040 if necessary. The net present value calculations are based on the costs and benefits of the production with and without water storage.

In a second stage of analysis, the NPV out to 2090 was estimated based on the size of the reservoir chosen in 2040 and the water availability between then and 2090. As a result, the most cost-effective investment of size based on current information can be made now. This will be reviewed in future, and the storage capacity will either be expanded or not, depending on the information and observations available at that time.

PROS AND CONS OF REAL OPTIONS ANALYSIS

Real Options Analysis has the following strengths:

- Allows flexibility to be incorporated into an investment appraisal.
- Allows for a wide range of futures, therefore an improvement on approaches that only consider one possible future.

However, ROA has the following weaknesses:

- Requires an estimation of the likelihood of different futures (e.g. Representative Concentration Pathways). This is not knowable, so the most conservative approach is to assume they are all equally likely.
- Relatively high complexity and resource-intensiveness.

ADDITIONAL RESOURCES

Dittrich, Ruth, Anita Wreford, and Dominic Moran. 2016. ‘A Survey of Decision-Making Approaches for Climate Change Adaptation: Are Robust Methods the Way Forward?’ Ecological Economics: The Journal of the International Society for Ecological Economics 122: 79–89.

Lazarow, N. (2016). Real Options for Coastal Adaptation. https://coastadapt.com.au/sites/default/files/factsheets/T4W5_Real_options.pdf

Wreford, A., Dittrich, R., Zammit, C., Rajanayaka, C., Renwick, A., Collins, D (2020) Robust adaptation decision-making under uncertainty: Real Options Analysis for water storage. Wellington, Deep South National Science Challenge CO1X112. https://deepsouthchallenge.co.nz/wp-content/uploads/2021/02/Robust-adaptation-decision-making-under-uncertainty-ROA-for-Water-Storage-Final-Report.pdf

ADDITIONAL DECISION-MAKING APPROACHES/ CONCEPTS

The previous section summarised the approaches we consider to have the greatest potential for decision-making under uncertainty, particularly in the planning and investment areas. Other approaches exist and may be more suitable in different situations, for example in agricultural contexts or land-use planning. The area of decision-making under uncertainty is continually evolving.

Some other approaches are described briefly here:

PORTFOLIO ANALYSIS (PA)

Portfolio analysis works on the premise that diversification hedges against uncertainty as not all assets fail under the same conditions. This concept was developed in financial economics and is similar to the idea of diversified financial portfolios. PA is most useful when several adaptation options are likely to be complementary in reducing climate risks by performing differently under the same climate change scenario. A low return on one asset will be partly offset by higher returns from other assets during the same period. PA has been used particularly for land-use decisions, such as diversified crop species, or nature conservation.

NO-REGRET, LOW-REGRET AND WIN-WIN ACTIONS

No-regret actions are cost-effective, independent of the climate scenario, and don't lock out future actions or negatively affect other objectives. However, every action has opportunity costs. Low-regret actions are like no-regret actions, but the costs are considered negligible, or the benefits are large relative to the costs under all climate scenarios. Win-Win actions contribute to planning goals but provide social, economic and environmental co-benefits (Martin, n.d.). Generally, the actions are short-term and can be implemented quickly, allowing time for learning, and reducing uncertainty.

ASSUMPTION BASED PLANNING (ABP)

Assumption Based Planning is the basis of Adaptive Planning but does not include any adaptive actions and therefore does not require triggers. Assumption Based planning looks for the "load-bearing assumptions" in plans and then identifies actions that can be used to address these weaknesses using Shaping actions (actions that shore up plans to vulnerabilities) and Hedging actions (preparing for a failure despite trying to "shore it up").

Further useful resources include:

Kalra, Nidhi; Hallegatte, Stephane; Lempert, Robert; Brown, Casey; Fozzard, Adrian; Gill, Stuart; Shah, Ankur. 2014. Agreeing on Robust Decisions : New Processes for Decision Making under Deep Uncertainty. Policy Research Working Paper;No. 6906. © World Bank, Washington, DC. http://hdl.handle.net/10986/18772 License: CC BY 3.0 IGO.

REFERENCES

Allison, Andrew, Scott Stephens, Judy Lawrence, Shailesh Singh, Paula Blackett, Yvonne Matthews, and Jan Kwakkel. 2022. 'Adaptive Tools for Decisions on Water Infrastructure Affected by Compounding Climate Change Impacts'. In Coastal Adaptation: Adapting to Coastal Change and Hazard Risk in Aotearoa New Zealand. 'New Zealand Coastal Society'.

Aven, Terje, Yakov Ben-Haim, Henning Boje Andersen, Tony Cox, Enrique López Droguett, Michael Greenberg, Seth Guikema, et al. 2018. 'Society for Risk Analyss Glossary'. {Scociety for Risk Analysis}. https://www.sra.org/wp-content/uploads/2020/04/SRA-Glossary-FINAL.pdf.

Bendall, Simon, and Mitchell Daysh Ltd. 2018. 'Clifton to Tangoio Coastal Hazards Strategy 2120'. https://www.hbcoast.co.nz/assets/Uploads/Assessment-Panel-Report-FINAL-28.2.18-reduced-size.pdf.

Cardin, Michel-Alexandre, Mehdi Ranjbar-Bourani, and Richard de Neufville. 2015. 'Improving the Lifecycle Performance of Engineering Projects with Flexible Strategies: Example of On-Shore LNG Production Design'. Systems Engineering and Electronics 18 (3): 253–68.

Curran, Patrick H., Anita Wreford, and Tom M. Logan. 2023. 'Which, When and How: Decision Making Under Deep Uncertainty Approaches for Use in Urban Planning'. Manuscript in Preparation.

Dittrich, Ruth, Anita Wreford, and Dominic Moran. 2016. 'A Survey of Decision-Making Approaches for Climate Change Adaptation: Are Robust Methods the Way Forward?' Ecological Economics: The Journal of the International Society for Ecological Economics 122: 79–89.

Haasnoot, Marjolijn, Jan H. Kwakkel, Warren E. Walker, and Judith ter Maat. 2013. 'Dynamic Adaptive Policy Pathways: A Method for Crafting Robust Decisions for a Deeply Uncertain World'. Global Environmental Change: Human and Policy Dimensions 23 (2): 485–98.

Hall, Jim W., Robert J. Lempert, Klaus Keller, Andrew Hackbarth, Christophe Mijere, and David J. Mcinerney. 2012. 'Robust Climate Policies Under Uncertainty: A Comparison of Robust Decision Making and Info-Gap Methods'. Risk Analysis: An Official Publication of the Society for Risk Analysis 32 (10): 1657–72.

Infometrics, and PS Consulting. 2015. 'Flood Protection: Option Flexibility and Its Value'. Greater Wellington Regional Council. https://archive.gw.govt.nz/assets/floodprotection/Hutt-River-FMGM/Optionflexibilityanditsvalue.pdf.

IPCC. 2014. 'Summary for Policymakers'. In Climate Change 2014: Impacts,Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects.

Jafino, Bramka Arga, Jan H. Kwakkel, Frans Klijn, Nguyen Viet Dung, Hedwig van Delden, Marjolijn Haasnoot, and Edwin H. Sutanudjaja. 2021. 'Accounting for Multisectoral Dynamics in Supporting Equitable Adaptation Planning: A Case Study on the Rice Agriculture in the Vietnam Mekong Delta'. Earth's Future 9 (5). https://doi.org/10.1029/2020ef001939.

Kalra, Nidhi; Hallegatte, Stephane; Lempert, Robert; Brown, Casey; Fozzard, Adrian; Gill, Stuart; Shah, Ankur. 2014. Agreeing on Robust Decisions : New Processes for Decision Making under Deep Uncertainty. Policy Research Working Paper;No. 6906. © World Bank, Washington, DC. http://hdl.handle.net/10986/18772 License: CC BY 3.0 IGO.

Lawrence, Judy, Rob Bell, Paula Blackett, Scott Stephens, Daniel Collins, Nicholas Cradock-Henry, and Matthew Hardcastle. 2020. 'Supporting Decision Making through Adaptive Tools in a Changing Climate: Practice Guidance on Signals and Triggers'. The Deep South.

Lawrence, Judy, Marjolijn Haasnoot, Laura McKim, Dayasiri Atapattu, Graeme Campbell, and Adolf Stroombergen. 2019. 'Dynamic Adaptive Policy Pathways (DAPP): From Theory to Practice'. In Decision Making under Deep Uncertainty: From Theory to Practice, edited by Vincent A. W. J. Marchau, Warren E. Walker, Pieter J. T. M. Bloemen, and Steven W. Popper, 187–99. Cham: Springer International Publishing.

Lazarow, N. (2016). Real Options for Coastal Adaptation. https://coastadapt.com.au/sites/default/files/factsheets/T4W5_Real_options.pdf

Lempert, Robert, Steven Popper, and Steven Bankes. 2003. Shaping the Next One Hundred Years: New Methods for Quantitative, Long-Term Policy Analysis.

Marchau, Vincent A. W. J., Warren E. Walker, Pieter J. T. M. Bloemen, and Steven W. Popper. 2019. 'Introduction'. In Decision Making under Deep Uncertainty: From Theory to Practice, edited by Vincent A. W. J. Marchau, Warren E. Walker, Pieter J. T. M. Bloemen, and Steven W. Popper, 1–20. Cham: Springer International Publishing.

Marchau, Vincent A. W. J., Warren E. Walker, and Jan-Willem G. M. van der Pas. 2019. 'Dynamic Adaptive Planning (DAP): The Case of Intelligent Speed Adaptation'. In Decision Making under Deep Uncertainty: From Theory to Practice, edited by Vincent A. W. J. Marchau, Warren E. Walker, Pieter J. T. M. Bloemen, and Steven W. Popper, 165–86. Cham: Springer International Publishing.

Martin, Suzanne. n.d. 'Examples of "No-Regret", "low-Regret" and "Win-Win" Adaptation Actions'. ClimatexChange. https://www.climatexchange.org.uk/media/1611/adaptation_noregret_actions.pdf.

Ministry for the Environment. 2017. Coastal Hazards and Climate Change: Guidance for Local Government. Vol. ME1341.

Neufville, Richard de, Kim Smet, Michel-Alexandre Cardin, and Mehdi Ranjbar-Bourani. 2019. 'Engineering Options Analysis (EOA): Applications'. In Decision Making under Deep Uncertainty: From Theory to Practice, edited by Vincent A. W. J. Marchau, Warren E. Walker, Pieter J. T. M. Bloemen, and Steven W. Popper, 223–52. Cham: Springer International Publishing.

New Zealand Infrastructure Commission. 2022. 'Rautaki Hanganga o Aotearoa New Zealand Infrastructure Strategy'. https://media.umbraco.io/te-waihanga-30-year-strategy/1sfeoqra/rautaki-hanganga-o-aotearoa-new-zealand-infrastructure-strategy.pdf.

Popper, Steven W. 2019. 'Robust Decision Making and Scenario Discovery in the Absence of Formal Models'. Futures & Foresight Science 1 (3–4): e22.

Rahman, S. Adnan, Warren E. Walker, and Vincent Marchau. 2008. 'Coping with Uncertainties About Climate Change in Infrastructure Planning – An Adaptive Policymaking Approach'. ECORYS. https://www.rli.nl/sites/default/files/Achtergrondstudie%20Coping%20with%20Uncertainties.pdf.

Schlumberger, Julius, Marjolijn Haasnoot, Jeroen Aerts, and Marleen de Ruiter. 2022. 'Proposing DAPP-MR as a Disaster Risk Management Pathways Framework for Complex, Dynamic Multi-Risk'. IScience 25 (10): 105219.

Smet, K. S. M. 2017. 'Engineering options'. Edited by Richard de Neufville and Michael McElroy. Harvard University. https://library.wur.nl/WebQuery/wurpubs/fulltext/446335.

Stephens, Scott A., Robert G. Bell, and Judy Lawrence. 2018. 'Developing Signals to Trigger Adaptation to Sea-Level Rise'. Environmental Research Letters: ERL [Web Site] 13 (10). https://doi.org/10.1088/1748-9326/aadf96.

TCFD. n.d. 'The Use of Scenario Analysis in Disclosure of Climate-Related Risks and Opportunities'. Task Force on Climate-Related Financial Disclosures. Accessed 25 April 2023. https://www.tcfdhub.org/scenario-analysis/.

Walker, Warren E., Vincent A. W. J. Marchau, and Jan H. Kwakkel. 2019. 'Dynamic Adaptive Planning (DAP)'. In Decision Making under Deep Uncertainty: From Theory to Practice, edited by Vincent A. W. J. Marchau, Warren E. Walker, Pieter J. T. M. Bloemen, and Steven W. Popper, 53–69. Cham: Springer International Publishing.

Walker, Warren E., Robert J. Lempert, and Jan Kwakkel. 2013. 'Deep Uncertainty: Uncertainty in Model-Based Decision Support'. Encyclopedia of Operations Research and Management Science 1 (1): 395–402.

Watkiss, P. (2011). Aggregate economic measures of climate change damages: explaining the differences and implications. WIREs Climate Change, 2, 356–372.

Wilby, R. ., & Dessai, S. (2010). Robust adaptation to climate change. Weather, 65(7), 176–180. https://doi.org/10.1002/wea.504

Wreford, A., Dittrich, R., Zammit, C., Rajanayaka, C., Renwick, A., Collins, D (2020) Robust adaptation decision-making under uncertainty: Real Options Analysis for water storage. Wellington, Deep South National Science Challenge CO1X112.

Wreford, A., Dittrich, R., & van der Pol, T. D. (2020). The added value of real options analysis for climate change adaptation. Wiley Interdisciplinary Reviews: Climate Change, 11(3), 1–10. https://doi.org/10.1002/wcc.642