VICTORIA UNIVERSITY OF WELLINGTON
TE HERENGA WAKA

National Science Challenges

THE DEEP SOUTH

Te Kōmata o Te Tonga

# Supporting decision making through adaptive tools in a changing climate

## Practice guidance on signals and triggers


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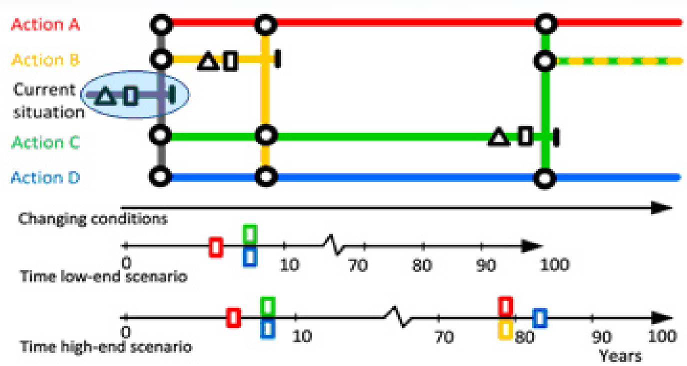


Source: Haasnoot et al., 2013; Hermans et al., 2017.


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Deep South Challenge: Impacts and Implications

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# Executive summary

## The Research problem

The mission of the Deep South Challenge is to “enable New Zealanders to adapt, manage risk and thrive in a changing climate”. To achieve this, new and practical tools are needed to enable decision makers to respond appropriately to climate change impacts that will limit damage and costs to communities. With uncertainty about the timing and severity of climate change impacts, local government and infrastructure providers in particular need new ‘fit for purpose’ decision-making tools that take into account changing risk profiles to enable timely adaptation actions; for example, to plan ahead for climate change and rising sea levels and the consequences on flood frequency, rainfall intensity, as well as a changed vulnerability due to economic and population growth and changes in society’s perspectives and values over time.

## Supporting DAPP decision tools

Dynamic Adaptive Pathways Planning (DAPP) has emerged internationally and in New Zealand as a practical approach to support adaptive decision-making in a changing climate with widening future uncertainties. Implementation of proactive adaptive planning and decision making, however, requires signals and triggers to be designed and monitored to track situational change prior to frequent damaging impacts occurring. These have not yet been developed for practical decision settings for DAPP. Most adaptive management approaches being used currently, globally and in New Zealand (Appendix 1), work from a static plan that is monitored and then adapted or has contingency actions as part of the plan to hedge against potential changes (Walker et al., 2019). DAPP on the other hand makes the whole plan adaptive, and its implementation is based on pre-agreed adjustments as conditions start to change (Haasnoot et al., 2019; MfE, 2017; Lawrence et al., 2019c) enabling proactive and timely decisions to be made.

Climate and socio-economic scenarios are also required to ‘stress test’ the signals and triggers for their sensitivity to different futures, thus enabling adjustments to be made between different future options and pathways. In particular, signals can be used proactively to highlight for decision makers conditions under which current policy actions or levels of service are stressed, offering opportunities to reduce risks and enable sustainable, climate-resilient decision pathways to be attained through timely decision-making.

The DAPP approach has been adopted in the New Zealand national Coastal Hazards and Climate Change Guidance for Local Government (MfE, 2017). The approach has been applied effectively by several local and regional councils in New Zealand, led by the Climate Change Research Institute at Victoria University of Wellington, with NIWA and Landcare Research and supported by the Ministry for the Environment and the MBIE-funded Deep South and Resilience to Nature’s Challenges National Science Challenges. However, none of these applications or the guidance has addressed adequately how situational changes can be monitored and the adaptive plan adjusted in a proactive and timely manner.

This report sets out a process and criteria for developing signals and triggers in coastal and riverine flood settings, and how to formalise signals and triggers through statutory and non-statutory channels so they can be reviewed over time using an appropriate monitoring system that can inform when to implement or adjust the plan in a proactive manner. This adds new generic knowledge to that already in Coastal Hazards and Climate Change Guidance (MfE, 2017). The procedure is presented as Practice Guidance and illustrated with examples of the methodologies that can be used in riverine flood and coastal settings.

## Conclusions

This research, conducted to develop signals and triggers to enable monitoring of the impacts of climate change, has concluded that different signals and triggers for different adaptation options and different implementation channels and time frames can be developed using a process that is not onerous.

We have developed a method from which we can design signals to trigger timely adaptation before unacceptable adaptation thresholds, caused by frequent and larger coastal flood events, occur. The method accounts for uncertainty in timing so it can be used to provide adequate lead-in time to trigger adaptation before damaging adaptation thresholds are reached. However, the nature of that uncertainty, which results from randomness in storm-tide timing and uncertain future sea-level rise rates, means that other political, social, economic, or cultural signals are needed to complement the signals and triggers.

Because of the capriciousness of floods, one large flood occurring in the future is not, by itself, a sign that climate change has materially altered the flood regime, even if it is the largest flood on record. Only by comparing a series of future floods, across many years, with past floods can we conclude that flood characteristics are changing. While the reliability of the signal/trigger we tested is useful, in that it will more likely offer a true prediction than not, it is not a highly reliable basis for decision making and investment. This means that it cannot be the sole DAPP monitoring indicator used. Instead, other signals/triggers need to be used, such as those that reflect social, cultural, economic, and environmental conditions. Alternatively, DAPP indicators can be used alongside other decision-making tools that do not rely upon the monitoring of indicators, such as approaches that test the robustness of decision processes for their performance across a range of futures.

When using DAPP in a riverine flood situation we found that technical barriers can reduce the accuracy of model-based approaches, and institutional barriers can limit the possible uptake of adaptive plans once work is completed. However, careful preparation can build individual and institutional understanding and buy-in about the benefits of DAPP and other decision-making tools that can account for uncertainty and change over time. This can lead to adaptive plans being implemented through appropriate policy frameworks and other measures. Prospective DAPP users should seek to understand the available range and levels of DAPP applications (e.g., model-based analysis versus scorecard-based analysis) and how these align with available information so that informed decisions can be made.

River and coastal hazard managers should have confidence in applying DAPP to their river and coastal system, knowing that useful and meaningful information will emerge on climate-derived changes for decision making.

Undertaking a deliberative process with a community elicits important information about what drives decision choices. Asking the participants what they didn't want to happen enabled a discussion of the objectives (e.g., what they wanted to avoid). This led to an understanding of what the community might tolerate and what might signal their concern. This enables a council to act with confidence early in anticipation of changing conditions that might necessitate a shift of pathway leading to a better understanding of community tolerability of change and how this is influenced by specific community conditions. Council participants recognised that signals and triggers also involve council-driven indicators relating to their statutory responsibilities for levels of service and community wellbeing, and the ability to monitoring the signals and triggers over long time-frames, including for public safety, health and wellbeing, planning, and building standards.

Scenarios enable focused discussions and exploration of options by different groups (e.g., scientists and researchers, policy and decision makers, and community groups or other stakeholders) and development of adaptive pathways. This presents an opportunity to integrate expert knowledge alongside quantitative modelling and to validate model outputs in the 'real world' where there is uncertainty over long time-frames, temporal and spatial dependence, multiple and changing hazards, and socio-economic conditions. Local capability and capacity for adaptation planning will be enhanced by incorporating local characteristics into scenarios. Stakeholders can readily express what the future might look like in ways they may not have done before, revealing new information and possible opportunities without promoting delayed adaptation action. In our work, scenarios were found to be a practical tool to support adaptive pathways planning, and for impacts and vulnerability assessments at a local level. Using participatory and non-technical planning methods and goals could be achieved in relatively short time-frames and on limited budgets by practitioners working closely with local communities. This approach added to the relevance, credibility, and legitimacy of decision-making processes under uncertain and changing climate conditions and their impacts.

There is an appetite for applications in other domains of interest that can help to fine-tune the process for specific local or national-scale applications. Further research is needed to support DAPP and its uptake including appropriate monitoring signals across a range of conditions across the biophysical and socio-economic domains; the institutional channels for creating sustainable monitoring systems that include signals and triggers; the economic evaluation of pathways; and resolving conflicts between different values, and with agency and private values and preferences within and across generations.

## 1. Introduction

Practical new tools are needed to fulfil The Deep South Challenge's Mission to enable New Zealanders "to adapt, manage risk and thrive in a changing climate". Dynamic Adaptive Pathways Planning (DAPP)[4] planning has emerged internationally and in New Zealand as a practical approach to support decision making in a changing climate with widening future uncertainties. Most adaptive management approaches that have been used to date, globally and in New Zealand (Appendix 1), work from a static plan that is monitored and then adapted. Similarly, adaptive policy-making (Walker et al., 2019) has a static plan with contingency actions as part of the plan to hedge against potential changes. DAPP, on the other hand, makes the whole plan adaptive, and its implementation based on adjustments as conditions start to change (Haasnoot et al., 2019; MfE, 2017; Lawrence et al., 2019c), enabling proactive decisions to be made.

DAPP is beginning to meet the demand for a suite of practical adaptive tools that can be used to plan for changes relating to a range of natural hazards including sea-level rise, changing flood frequency and rainfall intensity, and drought. Implementation of an adaptive plan, however, requires decision signals and triggers prior to damaging impacts, and the use of socio-economic scenarios to 'test' the signals and triggers under different future pathways. By using 'fit for purpose' tools, for a problem beset with change and uncertainty, will enable flexible transitions between adaptation options, whatever the rate and magnitude of climate change.

Drawing from our collective multi-disciplinary expertise in climate, hydrology, coastal hazards, climate change adaptation, and policy research, we engaged with local government practitioners in workshops to develop a methodology for designing physical, social, economic, and cultural signals and triggers, as well as for using New Zealand-relevant socio-economic scenarios to test the sensitivity of the derived signals and triggers to different futures. We worked with scientists in the Netherlands at Deltares (where DAPP was first developed), the Dutch Delta Commission staff Signals Group that is developing signals and triggers for the long-range Delta Plan, and the international Society for Decision Making Under Deep Uncertainty.

The methodology used in the research to derive signals, triggers, and thresholds required consultation with technical, political, and community participants, allowing community and council values to be integrated into indicator choice for the DAPP process.

This report outlines a framework for defining indicators to monitor the detection of early signals and triggers (decision points) for activating and implementing further actions in an adaptive plan at Steps 7–8 of the decision process in Figure 1, to prevent the Adaptation Threshold (AT) from being reached. Guidance is also provided on a crucial part of the framework at Steps 9 and 10 in the decision process in Figure 1, about how the monitoring of signals/triggers can be embedded into the responsible organisation's routines, and how these might be regularly reviewed and by whom (see process set out in Figure 5 and section 2). The process requires responsibilities to be developed within organisations for deciding when signals and triggers have reached pre-agreed levels and how the next pathway or action in the adaptive plan should be decided upon.

[4] DAPP was originally adopted by Haasnoot et al 2013 as Dynamic Adaptive Policy Pathways. Dynamic Adaptive Pathways Planning has been adopted in New Zealand (MfE, 2007) as the planning process associated with DAPP.

## 1.1 Context

Adaptive management approaches, which enable actions or policies to proceed in the light of uncertainties, are not new. They have been used for resource management decision-making (e.g., water quality) and policy development both internationally and in New Zealand over the last few decades (see examples in Appendix 1). In response to rising sea levels around our shores, the New Zealand Coastal Policy Statement (NZCPS) and recent coastal guidance (MfE, 2017) advocate the use of an adaptive planning approach to deal with the uncertainty and change around associated risks in the future. Policy 27 of the NZCPS outlines a strategy for managing the rising risk to existing coastal developments from climate-change effects, where a range of options for reducing coastal hazard risk should be assessed over "at least 100 years" and include "identifying and planning for transition mechanisms and time frames for moving to more sustainable approaches" [NZCPS Policy 27(1)(e)].

The 2010 Guidance Manual for local government *"Tools for estimating the effects of climate change on flood flow"* also embodies adaptive planning, by advocating a risk-management framework through the following principles: adopting a precautionary approach; ensuring adaptive management; taking a low-regrets or even no-regrets approach to risk treatment; avoiding locking in options due to adaptation and development decisions that limit further adaptation in the future; targeting progressive risk reduction; and planning an integrated and sustainable approach.

These principles are reflected in the three steps in the guidance that estimate the impacts of climate change on future rainfall, convert changes in rainfall to changes in run-off flows, and convert changes in flows into changes in inundation. However, these estimates are fraught with uncertainties that could be as large as the estimated impacts due to existing variabilities. This makes it difficult to design physical signals and triggers that are meaningful for decision making around flood flows under a changing climate. Such difficulties are examined in the example in section 3.2 of this report, which suggests how DAPP can assist in conceptualising signals and triggers in riverine flood setting.

The latest guidance for coastal hazards and climate change (MfE, 2017) is framed around a generic 10-step decision cycle (Figure 1). This can be used in any domain of interest for setting-up and implementing an adaptation strategy based on dynamic adaptive pathways planning (DAPP) and with community engagement at its core. The key question that underpins DAPP is: *Under what conditions does the action or option in the plan (or for the existing situation) no longer meet objectives?* This introduces the concept of forward planning to anticipate and avoid the AT – the point at which a range of evolving conditions would become unacceptable and objectives or levels of service are no longer met. This requires a planned, timely approach up to and beyond the AT (e.g., Policy 27; NZCPS).

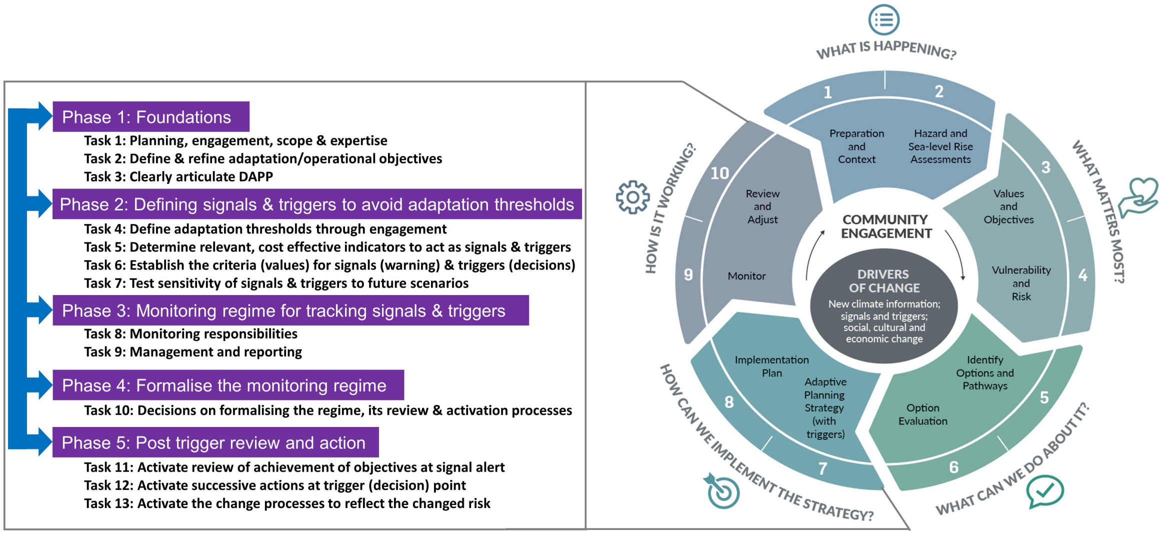


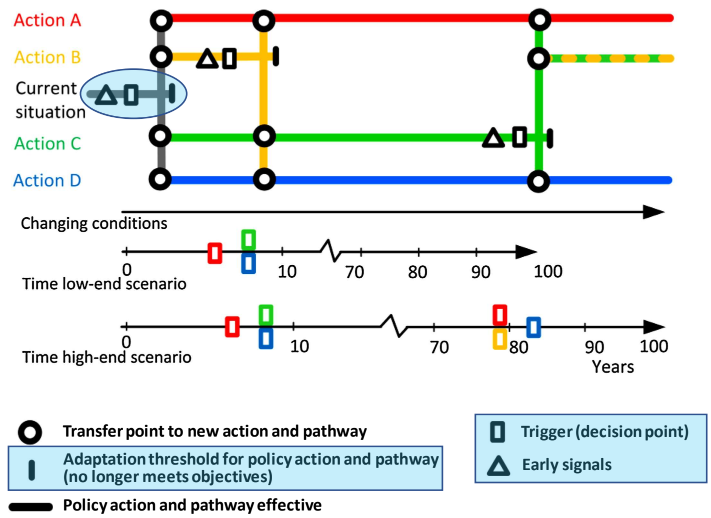

**Figure 1**: 10-step decision cycle and associated key questions used for framing an adaptive approach to climate-change adaptation. Steps 7-10 are the focus of this report, which is broken down into 13 tasks in five phases. Source: MfE (2017).

Adaptive planning approaches, such as DAPP, aim to anticipate uncertain future changes by co-developing combinations of low-regret short-term actions and long-term options in alternative pathways. These enable adaptive actions to be decided and implemented before a pre-agreed threshold is reached (Haasnoot et al., 2013; Lawrence & Haasnoot, 2017; MfE, 2017). This contrasts with the traditional 'response and recovery' approach to climate events, which is unsuited for increasingly more frequent coastal hazard events, for rising risks from ongoing sea-level rise, and for expected increases in intensity of rainfall and river flooding. For such ongoing changing risk situations, monitoring and timely detection of emerging changes, and their proximity to critical ATs, are crucial to ensuring effective and timely adaptation choices are made before the AT is reached (Haasnoot et al., 2018). Such proactive monitoring is distinct from retrospective monitoring and evaluation of the effectiveness of current adaptation plans (Araos et al., 2016).

Local government in New Zealand is already embarking on adaptive coastal planning. Building on past experiences (often contested) in coastal hazard (Bendall, 2018) and flood risk management settings (Lawrence et al., 2019c) local government also has a role in monitoring environmental changes (e.g., state of the environment reporting) and changes which may be relevant to managing significant natural hazard risks [s6(h), RMA].

## 1.2 Dynamic Adaptive Pathways Planning framework

Dynamic Adaptive Pathways Planning enables a range of possible options and alternate pathways to be developed with decisions made on a mix of short-term actions (that avoid entrenching path dependency) and/or long-term options. These can be visualised as a metro-map (Figure 2). Each option and pathway can be tested for its performance in reaching the adaptation objective against a range of scenarios representing uncertainty values for a range of possible futures. This illustrates the time required for switching pathways, before a pre-agreed AT is reached (vertical black bars in Figure 2). The DAPP approach can be applied to any domain of interest that contains elements of uncertainty and where decisions need to be taken today.




*After Haasnoot et al. (2013), Hermans et al. (2017)*

**Figure 2**: Conceptual metro-map of the dynamic adaptive pathways planning (DAPP) approach comprising in this example four alternative actions or options (A–D) to deal with the current situation which is imminently at an AT ("end of the line") as represented by the vertical black bars. Triangles and rectangles symbolise the timing of an earlier signal followed by a trigger (decision point) to implement the next option before the AT is reached. For clarity, only two future scenarios are shown as timelines, but the 2017 MfE Coastal Guidance recommends for coastal settings the use of four sea-level scenarios to stress-test pathways and assess the shelf-life of options.

The process for co-producing a DAPP adaptation strategy for any particular location, encompassing engagement with communities, iwi/hapū, and stakeholders, is set out in Chapters 9 and 10 of the MfE Coastal Guidance (Steps 5–7; Figure 1). The application of the DAPP approach in the Hawke's Bay Coastal Strategy 2120 and the lessons learnt through the first applications in a New Zealand coastal setting are discussed in Lawrence et al. (2019a) and in a New Zealand riverine flood setting in Lawrence et al. (2019c).

### *1.2.1 Signals and triggers*

An essential element of any adaptive management or planning approach is coupling the monitoring of relevant indicators with implementation of the adaptive plan to track and document changes or trends relative to a pre-agreed critical threshold. To do this, indicators (metrics or qualitative values) are used to monitor both a **signal**, providing an early indication of a need to start re-engaging and reviewing the adaptive plan, and a **trigger** or decision point, when implementation of an alternative plan or pathway is required to avoid the impacts of reaching an AT. In some cases, the signal will have been observed. In other cases, there may be difficulty designing a signal ahead of a trigger or the AT with lead time to act, for example, in riverine flood contexts (see example in section 3.2).

When developing a suite of signals and triggers, the starting point is defining and agreeing on an appropriate AT (Figure 2) by exploring objectives, what people value (and wish to remain uncompromised, if that is possible), and including regulatory requirements of the responsible agency (Steps 3–5 in the 10-step decision cycle - Figure 1). Then, for each of the subsequent pre-agreed options (e.g., options A–D for the current situation in Figure 2), the lead time must be established.

Lead time needs to include all the necessary processes to implement each adaptation option, including, for example, community and iwi/hapū engagement to confirm the next adaptive pathway, option design, economic costings, funding model (including rates apportionment), land-use plan changes, consenting/hearing processes, purchase of land (if required), land clearance (if retreat), and, if protection is required, construction (Olufson, 2019). In the case of staged managed retreat as the next option, a lead time of a few decades will likely be required, depending on the scale of the retreat. In contrast, beach nourishment or a groyne may only need a short lead time (depending on any planning and consenting requirements).

The use of several future scenarios to test the sensitivity of options and pathways to different future conditions enables a range of uncertainties to be considered. This reflects that the pre-agreed AT could occur any time over a period of decades, hence the need to monitor signals and triggers to track the changes in risk (e.g., climate, economic, and societal changes) and decreases in chosen option performance, or to identify when objectives (e.g., health and safety, environmental quality, or unacceptable damage) are becoming compromised.

Conceptually, the utility of signals and triggers is shown in Figure 3 in the context of diminishing performance for two possible scenarios (relative to an objective) or reducing level of service (e.g., functionality of lifeline utilities or infrastructure). Both the signal and trigger need to be positioned earlier to account for the necessary **lead time** to implement a particular option before the pre-agreed AT is reached. This lead time reflects the actual time required to plan and implement adaptation actions. For some short-term actions this might be a few years, whilst managed retreat from a coastal or river floodplain could be sequenced over several decades.

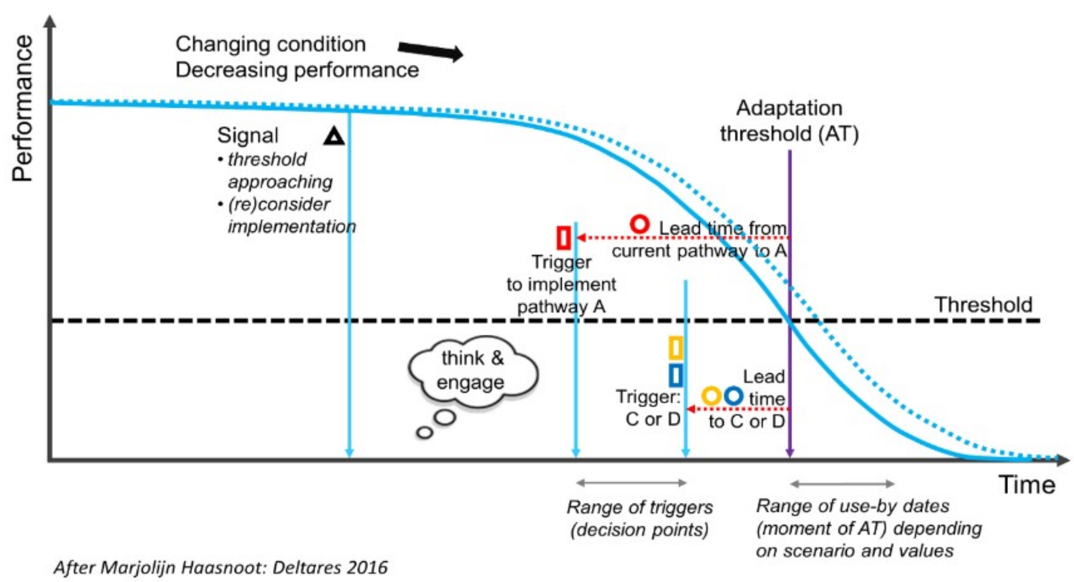



**Figure 3**: Concept of using monitored indicators, set up as defensible signals (Δ) and triggers (▯) to awaken and prompt implementation of the next pathway option or action. In this example, option A requires a longer lead time than options C and D to implement. Note: Only two future scenarios are shown here for clarity, focusing the graphic on the bold blue line as an example. The 2017 MfE Coastal Guidance recommends using four sea-level scenarios to stress-test adaptation plans, including bracketing the time when the AT might occur.

## 1.3 Designing indicators to monitor for signals and triggers

For signals and triggers to be robust measures of change they need to be measurable, or derived semi-qualitatively from stakeholder/community surveys (e.g., insurance coverage), or at least detectable and reliable so they are convincing over and above the background variability (noise) in the system. To achieve this, indicators (expressed as metric or qualitative values) are required for monitoring pathways that can pick up changes or trends above natural climate variability and in sufficient time to support timely adjustments. Ideally, some indicators will straddle a range of drivers of change in the system, to make them salient[5], credible, and legitimate for decision makers and the community. The steps in designing indicators to act as signals and triggers were first proposed in Haasnoot et al. (2018).

It is essential to know whether the adaptive strategy can still achieve the objectives of the adaptive plan and, in particular, whether there are developments or insights that require (Haasnoot et al., 2018):

- implementation or delay of the next action of a pathway;
- a decision about alternative pathways in the adaptive plan;
- contingency actions to stay on track or reduce unintended effects; and
- consideration of potentially better options in the light of new information or changes in social preferences or risk tolerance.

**Signals** warn when the performance of the system is beginning to diminish (Figure 3) expressed as indicators that highlight impending changes in risk; for example, increase in insurance premiums / excesses, difficulty in financing property, and early signs of repeat and increasing “nuisance” impacts (e.g., flood frequencies in Stephens et al., 2018 and see example in section 3.1).

A **trigger** plays the role of activating a chain of decisions to ensure implementation of the adjustments or next option is complete prior to the AT being reached. A single indicator for a trigger will seldom conclusively represent the onset or precursor of conditions where the objective(s) is beginning to fail – especially if a long lead time is required. In addition to the broad types of indicators shown in Figure 4, indicators for a trigger can be closer to the source of the change (upstream from the impact), a performance indicator (associated with the impact), or a socio-economic indicator (associated with coping capacity of people or funding limitations of agencies). This means that having multiple indicators of different types will give greater confidence that any change is on a critical trajectory towards an AT. This also manages the situation where if a single trigger is not activated the AT is not averted, thus providing several lines of evidence for verification purposes. When designing indicators, using criteria such as measurability, timeliness, reliability, convincibility, and institutional connectivity (Haasnoot et al., 2018) will also enable the triggers to be relevant, credible, and legitimate for decision making. Along with careful design of the monitoring programme, consideration of such criteria will support more sustainable and defensible choices about options and pathways at the point of adjustment of the plan options/pathways.

The role of signals and triggers in the DAPP process is shown in Figure 4 for one pathway. Signals and triggers could use the same indicators, but the threshold for the severity/frequency of the effects or changes should be different, otherwise both would occur at the same time within a DAPP process.

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[5] Refers to the extent to which the monitoring system addresses the particular concerns of the user or community; for example, it must be relevant to current policy or specific decisions to be taken and address those elements relevant for the user (Haasnoot et al., 2018).

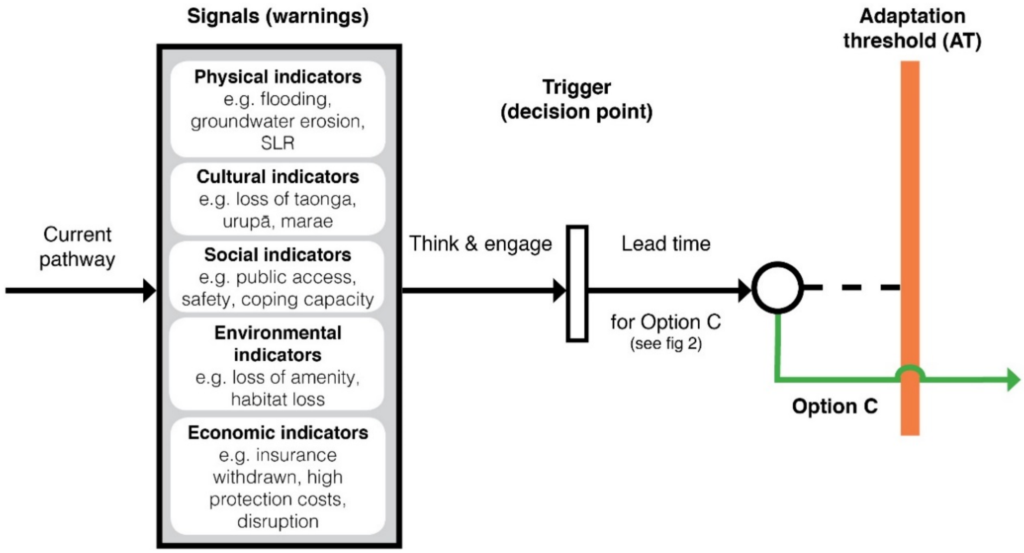


**Figure 4**: Categories of indicators, with some examples, for signals and triggers to monitor changing conditions in a DAPP process (showing an example timeline for one pathway - nominally Option C). Dashed line is current pathway if no action is taken.

## 2. Guidance on the development and implementation of thresholds, signals, and triggers

The process for developing signals and triggers involves twelve interrelated tasks (Figure 5) that sit within Steps 7-10 of the 10-step decision cycle (Figure 1) underpinned by knowledge gained from the preceding steps (steps 1-6 on Figure 1). This process was informed by input and testing in five elicitation workshops with local government technical participants in Wellington, Hawke's Bay, and Tauranga, and one workshop with the Community Panels set up for the Clifton to Tangoio Coastal Hazards Strategy 2120, led by a Joint Committee of the regional council, the two coastal district councils, and mana whenua in Hawke's Bay during 2018. The process developed can be used in most situations where uncertainty and change exists and DAPP is the framework used for development of adaptive plans.

Note that while the process outlined in this report for developing the signals and triggers is based on local input and 'testing', signals and triggers could be similar for different ATs and decisions in different settings across New Zealand and world-wide. Within New Zealand, a national set of signals and triggers could support a national monitoring system to inform, for example, the National Adaptation Plan and the State of the Environment Reporting outcomes.

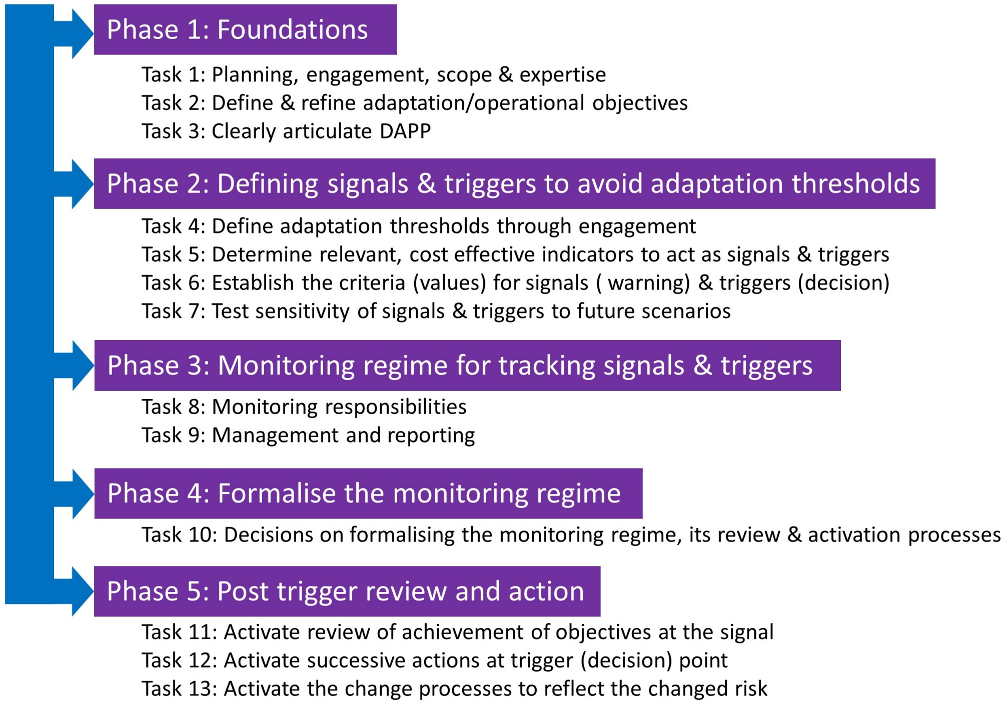


**Figure 5**: Development of signals, triggers, and thresholds for DAPP.

## Phase 1: Foundations

The preparation tasks will have already occurred, to a degree, in the preceding steps of the 10-step decision cycle, but some refinement and reframing may be required for the specific circumstances of the location to support signal and trigger identification.

### *Task 1: Planning, engagement, scope, and expertise*

This task initiates the planning and engagement processes and determines the scope and expertise for the signal/trigger tasks to support DAPP. As for the other steps in the 10-step decision cycle, a range of specialist skills is required to explore signals and develop triggers in partnership with affected sectors, communities, iwi, and hapū. Technical expertise coupled with knowledge of planning instruments and engagement skills are essential.

### *Task 2: Define and refine adaptation/operational objectives*

Agreed community and council values (e.g., regional and district plans and infrastructure, biodiversity, and flood and health standards) and acceptable outcomes (e.g., well-beings, levels of service) will have already been described in step 3 of the 10-step decision cycle (Figure 1); however, these will need to be translated into adaptation/operational objectives. Such objectives are critical in developing signals and triggers to avoid thresholds, by re-aligning community and management priorities within existing policy contexts. Objectives may require changes in scale and focus to be appropriate for the DAPP in question.

### *Task 3: Clearly articulate DAPP*

The DAPP process, options, and pathways have been described and contain all the necessary details to underpin subsequent discussion and decisions including:

- agreement that the DAPP options/actions and suite of pathways can achieve the set of clear objectives identified in Task 2;
- knowledge of the conditions under which each option could fail or be compromised; and
- identification of lead times for each option/action to prepare for and implement the switch in pathways with enough time to avert the AT. For example, implementing a small-scale beach re-nourishment may only require a few years, whereas a managed retreat strategy could take a decade to prepare and plan the necessary steps and to implement.

## Phase 2: Defining signals and triggers to avoid the adaptation threshold

The relationship between ATs, signals, and triggers is illustrated in Figures 2 and 3. The process used with community and council participants to design and 'stress-test' the sensitivity of the signals and triggers to different socio-economic scenarios of the future was undertaken in workshops and is set out in sections 4.1 and 4.2.

### *Task 4: Define the adaptation thresholds through engagement*

An AT is "what people do not want to happen" and needs to be defined with communities, iwi/hapū, and stakeholders to reflect physical, social, cultural, or economic perspectives. Councils or infrastructure operators will also have thresholds on levels of service or other statutory objectives that ordinarily are expected to be met. Useful ATs reflect values about what matters most, which will have been detailed in step 3 in the 10-step decision cycle (Figure 1) and with some modifications in Task 2. Adaptation objectives informed by what people value and why, about living in a specific place, or a sector operating in a particular location, can directly inform what an AT might be (see Chapter 7, MfE, *Coastal hazards and climate change: Guidance for local government* for further details). Useful thresholds could include, but not be limited to (see Appendix 2):

- health and safety (casualties, water quality, safe vehicle, or cycling limits);
- frequency or severity of damaging or disruptive events;
- withdrawal of maintenance and decline in levels of service and utilities (e.g., road access, sewerage system, drainage, and stopbanks);
- unaffordable insurance premiums or withdrawal of insurance and bank finance;
- loss of amenity and cultural values; and
- lengthy displacement of people following extreme events.

Note that the responsible agency for the adaptation plan will need to come to a decision, informed by community input, as to the threshold that is to be avoided.

### *Task 5: Determine relevant, cost-effective indicators to act as signals and triggers*

Once ATs have been agreed, Task 5 seeks to identify a set of relevant and cost-effective indicators to act as signals (warnings) and triggers (decision-points) for monitoring progress relative to the pre-determined objective for the pathways (e.g., a design flood flow, a mean sea level) and to avoid reaching the agreed thresholds. The same indicators might be used for both signals and triggers – only differing in the criteria values. Alternatively, there could be a mix of different indicators used to suit their different purposes – early warning, to think and engage on the changing situation, and the decision point, to trigger the implementation process, allowing sufficient lead time to have a pathway option in place before the AT is reached.

Generic questions for generating suitable signals and triggers to support the DAPP include:

- What type of indicator? Direct, indirect (i.e., proxies of the changes), inferred, or an index that combines information from several variables into a single number or descriptor?
- How can indicators be linked to objectives? Establishing what is unacceptable performance in terms of limits, target, range of variability, statutory rules, or standards for compliance for some services (e.g., continued provision of potable water; water quality in relation to wastewater systems; and when and how often water depth or wave overtopping exceeds safety limits for vehicles, pedestrians, and cyclists)?
- How many indicators? For multiple indicators, what criteria can collectively (either–or, *or* and–and) be used for assessment and review for tracking progress against the objective(s) and making implementation decisions?
- Are there any current indicators that could be utilised or augmented?
- Are there some common indicators that can be monitored more generically across a region or district or city – rather than having a different set of indicators for each coastal area? [Note: There may also be a need for a locally-relevant indicator in the suite of indicators.]
- Are the indicators understandable and relevant to the community and decision makers with respect to the objective?
- Are indicators sustainable and measurable for long-term support of the DAPP process under changing conditions?

*Task 6: Establish the criteria (values) for signals (warning) and triggers (decision)*

What constitutes an actionable signal is explored in examples discussed in 3.1 and 3.2 below for coastal and riverine flood settings.

Questions for determining actionable signals include the following:

- Can significant changes to the indicator be reliably distinguished from the noise (variability such as seasonal and inter-annual climate cycles, or externalities such as land use change, transfer to low-carbon economy, or reset of policies) whilst leaving enough lead time to implement the pathway/option? [Note: The background analyses for the coastal example in section 3.1, shows that tracking mean sea level (MSL) change on its own does not reliably provide a timely signal or trigger criteria, due to the year-to-year variability – rather, monitoring the change in the number of defined moderate coastal floods in a defined period can better resolve when an AT is emerging. However, the example in section 3.2 relating to riverine flood situations suggests that resolving signal to noise ratio will be very difficult and that using an adaptive approach such as DAPP will be more robust that those approaches used currently.]
- How much precaution should be applied in setting indicator levels for signals and triggers to cover the uncertainty of changing conditions?
- How precise or robust should the signals and trigger values be to match the risk and degree of precaution applied?

*Task 7: Test sensitivity of signals and triggers to different scenarios of the future*

Once described, the signals and triggers can be tested against climate and the New Zealand Shared Socio-economic Pathway (NZSSP)[6] scenarios (see section 4.2). Signals and triggers should remain relevant and actionable under a wide range of possible futures. As the future is not certain in all respects (we know the direction of travel, but not the timing), and in some cases the future is unknowable, a plausible range of scenarios should be used to “stress test” the signals and triggers for their performance under a range of future climate and societal conditions. This will enable more robust decisions to be made that are relevant, credible, and legitimate. Signals and triggers also need to be actionable and enable long-term monitoring.

## Phase 3: Monitoring regime for tracking signals and triggers

The critical aspect when designing any monitoring regime is being clear about its purpose, and how the data are to be used, before designing the monitoring framework (Bell et al., 2002) and beginning detailed design (e.g., types of indicators and threshold values, ability to detect change).

The conceptual design of the signals and triggers monitoring regime is not a simple linear process. It is critical that the initial set-up step is an iterative process, informed by council engagement with interested parties within the community, iwi/hapū, and stakeholders (including utilities and infrastructure operators and lifelines agencies). As well as the end uses of the monitoring results being identified up front, the roles of those taking part in the decision or review elicitation process must be clearly defined to promote transparency and equity amongst stakeholders. Engagement over signal and triggers will also produce benefits by identifying who holds existing information that will help to pool data and resources for the subsequent monitoring processes. This could include some indicators monitored by local citizens, for example, king tide photos, or iwi/hapū observations within their rohe.

*Task 8: Monitoring responsibilities*

To enable sustainable, long-term, and continuous monitoring, it is necessary to resource and assign responsibilities for undertaking the monitoring, deciding which agency/individual monitors the signals and triggers and is responsible for activating the next steps, so that decisions can be made with sufficient lead time ahead of the adaptation thresholds. Chapter 11 of the *Coastal Hazards and Climate Change Guidance* (MfE, 2017) sets out the elements for monitoring and reviewing the adaptive plan and its monitoring framework, which is relevant to any monitoring programme using DAPP.

Questions relevant for setting up a monitoring regime to support the DAPP include:

- What new or revised statutory processes and council priorities are needed to support the monitoring of indicators and setting and documenting signals and triggers?
- Will the processes and monitoring/review require training and/or increased awareness at various levels of decision making?
- Have responsibilities for monitoring been assigned so the indicators are sustainable for long-term support of the DAPP process?
- Which agency or group in council should carry out monitoring, recording the results, and reporting them (both across council units and publicly)?

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[6] Shared Socio-economic Pathways, i.e., different types of futures depending on the drivers of greenhouse gas emissions mitigation (or lack thereof) and how adaptation plays out.

- Has a formal “institutional memory” been established so that responsibility can be passed on as personnel change over time?
- Who or what partnership funds the monitoring?

*Task 9: Management and reporting*

The final task is to decide who has the responsibility to analyse, aggregate, or synthesize measurements and information to support indicators, and to provide regular feedback, information, and interpretation to decision makers and the public/stakeholders. Comprehensive oversight of the indicators at different scales can support DAPP at a range of locations and situations.

Questions relevant to accomplishing this task include:

- Who is responsible for managing the AT?[7]
- Who reviews the reporting of how the monitored indicators are tracking relative to the pre-agreed values for signals and triggers?
- Who audits the reporting when signals and triggers are reached?
- What resources are available to monitor indicators (including any longitudinal surveys)?

There are a number of contextual considerations that affect how a monitoring regime is developed.

The ability to implement DAPP signals and triggers, monitor them, and then respond appropriately in a timely manner, will be influenced by the prevailing political settings, governance arrangements, statutory frameworks and their practice, and economic conditions. Such context may constrain or enable effective monitoring of change. For example:

- The three-year election cycle in New Zealand motivates short-term decision-making and frequent turn-over of governing personnel, often constraining long-term monitoring.
- Funding allocations are made annually at central government and through annual plans at local level, albeit on a 10-year basis with three-yearly reviews through 10-year council Long-Term Plans (LTPs), promoting short-term deterministic approaches to management. The longer 30-year local government Infrastructure Plans provide for a longer view on funding future utility services.
- Funding often has a focus on structural investments for ‘protecting’ communities from coastal and river flooding, as opposed to reducing future risk (including residual risk), which will affect response preferences and actions taken at trigger points.
- There is never certainty of funding at any time in the future through an LTP, because of competing projects that may also be affected by future values, social and economic preferences, and prevailing vulnerabilities.

Monitoring systems that can be maintained over time are required within these local contexts, particularly for coastal situations where sea level will continue rising for centuries, making long-term tracking and assessment of changes essential. Well-designed statutory frameworks and consistent decision practices will facilitate ongoing monitoring and pathway choices contingent on signals and triggers.

[7] Also needs to involve Civil Defence Emergency Management (CDEM) Groups and Lifeline Utilities.

Several statutes provide the mandate for implementing a formal monitoring framework for signals and triggers for DAPP decision-making. These are set out in Appendix 3.

## Phase 4: Formalise the monitoring regime

For signals and triggers to be effective and relevant over time as the climate changes, long-term consistency is required. This means that the identified signals and triggers will need to be embedded within a council monitoring system that embodies review, reporting, audits, and decision making, so that decision makers remain informed of changes over time and can act, if necessary, in a timely and transparent manner. Relevant questions at this phase include:

- To what extent should the monitoring of signals and triggers be formalised?
- How can the process be formalised to ensure its longevity?
- Can DAPP facilitate the identification of enablers and entry points for a robust and flexible implementation pathway?
- How can the planning approach, and the decisions made, persist?

### *Task 10: Decisions on formalising the monitoring regime, its review and activation processes*

The ability to implement adaptive plans using DAPP requires decisions on how to formalise (or otherwise express) the policy choices, the monitoring of signals and triggers that support them, and the process to be applied when directional changes are required to adapt to climate and/or society changes. Formal partnership agreements will be necessary between any central government agencies, regional councils, and territorial local government when the monitoring regime is shared (likely), to establish clear lines of accountability.

Questions that can guide choices about implementation channels include:

- What implementation channels are there available for formalising the monitoring regime with signals and triggers?
- Are there any current indicators or monitoring regimes that could be utilised (and extended) and continue to be monitored?
- Is there other guidance available for implementation of adaptive plans?
- Are the available channels complementary to each other?
- Are the available channels enduring?
- Are the available channels well supported by their organisational home?

There is a range of possible channels for managing the monitoring of signals and triggers through non-statutory and statutory frameworks available to councils, singly or in partnership across levels of local government, and in some cases with central government agencies (e.g., New Zealand Transport Agency, Department of Conservation, and Lifelines groups). The following suggestions are based on elicitation with local government practitioners for this project and through the 'national guidance for coastal hazards and climate change' workshops (MfE, 2017) held with local government in 2017 and 2018. Note that the suggestions are relevant for any domain of interest, not just for coastal settings. Since DAPP methods are likely to lead to statutory mechanisms to implement actions or long-term options, channels must be developed in a rigorous manner, considering alternatives and based on sound information and using participatory processes, for example, 1st Schedule Resource Management Act (RMA) and Local Government Act (LGA) engagement processes and principles.

Note that in Chapter 10 of the MfE coastal guidance, Table 25 sets out the types of plans and planning processes and Table 26 sets out the planning methods and techniques available to local government when undertaking adaptive management. These are also relevant and available for climate change risk reduction in other domains.

The following channels are currently available for integrating the monitoring system into existing council processes and systems. Several of these channels will be necessary to provide alignment across levels of plans to ensure complementarity and consistency, which will give confidence to decision makers about the robustness of their decisions.

- Non-statutory plans, such as spatial and strategic planning and growth strategies, natural hazard management strategies, and community-based planning, such as community vision statements and plans, collaborative planning, and iwi management plans [s61, 66, 74, RMA]. While such plans and strategies may have used DAPP processes and have DAPP concepts embedded, a link to the formal monitoring regime in other statutory channels will be needed.
- LGA statutory requirements, such as the regular Long Term Plan (LTP) cycle (10-year view and three-year reviews) and annual plans addressing Levels of Service (LoS), can contain budgetary items arising from the DAPP and implementation of the monitoring of signals and triggers (e.g., share of buy-back for coastal retreat, additional coastal protection, staff resources, and the cost of ongoing planning and review); and infrastructure strategies (30-year view) and asset management plans (three waters, roads, parks and reserves, stopbanks, and other assets).
- Statutory RMA Policies and Plans:
    - Regional Policy Statement, Regional Coastal Plan/Regional Plan and District Plan. Objectives policies, rules, and methods could include DAPP pathways with signals and triggers.
    - A range of tools including defined activity status (including prohibited) with signals, triggers, and thresholds, and special devices like scheduled areas and retreat lines.
    - Deferred zoning/closed residential zoning attached to a trigger (e.g., Tasman District Mapua Plan Change 22. See Box 6 in MfE *Coastal Hazards and Climate Change Guidance for Local Government* (2017)).
    - Requiring consents enables specific evaluation and targeted outcomes conditions; for example, duration tied to trigger conditions - section 106 RMA gives district councils the right to refuse subdivision consent or apply special conditions where land is subject to significant risk from natural hazards regardless of a plan's subdivision provisions.
    - There must be clear and justifiable policy flow from RPS to plan policy and rules.
- Other relevant legislative responsibilities that confer opportunities to embed signals and triggers include CDEM Group Plans, Reserves Management Plans, and various provisions of the Local Government Rating Act (targeted rates tied to funding impact), Soil Conservation and Rivers Control Act, Public Works Act, Local Government Official Information and Meetings Act (LIMs), and the Building Act and the Building Code application (PIMs).
- Other council channels include:

  - cross-council partnership processes with primary responsibilities agreed;
  - Treaty of Waitangi responsibilities as set out in section 4 of the LGA to provide opportunities for participation by Māori in decision making and Parts 2 and 6 to facilitate participation by Māori;
  - leadership, education, information, and communication with the public and stakeholders to keep them informed;
  - covenants, easements on consent notices on titles;
  - bonds (e.g., Mahanga E Tu Hawke's Bay Regional Council and Wairoa District Council [2014] NZEnvC 83, 10 December 2014);
  - the purchase of council land for buffers, refuges, and open-space areas as part of a signal and trigger system;
  - building on existing monitoring programmes and processes;
  - council staff KPIs (e.g., CEOs and CFOs);
  - council risk framework; for example, signals and triggers formalised with the Liability and Risk Audit Committee.
- Citizen science to monitor some signals and triggers as part of a monitoring system.
- Longitudinal community surveys to monitor values, risk perceptions, and sensitivity to signals and triggers and for their review over time.

## Phase 5: Post trigger review and action

Once the signals and triggers are decided and embedded in a monitoring regime and formalised, the next phase is to set up a process to activate any necessary review of the achievement of objectives and successive actions. These actions comprise either enacting the next option in the current pathway, or pursuing different actions or pathways. Steps 11-13 set out what is required. These tasks will continue to require engagement with affected communities and agencies. Good documentation of processes in deriving pathways, triggers, and thresholds (e.g., out-comes, values, objectives, measures, preferences of stakeholders, etc.) will enable smooth pick-up of previous deliberations and analysis over time.

Questions relevant to this phase include:

- How can the adaptive plan objectives be revisited when the operating conditions and enablers (statutes or guidance) change?
- Does the approach hold under 'fire' from communities directly affected by the risk, and when surprises or disasters happen?
- What are the risks (including residual risk) if the signals and triggers fail to anticipate the impending (AT) in time (noting that surprises and new climate records (hot days, fire days, amount of rainfall, or drought) will be the new norm)?
- How can the findings from the monitoring of indicators be communicated in the context of the pre-agreed DAPP ATs?
- What opportunities are there for the community and stakeholders to be kept engaged and involved?  (See section 11.3 - 2017 MfE Coastal Guidance).

### *Task 11: Activate review of achievement of objectives at the signal*

Prior to any action following a trigger, a review will determine whether the objectives (from task 2) are still relevant, whether the existing pathway will still meet those objectives, and whether a change in a previously agreed next option or pathway is required. The review will be informed by the ability of the options to meet the objectives as reviewed and will be influenced by the prevailing political settings, governance arrangements, statutory frameworks and their practice, societal and cultural perceptions, and the social, cultural, and economic conditions. If the existing options are not workable or sustainable after the review process, a decision will need to be made on one of the alternative options and/or pathways.

The purpose of the review is twofold:

- To determine the robustness of signalling the exceedance of the threshold at both the signal and trigger activations. For example, is the exceedance related to climate variability or a clear change signal?
- To determine the effectiveness of the existing action including supporting land-use planning controls in place. For example, are the existing actions working as planned or resulting in more vulnerability?

Questions that can be asked at this stage include:

- How does the combination of other indicators build up as an AT approaches, for example, the changes in climate, social, and economic conditions?
- What are the cumulative demands of adaptation implementation across a region? How is the cumulative cost tracking? Have funding sources and affordability changed?
- Is re-prioritization of actions needed due to cost-effective physical resources being diminished, for example, for rock or stopbank fill?
- Have coping capacity or risk perceptions changed?

Reviews need to be undertaken by a small multi-disciplinary team covering climate-hazard science, engineering/assets, social science, financial, and planning, with a public and iwi/hapū engagement process for feedback and testing of the thresholds versus experience to date, updated climate projections, and the appropriateness of the signals and triggers. The outcome should be audited and reported to the council then the community and relevant stakeholders before a decision to commence the adaptation is made.

### *Task 12: Activate successive actions at trigger (decision) point*

Once a decision has been made, the successive actions are initiated. These actions at the trigger point will include alter, cease, or expand the immediate actions or services in response to monitoring information, where the trigger value has been exceeded. The review will inform which action or pathway is decided and then the appropriateness of the signals and triggers, which will need to be aligned with any new adaptive plan objective and the pathway option chosen. Actions can include planning out the 'implementation plan', which could extend over several years (or a decade or more in the case of managed retreat), and re-appraising the lead time for implementation that was previously estimated.

### *Task 13: Activate the change processes to reflect the changed risk*

The last step is to consider the flow-on effects (if any) for statutory plans, Council budgets, and other consequences of actions, and activate the change processes required to reflect the new level of risk, including how the follow-on signals and triggers might be reflected in the plans. From this point, the process cycles back to refining the adaptive plan objectives (Task 2), or resetting the next AT (Task 4) and related signals and triggers for the next option in the adaptive pathway (Figure 5).

# 3. Examples of signal and trigger design

This section presents two examples of how DAPP signals and triggers in a coastal and a riverine flood setting can be designed. These are followed by some lessons learned from using DAPP in two river case studies that illustrate the application of the generic guidance in this report.

## 3.1 Physical signals and triggers for coastal flooding

Scott Stephens

### 3.1.1 Developing signals and triggers in the context of adaptation to sea-level rise

Sea-level rise (SLR) is causing more frequent flooding along many coasts globally, including in New Zealand. In future, the frequency of coastal flooding is predicted to increase, contributing to saltwater intrusion into groundwater and rivers, geomorphological adjustment of coastline, rising groundwater levels, and vegetation changes (Stephens et al., 2018). Exposed communities will need to adapt to these consequences, but long-term planning is complicated by uncertainties in the height and timing of storm-tides[8] and SLR, which drive flooding (Stephens et al., 2017). This example shows how early signals (warnings) and triggers (decision-points) can be designed to begin adaptive action before coastal flooding reaches an adaptation threshold beyond which undue harm occurs and costs of adaptation increase (MfE, 2017).

Dynamic Adaptive Pathways Planning (DAPP) is emerging as a 'fit-for-purpose' method for climate-change adaptation planning that can address widening future uncertainty and the long planning time-frames required for addressing changing risk profiles arising from changing climate impacts.

DAPP enables:

- identification of adaptation thresholds to avoid;
- design of a series of actions over time (pathways) to achieve objectives (avoid thresholds) under uncertain and changing conditions;
- monitoring of indicators of change, such as flooding and storm events;
- signals to provide early warning of the emergence of the trigger (decision-point); and
- triggers to provide timely adaptive actions (change pathway/behaviour) before a harmful adaptation threshold is reached (Figure 6).

[8] Storm-tide height = total sea-level height at or near high tide due to the combination of astronomical tide and weather-driven ocean surge. Breaking waves can further add to the storm-tide height by driving water inland.

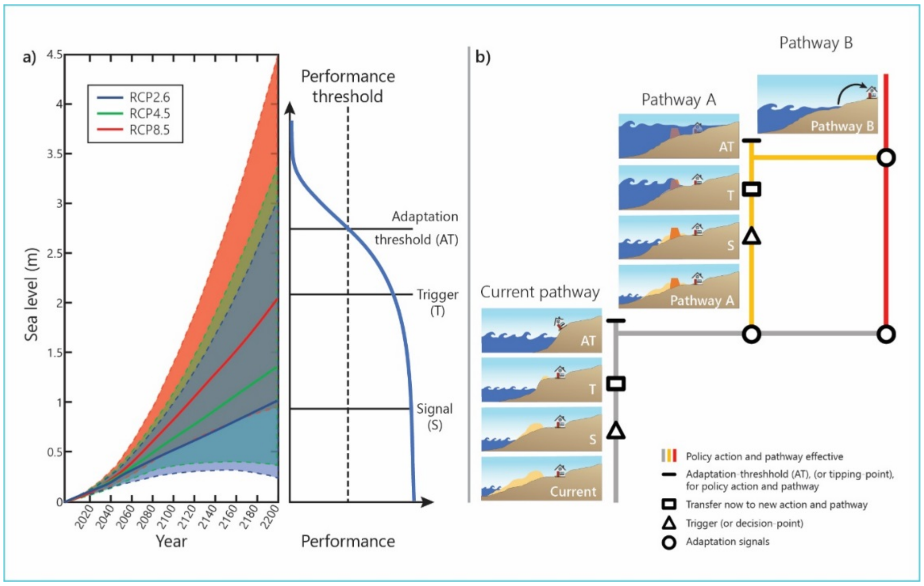


**Figure 6:** Key concepts for adaptive actions to SLR. a) Probabilistic SLR projections for Representative Concentration Pathway (RCP)2.6, RCP4.5, and RCP8.5 scenarios from Kopp et al. (2014) showing median projection (line) and 95% confidence intervals (shaded), along with a schematic illustrating adaptation threshold, trigger (decision-point), and early signal in relation to SLR and pathway performance. b) Illustrated dynamic adaptive policy pathways example where pathway A shows a seawall whereas pathway B shows managed retreat.

### 3.1.2 What we did

Flooding frequency is framed in terms of probable timing of several high sea-level events (i.e., storm-tides) reaching a specific height threshold within a set monitoring period. By clearly defining a monitoring period, actions might be taken before a specific number of threshold exceedance events is reached, thus accounting for variability whilst maintaining a definitive trigger. Decision triggers can be designed to ensure that a change from the current planning trajectory to a new pathway (e.g., from beach re-nourishment to relocating communities) will be triggered before an adaptation threshold occurs. The method is flexible by allowing choice of threshold and number of events over time, enabling an AT to be co-designed with communities to accommodate social, economic, and cultural values and aspirations. In this example, a 10-year monitoring period was chosen because it matches the lifespan of coastal land-use plans and Long Term Plans in New Zealand and it is long enough to observe discernible changes as the sea level continues to rise.

Signals and triggers need to be relevant and credible whilst being simple to measure over time. Although MSL trends can be monitored, extreme events are perceived to be more relevant to social impacts and decision making (Haasnoot et al., 2015). Extreme events are strongly influenced by climate variability effects on storms (Ceres et al., 2017), and this variability makes it difficult to detect climate change trends in extreme values or the emergence of underlying MSL trends (Jordà, 2014). Therefore, rather than use MSL trends, or incremental change as signals and triggers, we used increases in the frequency of smaller storm-tides (quite visible and able to be tied to adaptation thresholds), to signal the future increase in frequency of large storm-tides. Although the ATs, which we aim to avoid, are likely related to extreme sea-levels, the trigger levels and signals relate to an increasing frequency of smaller "nuisance" events that could in themselves be cumulatively impactful. We can monitor less-extreme events to trigger adaptation before the high-impact thresholds are reached. To be relevant to those monitoring change in local government, we modelled the time window (time range) when a threshold storm-tide height is reached five times in 10 years. This approach is consistent with monitoring periods and adaptive planning time-frames used by decision makers where time is critical. The approach provides a way to design signals and triggers relative to the adaptation thresholds, accounting for uncertainty and the spread of timing of signals and the probability of premature warnings.

The method relies on having a nearby sea-level record from which to calculate the likelihood of various sea-level height thresholds being reached, and a system for ongoing monitoring of sea-level events to identify signals and triggers.

The method is now demonstrated in a New Zealand context.

### *Adaptation threshold*

We chose the following adaptation threshold: An increase in the frequency of storm-tide events reaching a height presently associated with a 1% annual exceedance probability (AEP) at present-day MSL to 50% AEP in future. This is a shift from one storm-tide event reaching that height about every 100 years, to five events reaching that height about every 10 years on average. In other words, we chose a sea-level height that is large and damaging and currently very rare (in line with other hazard analyses), and defined our AT before that event becomes unacceptably frequent in the future. This means that the threshold has relevance and credibility with decision makers. In practice, adaptation thresholds would be determined through a community engagement process, to ensure relevancy and community support, to enable effective implementation of the adaptive plan.

### *Signal and trigger*

- The signal and trigger were chosen relative to the adaptation threshold based on the probability that they would occur before the adaptation threshold was reached. The following bullets relate to signals to provide early warning of the emergence of the trigger (decision-point) and triggers for timely adaptive actions before AT is reached.
- The signal and trigger were ascribed respectively to “minor” and “moderate” extreme events today, which will become more frequent with SLR.
- The early signal was chosen as the start of a sliding 10-year monitoring period in which five × 20% AEP (“minor” and quite frequent) storm-tide events (evaluated at present-day MSL) are expected to occur. Like the AT (except smaller), this is a storm-tide height chosen for its present-day likelihood, but which we can monitor for increasing frequency in the future.
- The trigger to change the adaptation pathway was chosen as the start of a sliding 10-year monitoring period in which five × 5% AEP (“moderate” and less frequent) storm-tide events are expected to occur.
- The combined uncertainty accounting for uncertain future SLR rates enables design of the signal and trigger threshold to ensure adequate lead time ahead of the AT. For example, if the more-frequent (20% AEP) “signal” storm-tide height is reached five times in 10 years, later followed by the moderately-frequent (5% AEP) “trigger” storm-tide occurring five times in 10 years, this would signal that the large and infrequent (1% AEP) “adaptation threshold” storm-tide event may soon occur five times in 10 years.
- The mixed distributions for six New Zealand coastal-gauge sites are shown in Figure 7. The New Zealand sites exhibit a gently-rising sea-level distribution toward low AEP - elevation differences between the distributions are driven mainly by differences in tidal range.
    - We used the New Zealand SLR projections from MfE (2017).

- We convolved the SLR probability distribution with the exceedance probability from the mixed distributions of storm-tide (which is assumed to stay constant over time), to produce a unique total sea-level probability distribution through time (Hunter, 2010)[9]. For a more detailed description of the calculation method see Stephens et al. (2018) [10] and supplementary data[11].
- We then calculated the expected timing and its uncertainty of the start of the *T* = 10-year monitoring period when we would expect to see *N* = 5 events occur for each of the 1, 5 and 20% AEP thresholds (respectively the adaptation threshold, trigger, and early signal).

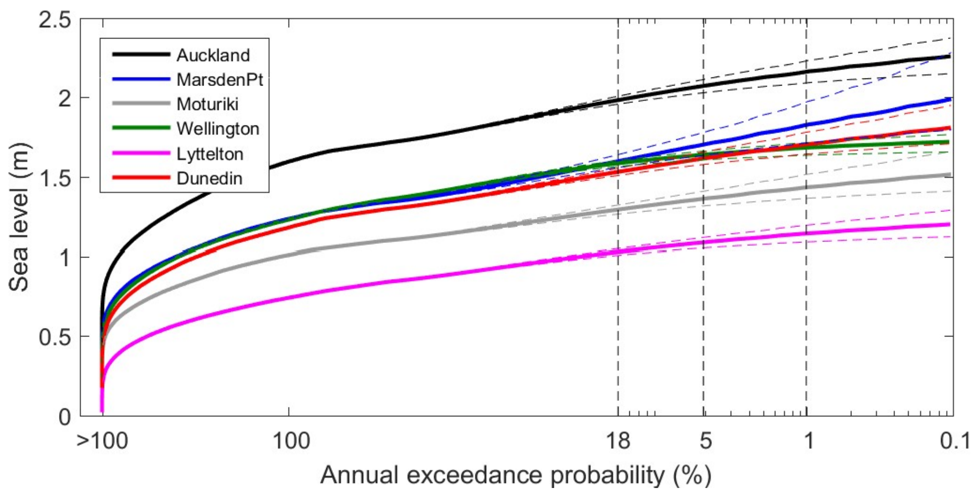


**Figure 7**: Mixed distributions of the measured sea level at six New Zealand sites, after removal of long-term linear trends. All sites exhibit a gently-rising sea-level distribution at low annual exceedance probability (AEP), and elevation differences between the distributions are driven mainly by differences in tidal range (with tides dominating the high-frequency sea levels). The solid lines mark the medians and dashed lines mark the 95% confidence intervals. Sea level is plotted relative to an MSL of zero (no local vertical datum offset).

#### *Calculating lead time*

Successful implementation of DAPP requires that decisions to change pathway are made with enough lead time to implement the new pathway before damaging adaptation thresholds are reached (Figure 6). We used our method to estimate the uncertain timing of adaptation thresholds and their signals and triggers. The method can also be modified to investigate the time between occurrence of a trigger and an adaptation threshold (or between a signal and a trigger), and its uncertainty. This could be used to design triggers with sufficient lead time for effective adaptation. Our approach is consistent with those being developed internationally (Haasnoot et al., 2018).

### 3.1.3 What we learned in the design process

Figure 8 shows the expected timing of the start of the sliding 10-year monitoring period in which the chosen adaptation threshold, early signal, and trigger would be reached, evaluated for three SLR scenarios for six sea-level site records in New Zealand.

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[9] https://link.springer.com/article/10.1007/s10584-009-9671-6
[10] https://iopscience.iop.org/article/10.1088/1748-9326/aadf96
[11] https://iopscience.iop.org/1748-9326/13/10/104004/media/ERL_13_104004_SD.pdf

- The median values show that the signals are generally expected to occur before the triggers, and the triggers before the adaptation thresholds are reached, but there is overlap between the time windows.
- The median expected timing of the start of the 10-year monitoring period for the adaptation threshold, trigger, and early signal, across all sites and all SLR scenarios, are the years 2054, 2043, and 2030 respectively, although there is considerable variation depending on the site within the 'New Zealand and SLR' scenario. One decade between the trigger and the AT may not be enough lead time for a transformational shift in adaptation pathway. Lead time could be increased by choosing a smaller and more frequent storm-tide trigger threshold.
- Adaptation thresholds, signals, and triggers are expected to be reached earlier for faster SLR scenarios and *vice versa*. The time windows are wider for slower SLR scenarios, and *vice versa*.
- The timing of the adaptation threshold is sensitive to the SLR scenarios. The timing of early signals and triggers is less sensitive because they are based on higher-frequency storm-tides, which are predicted to occur earlier, and because the uncertainty bands of the SLR scenarios are close together over the next few decades.
- Signals will be observed from 2021, so there is urgency to develop adaptive plans and associated signals and triggers for monitoring.
- Due to uncertainty in the timing windows, it is difficult to avoid the potential for premature adaptation or adapting too late. Therefore, political, social, economic, or cultural signals are needed to complement the signals and triggers based on coastal-hazard considerations alone.

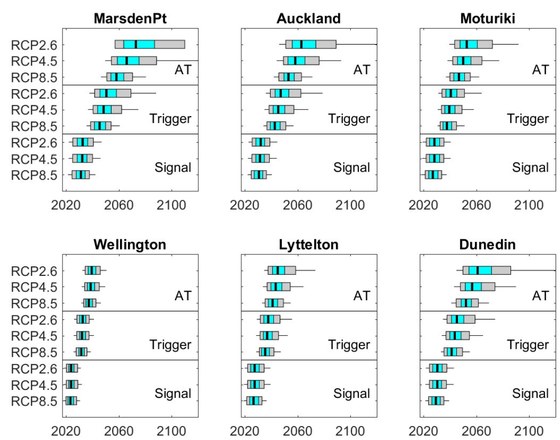


**Figure 8:** Time of the start of the T = 10-year monitoring period in which the adaptation threshold (AT) and its early signal and trigger are expected to be reached for the New Zealand case adopted. At each site, the adaptation threshold is shown in the top frame, with the trigger and early signal in the middle and lower frames respectively. The central vertical bars mark median projection; grey boxes mark 80% confidence intervals = "highly confident": light-blue boxes mark 50% confidence intervals = "medium confidence"; and the horizontal black lines mark 95% confidence intervals. It was not possible to determine the 95% confidence interval range for RCP2.6 scenario at Marsden Point because the upper 95% limit was not reached by the year 2200.

### 3.1.4 Conclusion

We have developed a method from which we can design signals to trigger timely adaptation before unacceptable adaptation thresholds occur that are caused by large and frequent and larger coastal hazard events. The method provides a clear picture of the emergence of signals, triggers, and adaptation thresholds resulting from the slow onset and ongoing sea-level rise. The method accounts for uncertainty in timing so it can be used to provide adequate lead time to trigger adaptation before damaging adaptation thresholds are reached. However, the nature of that uncertainty, which results from randomness in storm-tide timing and uncertain future sea-level rise rates, means that other political, social, economic, or cultural signals are needed to complement the signals and triggers to engender confidence in decision making to switch to the next pathway option.

## 3.2 Physical signals and triggers for riverine flooding

Daniel Collins

### 3.2.1 Developing hydrological signals and triggers in the context of adaptation to increased riverine flooding

New Zealand has a history of devastating riverine floods (Pearson & Henderson, 2004) that are projected to worsen over this century due to climate change (Collins & Zammit, 2016). To reduce the growing risk to communities and infrastructure it is important to understand how and where the risks are changing, and how to implement adaptation measures in a timely manner so as to avoid unacceptable impacts. Given the uncertainty of climate change projections and their impacts on riverine flooding across New Zealand, model projections alone cannot provide all the information necessary to inform decision making. A possible tool that can help decision makers navigate this uncertainty is Dynamic Adaptive Pathways Planning (DAPP).

DAPP involves developing a suite of possible policy options and pathways ahead of time, which decision makers may transition between, to avoid unacceptable climate change impacts or ATs. Given that implementing policies takes time, particularly consultation, and if any consenting, construction, or managed retreat are involved, it is necessary to develop early warning signals of an approaching threshold so that decision makers can change direction in a timely manner.

### 3.2.2 What we did

This study used modelled past and future river flows under climate change to explore the reliability of different early signals and triggers in warning of an approaching AT. In this study, the signals and triggers examined were hydrological in nature, although other physical and non-physical indicators may be used.

*Synthetic data*

The purpose of this study was to explore what could occur in the future and how planning could respond to gradually changing flood statistics. It used modelled river flows, past and future, to represent plausible flood characteristics (Collins & Zammit, 2016).

To assess whether an early signal or trigger is useful in anticipating an approaching AT, we examined the series of largest annual floods for every modelled river reach across New Zealand, and for each combination of GCM and RCP (24 in total).

*Selecting an adaptation threshold*

Adaptation thresholds should be chosen to reflect the needs and values of a vulnerable community, asset, or amenity. Thresholds will vary from river to river and from community to community. They will vary depending on the range of vulnerabilities a location may have to flooding, and they may be either quantitative or qualitative, physical, or societal (e.g., 10 bridge closures over five years, irreparable damage to a cemetery or urupa, and unattainable insurance coverage). As such, ATs need be developed with involvement of the affected parties.

For the purposes of this study a single AT was chosen based on purely hydrological conditions: a 50% increase in the Mean Annual Flood (MAF) compared to baseline conditions as simulated within the historical period 1986-2005. MAF is the long-term average of each year’s largest floods. It is not a large flood itself, as it occurs as often as every two to three years, but it is a measurable and a commonly used indicator of flood propensity. A value of 50% is chosen as this value is the approximate error of MAF from the latest flood frequency assessment for New Zealand (Henderson & Collins, 2016). This implies that deviations within the bound of +/- 50% would be unsurprising.

Good flood hazard management would ideally already account for this margin of error. Deviations of MAF estimates beyond this range in the future would suggest that the design flood level for management purposes would no longer be appropriate, either because of a changing climate making the design flood more frequent or because of a significant misunderstanding of historical flooding propensity, thus indicating that adaptation may be warranted. An increase in MAF of 50% serves as a potential AT for planning purposes and is used to explore the utility of early signals and triggers in this study.

### *Selecting early signals and triggers*

Having selected an AT, early signals and triggers must then be defined to be able to give sufficient warning of an approaching threshold. This is to enable timely adaptation while also not providing false alarms. The early signal may also need to provide sufficient lead time ahead of the trigger to facilitate discussion and planning ahead of implementing a new action. For this study, however, early signals and triggers were combined as they serve a similar purpose of warning of a future AT and the differences between a signal and trigger relate more to the specific social adaptation processes than the physical hydrological processes.

In selecting a signal and trigger, the same hydrological indicator was used as for the AT – change in MAF – but at lower magnitudes of change: 10, 20, 30, and 40% increases. These were measured over 20-year periods, offering a compromise between needing enough observations to make a statistical judgement and not having so many that a climate change trend influences the statistic. This reduces the noise that would otherwise obscure a climate change signal.

In addition to quantifying the change in MAF, it is also valuable to consider our confidence that MAF has indeed changed in a statistical sense. Due to natural variability, differences between two observed or simulated numbers may not be statistically significant and, therefore, of lesser importance for policy. We account for this by setting different statistical bars, quantifying whether numerical differences between past and future flood occurrences are “extremely likely different”, “very likely different”, “likely different”, and “more likely different than not”. In statistical terms, these correspond to significance levels ($\alpha$) of 5%, 10%, 34%, and 50%.

### *Lead time*

Within DAPP, the purpose of early signals and triggers is to provide enough lead time to implement a particular policy shift. For riverine flooding this may entail dredging the river, building a higher stop-bank, building flood-retention basins, or relocating vulnerable communities and amenities (‘retreating from the river’ or ‘room for the river’) among others. Each of these options will take different lengths of time to implement and therefore require different lead times.

In this study, we assessed signal/trigger reliability as it varies with lead time. Calculations of reliability are made across 20-year windows, shifted by five-year increments. A five-year increment is used in this study for illustrative purposes, but could also be as small as one year. It is possible that the selected signal/trigger is reached during the same year as the AT, providing no lead time for planning and implementation. The longest possible lead time examined here is 60 years, which is beyond where lead time matters.

### *Classifying signal success*

A successful early signal or trigger is one that warns of an approaching AT in the future with sufficient time to adapt (tailored to the action), but also, crucially, does not provide false alarms. The warning (or its absence) may not accurately predict an AT (or absence of one) all the time, but it is useful as long as it is likely to do so.

In this study, 24 simulations were undertaken for 43,862 river locations across New Zealand and were examined to identify the earliest emergence of a signal and AT, if they occur at all. These are then categorised into one of the following (Figure 9):

1. True negatives - instances where no signal/trigger was detected and no AT could have arisen;
2. True positives with non-zero lead time - instances where a signal/trigger and AT were both detected and there was a period of at least five years between the two;
3. True positives with zero lead time - instances where a signal/trigger and AT were both detected but were detected at the same time; and
4. False positives - Instances where a signal was detected but not an AT.

Due to the definition of the signal/trigger used here, false negatives, where the adaptation threshold is detected but not the signal/trigger, are not possible.

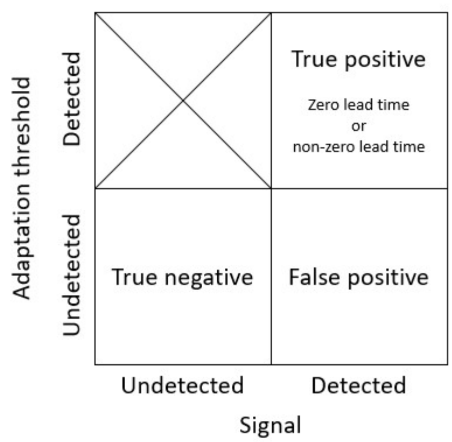


**Figure 9:** Classification of simulations based on whether the signal/trigger is detected and when. True positives with non-zero lead times and true negatives are informative.

Signal/trigger reliability, whether for New Zealand as a whole or for a single region, is subsequently defined as the total number of occurrences of categories 1 and 2 as a fraction of all the rivers and simulations within the area considered. A value of 50% means that the signal/trigger is correct as many times as it is incorrect and is thus not of any use. A value less than 50% is more misleading than informative.

### 3.2.3 What we learned in the design process

Using an AT of +50% MAF and signals of change in MAF of +10, 20, 30, and 40% between past and future time periods, we found that:

1. The most reliable signal of those considered here was a change in MAF of +40% under a highly certain statistical test. Forty percent is the highest change in MAF tested.
2. Signal reliability varied among regions from a high in Northland to a low in Otago (Figure 10). This relates to natural variability across New Zealand and the regional climate change trends.
3. Reliability of the signal depended mostly on correctly avoiding false alarms (i.e., the light-blue true negatives in Figure 10 are always the largest component). [Note: This is a reason for having multiple and different types of triggers. See section 1.3]

4. In most cases, the AT was crossed at the same time as a signal was detected, offering no lead time for adaptation planning (i.e., the yellow true positives with zero lead time in Figure 10 are always larger than the dark-blue true positives with non-zero lead time).

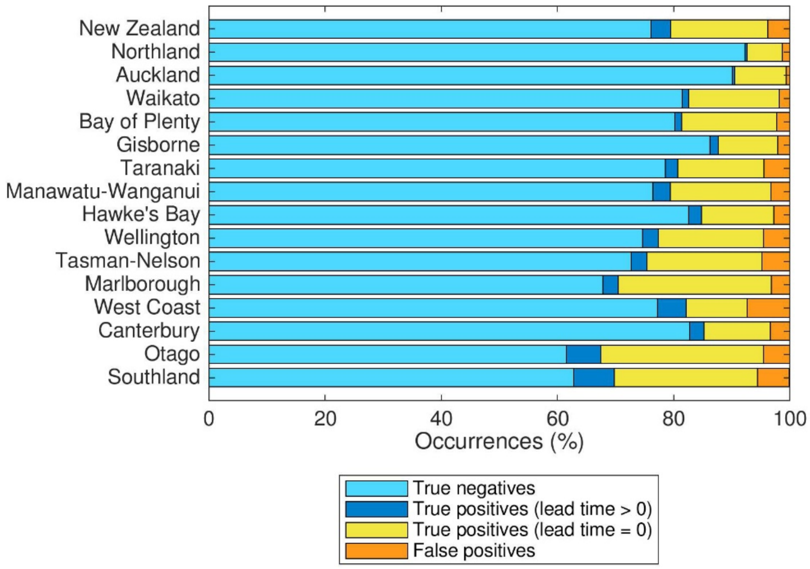


**Figure 10**: Regional and national occurrences of true negatives, true positives (for lead times equal to and greater than 0 years), and false positives for the signal +40% MAF and 0.05 $\alpha$ and the AT +50% MAF. The true negatives and the true positives (lead time > 0) reflect successful application of the signal.

5. In most regions, when a signal was detected, false alarms (orange in Figure 10) were more common than valid alarms (dark blue in Figure 10).

6. The relatively high rate of true negatives reflects the rarity of important floods. This makes early detection of ATs statistically difficult.

7. Signal reliability declined with longer lead times (Figure 11).

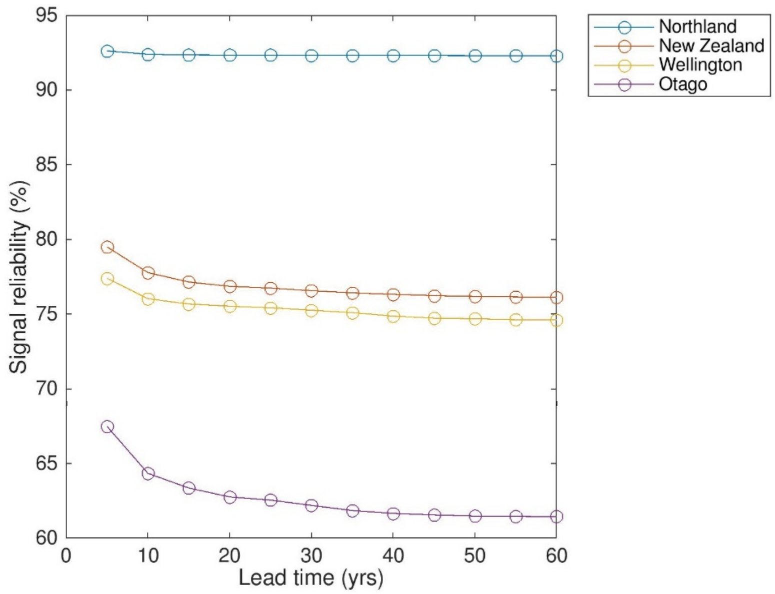


**Figure 11**: Decline of signal/trigger reliability with longer lead times for different areas.

8. While the signal/trigger offered better odds at anticipating an AT than randomly flipping a coin, reliability is generally not very high. Using this signal/trigger alone to anticipate the AT considered here is unlikely to assist in adaptation planning.
9. Alternatively, the +50% MAF could be used as the "early signal", thereafter, the number of damaging or large flood events could be separately monitored, while the trigger could be two to three more damaging events in a 10 or 20 year period (akin to, or slightly higher than, an insurance threshold). In these cases, it would be clearer from modelling which emissions pathway is progressing, so the **trigger** could be a pre-agreed threshold of one or several indicators, rather than a prescriptive statistical technique that is more appropriate for an **early signal** using changes in a lower-magnitude event like MAF.

It is important to note that this example is for illustrative purposes, showing the particular difficulties in a riverine flood situation compared with a coastal situation in finding physical climate impact triggers that are reliable. The reason for this is exemplified by Figure 10 showing, for example, Northland fitting a pattern of increasing true negatives as one goes north and north-east. However, these are model simulations with many uncertainties not accounted for. In addition, the variations across regions shown in Figure 10 arise because climate variability varies regionally, while climate change varies regionally. This means that whether a climate change signal emerges or not from the noise of climate variability will vary regionally as well.

### 3.2.4 Conclusion

Because of the capriciousness of floods, one large flood occurring in the future is not, by itself, a sign that climate change has materially altered the flood regime, even if it is the largest flood on record. Only by comparing a series of future floods, across many years, with past floods can we conclude that flood characteristics are changing. Using an average over 20 years is one such way to aggregate any climate change effect. While the reliability of the signal/trigger tested here is useful, in that it will more likely offer a true prediction than not, it is not a highly reliable basis for decision making and investment. This means that such an average should not be the sole DAPP monitoring indicator used. Therefore, when using DAPP for adaptation to changing flood risk, other signals/triggers need to be used, such as those that reflect social, cultural, economic, and environmental conditions. Alternatively, DAPP indicators can be used alongside other decision-making tools that do not rely upon the monitoring of indicators, for example, Robust Decision Making (RDM) (Lempert, 2019) to increase the robustness of decision processes in the sense that the action decided can perform across a range of futures.

## 3.3 Lessons learned for enhancing the uptake of DAPP

Matthew Hardcastle and Judy Lawrence

### 3.3.1 Two Rivers – The lower Whanganui and Hutt Rivers

Dynamic Adaptive Pathways Planning (DAPP) is becoming increasingly popular as a basis for local governments to make informed decisions regarding hazards affected by climate change, such as sea-level rise. However, there are relatively few applications of DAPP to New Zealand river management problems (Hardcastle, 2019) due to large uncertainties (both the magnitude and direction of future changes in floods) and technical barriers concerning the physical impacts of climate change on flood magnitudes and frequencies. Compared to coastal flooding (see example in 3.1), where the direction of ongoing rising sea level is clear, the future situation of changes for riverine floods (increases or decreases) is unclear. There are also lesser known process and institutional barriers (e.g., entrenched management practices) that can make it difficult for DAPP investigations to achieve necessary traction. Yet, developing adaptive river management plans is critical to ensuring that communities can thrive in an uncertain future without leaving large numbers of people, properties, and infrastructures at risk (Haasnoot et al., 2013; MfE, 2017). This example analyses findings from two DAPP case studies (the lower Whanganui River (Hardcastle, 2019) and the Hutt River (Lawrence et al., 2017; 2019c) to identify common barriers for local governments and river managers within three stages of DAPP uptake:

- overcoming initial inertia to DAPP as a tool to manage river flooding in the presence of significant uncertainties;
- using models to investigate the suitability of flood interventions and form the basis of developing adaptive plans; and
- incorporating adaptive plans within policy frameworks and measures.

*Case Study 1 – The lower Whanganui River*

Since a significant river flood in June 2015 (the second largest in New Zealand's recorded history – 5150m$^3$/s at the Whanganui City Bridge), Horizons Regional Council (HRC) has been considering future management options for the lower Whanganui River (LWR). Options include the construction of a new stopbank designed for the 1:200-year design flood flow, contributing $50,000 per year to a dedicated fund for managed retreat, and raising floor levels in vulnerable areas. A one year research project investigating possible effects of climate change on flooding in the LWR was carried out, with a specific focus on how national and local-scale models can be used as part of a DAPP process (Hardcastle, 2019). The project also included the development of a site-specific serious game that allows decision makers to explore possible long-term consequences of near-term decisions. Project findings were then presented to regional councillors, river management staff, and the general public at a live-streamed council meeting.

*Case Study 2 – The Hutt River*

The Hutt River case study investigated how DAPP, primed by serious simulation games (Lawrence & Haasnoot, 2017) (Appendix 4), could be used in a real-life flood-risk management decision setting and as a tool to gain traction with local and regional governments (e.g., Greater Wellington Regional Council (GWRC)). Driven by awareness within GWRC river management staff that new knowledge and capability were needed to address ongoing climate risks, the four-year project sought to raise awareness of dynamic adaptive planning concepts with technical staff, consultants, infrastructure agencies, and elected politicians using the New Zealand River Game[12]. DAPP was then used to develop options and pathways as a basis for community consultation and to enable decisions to be made under conditions of uncertainty (Lawrence et al., 2019b). Project findings (see Appendix 4) were successfully implemented in the local situation and have since been used to inform national and local policy, including the revised national Coastal Hazards and Climate Change Guidance for Local Government (MfE, 2017).

### 3.3.2 Case study barriers at three stages of DAPP uptake

#### *Overcoming initial inertia to DAPP as a tool to manage riverine flooding in the presence of significant uncertainties*

This first stage of DAPP uptake requires relationships and understanding to be built between stakeholders to achieve collective investment in the DAPP approach and its results. For the case studies, this stage was most successful when conducted over an extended period giving stakeholders time to properly consider new dynamic adaptation ideas, develop buy-in, and establish clear governance structures within and between institutions. Critically, the primary flood management agency (i.e., regional council) needed to be a clear advocate and driver of DAPP, rather than a passive participant, to give credibility and resources to facilitate the process and generate results. Failing to establish buy-in and clear governance was found to reinforce institutional barriers (e.g., entrenched views on how flood management should be approached). Such barriers affected subsequent stages of DAPP uptake in terms of reduced financial and emotional investment. In extreme cases, these barriers could result in alienation of key stakeholders and lead to continued use of conventional approaches, thus preventing dynamic adaptive plans being implemented in policy frameworks and measures. The use of games in both cases helped facilitate the breakdown of barriers to DAPP uptake, by creating a non-threatening environment within which parties could interact as teams and build familiarity and capability alongside independent knowledge brokers to introduce new tools and help facilitate their use. Therefore, establishing stakeholder investment through longer-term, consistent engagement across all actors within and outside the council, and experimenting with using DAPP, is key for the effective application of DAPP.

#### *Using models to investigate the suitability of flood interventions and form the basis of developing adaptive plans*

The second stage of the DAPP uptake process is gathering technical information to inform the development of adaptive plans. Here we discuss the technical barriers arising. The flexibility of DAPP means that technical information can either be used as inputs to quantitative models (i.e., model-based analysis through hydrological, impact, and intervention modelling – as seen in the LWR case study) or as a basis for qualitative discussion around the suitability of different interventions (i.e., scorecard analysis and as input to a multi-criteria analysis – as used in the Hutt River case study Figure 12).

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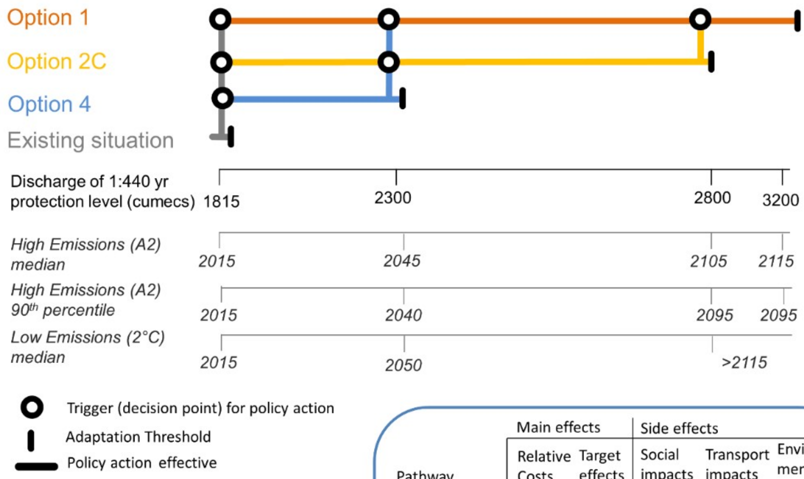
[12] Refers to a version of the Deltares Sustainable Delta Game tailored to the physical characteristics of New Zealand rivers: https://www.deltares.nl/en/software/sustainable-delta-game/




| | Main effects | | Side effects | | |
|---|---|---|---|---|---|
| Pathway | Relative Costs | Target effects | Social impacts | Transport impacts | Environ-mental impacts |
| 1 | $$$$ | ++ | ---- | +++ | ++++ |
| 2 | $$ | + | --- | ++++ | +++ |
| 3 | $$$$ | ++ | ---- | ++++ | ++++ |
| 4 | $ | - | 0 | ++ | + |
| 5 | $$$ | + | -- | ++++ | +++ |
| 6 | $$$$ | ++ | --- | +++ | ++++ |
| 7 | $$$$$ | ++ | ---- | ++++ | ++++ |

**Figure 12**: Hutt River City Centre Upgrade project showing options, pathways, scenarios, and decision points; the scorecard (bottom right) shows relative costs and direct effects of pathways and potential side effects. Note: All pathways (except pathway 4) have negative social impacts due to property purchase.

It was found that adopting a model-based approach for creating dynamic adaptive plans often presented technical barriers related to a perception of inaccurate models and missing or incomplete data. The impact of these barriers was very different between case studies. Similar issues were observed when trying to establish monitoring plans and designing triggers for a change in pathway where, unlike for sea-level rise for coastal flooding, there is no clear physical proxy for changing flood risk profiles (see example in section 3.2). In situations where significant technical barriers arose, these were often compounded by additional institutional barriers relating to data management and access protocols since different models and datasets were being maintained by different agencies and teams within the council. Such barriers highlight the need to establish a detailed framework for managing the availability of data and models at the beginning of a DAPP process so that appropriate arrangements can be made as necessary. Alternatively, if these barriers cannot be overcome, a scorecard DAPP analysis (Figure 12 bottom right) will still provide useful management information by examining possible options within a dynamic adaptive context. Such information can then be used by decision makers as a basis for making better-informed flood-management decisions.

### *Incorporating adaptive plans within policy frameworks and measures*

The final stage of DAPP uptake requires decisions about how dynamic adaptive plans will be used by management authorities as a long-term basis for decision making. Based on the case studies examined, the barriers experienced at this stage were often linked to those seen in stage one, in particular relating to establishing long-term stakeholder buy-in. If this buy-in was not clearly established, river managers were more likely to be sceptical of final project findings and therefore less likely to try and implement new plans that were different from entrenched practices. Even if stakeholder buy-in was clearly established, other barriers relating to ongoing monitoring costs and the need for long-term strategic policy by the council still had to be overcome. Therefore, it is important to take time at the beginning of a DAPP process to ensure that internal and external stakeholders are fully aware of long-term objectives, and that likely monitoring costs and responsibility for reporting triggers are established so that the appropriate preparations can be made and funding mechanisms developed.

### 3.3.3 Strategies to overcome barriers to DAPP uptake

Whilst there are a variety of institutional and technical barriers that can impede each of the three stages of DAPP uptake, most can be avoided through careful preparation and maintaining flexibility throughout the process (see Table 1). Specifically, DAPP uptake should not be rushed and instead be carried out over a time frame that ensures stakeholders have enough time to engage in the process and understand dynamic adaptive concepts. This will alleviate many of the observed institutional barriers discussed here. DAPP users should also be willing to tailor their processes based on what information and expertise is available, especially when considering complex model-based DAPP analyses. By thoroughly investigating all options and exploring possibilities to link disparate data sets, meaningful DAPP insights should be possible for any case study to inform flood-based decision-making.

**Table 1**. Overview of DAPP implementation barriers and possible strategies to overcome them

| Stage of DAPP Implementation | Institutional Barriers Identified from Case Studies | Technical Barriers Identified from Case Studies | Strategies to Overcome Barriers |
|---|---|---|---|
| Overcoming initial inertia to DAPP as a viable means to manage riverine flooding in the presence of significant uncertainties | • Short project time-frames can make it difficult for stakeholders to become invested in DAPP process and its outcomes<br>• Entrenched views within institutions on how flood management should be approached<br>• Day-to-day Council functions may be prioritised over long-term strategic thinking and limited investment in the long-term<br>• Difficult to get mutual commitment from stakeholders<br>• Assumption that local government action on climate change will reduce central government incentive to assist with adaptation | • Lack of knowledge about DAPP and its application to local case studies<br>• Lack of capability to shift from current practice to adopting new tools | • **Preparation** – make clear problems with using traditional, static flood-risk management practices under changing climate versus the benefits of DAPP<br>• **Preparation** – appoint long-term strategy champions within organisations outside day-to-day management functions<br>• **Preparation** – establish clear governance strategies at the beginning of the DAPP process<br>• **Preparation** – create space for clear ownership of the DAPP process to develop amongst stakeholders and managers<br>• **Preparation** – ensure roles and responsibilities are shared equitably amongst all stakeholders to facilitate long-term buy-in<br>• **Preparation** – appoint "knowledge brokers" to facilitate a common understanding of process and its components |
| Using models to investigate the effectiveness of flood interventions and form the basis of developing | • Lack of investment in locally relevant models<br>• Poor understanding of available data due to isolated knowledge | • Limited or inaccurate data regarding physical characteristics of floods, assets | • **Preparation** – necessary to develop a detailed overview of available models, data and how these might be used before starting this stage of DAPP implementation |

| Stage of DAPP Implementation | Institutional Barriers Identified from Case Studies | Technical Barriers Identified from Case Studies | Strategies to Overcome Barriers |
|---|---|---|---|
| adaptive plans | within institutions<br>• Mistrust of the ability of ‘simple’ models to provide useful information | at risk, and possible effects of interventions<br>• Unclear how available data might be used to address deep uncertainty problems (e.g., monitoring plans, triggers, and scenarios) | • **Flexibility** – match the type of DAPP process with the amount/quality of data available (e.g., basic scorecard when there is limited information available versus complex model-informed decision pathways)<br>• **Flexibility –** important to pool resources across organisations to maximise the amount of useful data and possible modelling options<br>• **Serious games** –a useful way to communicate model processes, demonstrate the long-term impacts of decisions, and build model and team trust<br>• **Flexibility –** important to use a range of metrics (economic, social, cultural, and environmental) to demonstrate the efficacy of adaptive plans<br>• **Preparation/flexibility**– development of monitoring plans and triggers, and use of scenarios to test them, require a variety of indicators to cover local (e.g., Mean Annual Flood, Expected Annual Damage), national (e.g., temperature and precipitation trends), and global (e.g., atmospheric circulation patterns) scales |
| Incorporating adaptive plans within policy frameworks and measures | • Ability of key individuals/communities to block implementation<br>• Ongoing monitoring costs | • Lack of long-term strategic policy at local government level | • **Preparation –** early collaboration to build buy-in with all relevant stakeholders and communities will minimise the likelihood of push-back in the implementation phase<br>• **Preparation –** monitoring frameworks are a necessary investment so that adaptive plans can be adjusted before highly damaging events occur<br>• **Preparation –** development of new local-level policy that focuses on proactive management will enable dynamic adaptive plans to become entrenched |

### 3.3.4 Conclusion

Using DAPP for any riverine flood situation is by no means quick or easy. Technical barriers can reduce the accuracy of model-based approaches, whilst institutional barriers can limit the possible uptake of adaptive plans once work is completed. However, based on the findings of two recent case studies, it is clear that many of these barriers can be overcome through careful preparation and maintaining flexibility of approach during the uptake process. By building individual and institutional understanding around the benefits of DAPP and other decision-support methods over time, greater opportunities for establishing buy-in and for collaboration will be uncovered, maximising the likelihood of adaptive plans being implemented through policy frameworks and other measures. Similarly, prospective DAPP users should seek to understand the available range and levels of DAPP applications (e.g., model-based analysis versus scorecard-based analysis), and how these align with available information, so that informed decisions can be made regarding what is appropriate for particular case studies. By adhering to these concepts, river managers should have confidence in applying DAPP to their river system, knowing that such an investigation will reveal useful and meaningful information on climate-derived changes for decision making.

# 4. Processes for designing signals and triggers

This section discusses the processes used in our research to develop the signal and trigger Phases and Tasks, and how to 'test' them, using socio-economic scenarios of the future. The processes discussed here in 4.1 and 4.2 differ from the quantitative examples in 3.1 and 3.2 for coastal and riverine flood settings in that they are qualitative (being based on community and expert elicitation). The two approaches can be complementary depending on the level and type of uncertainty present and the time frame of consideration.

## 4.1 Development of social, economic, and cultural signals and triggers

Paula Blackett and Judy Lawrence

### 4.1.1 Introduction

When developing signals and triggers for adaptive planning using DAPP to avoid ATs, community values and council responsibilities will influence how relevant, credible, and legitimate they are. We, therefore, undertook to improve our understanding of what a community, council staff, and councillors value by conducting five workshops during 2018 and one in 2019:

- Three workshops in Hawke's Bay:
  - One with a community panel that was set up for the Clifton to Tangoio Coastal Hazards Strategy 2120, led by a Joint Committee of the Hawkes' Bay Regional Council, Napier City and Hastings District Council, and mana whenua;
  - One with the Technical Advisory Group advising the Coastal Hazards Strategy 2120 development comprising members from the three councils; and
  - One with the Technical Advisory Group to the Coastal Hazards Strategy that was designing signals and triggers for the implementation of the Strategy.
- One workshop in Wellington with council staff and politicians from GWRC, Masterton District Council, Upper Hutt City Council, Hutt City Council, including coastal hazards, engineering, planning, and asset management.
- One workshop with a group of Tauranga-based regional council staff from the Bay of Plenty Regional Council, Tauranga City Council, and Western Bay of Plenty District Council including coastal hazards, planning, asset management, engineering, emergency management, and lifelines background.

### 4.1.2 What we did

First, participants were briefed by the researchers on the purpose of the workshop and how it would proceed. This involved identifying signals and triggers for pre-prepared pathways relevant to each location. These were then tested against the New Zealand Shared Socio-economic Pathway (NZSSP) scenarios to establish how sensitive they were to different futures (see section 4.2).

Participants were organised into groups of four to five people supported by a council officer and a researcher. Large blank sheets and pre-prepared cards with examples of signals, triggers, and thresholds were provided (Appendix 5). Participants were then asked to start identifying adaptation thresholds, triggers, and signals respectively, by answering the following questions:

- What do you <u>not</u> want to experience **(AT)**, and record reasons?
- What would **trigger** a decision to change pathway?

- What would give you warning **(signal)** that a trigger/decision point is coming?

The signals, triggers, and thresholds were recorded on the blank sheets (Figures 13 and 14). This was followed by a group-based discussion/feedback session - a plenary feedback session followed by a discussion of what was learned in the process. A summary of the different types of triggers derived from all five workshops and the research team's knowledge is shown in Appendix 2.

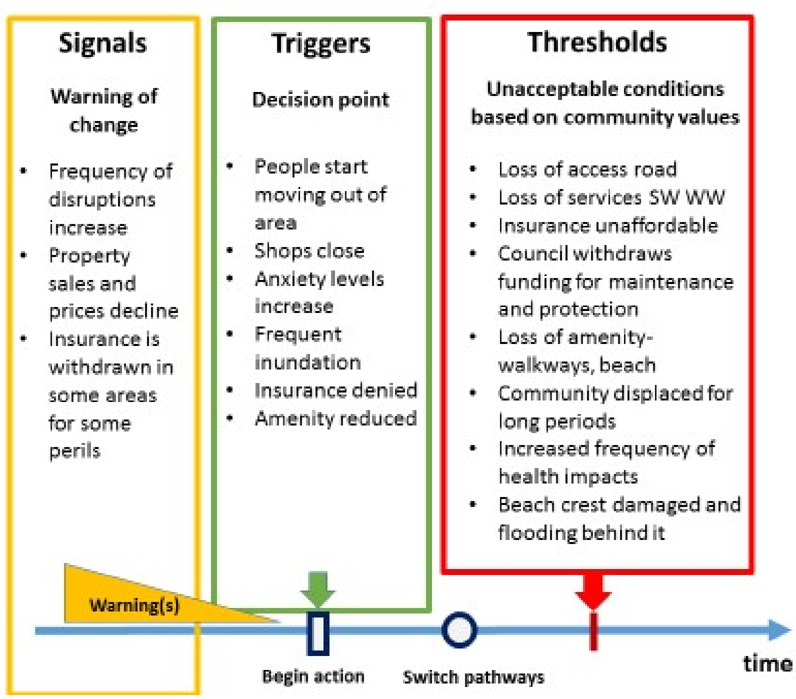



**Figure 13**: Worksheet for recording signals, triggers, and thresholds.

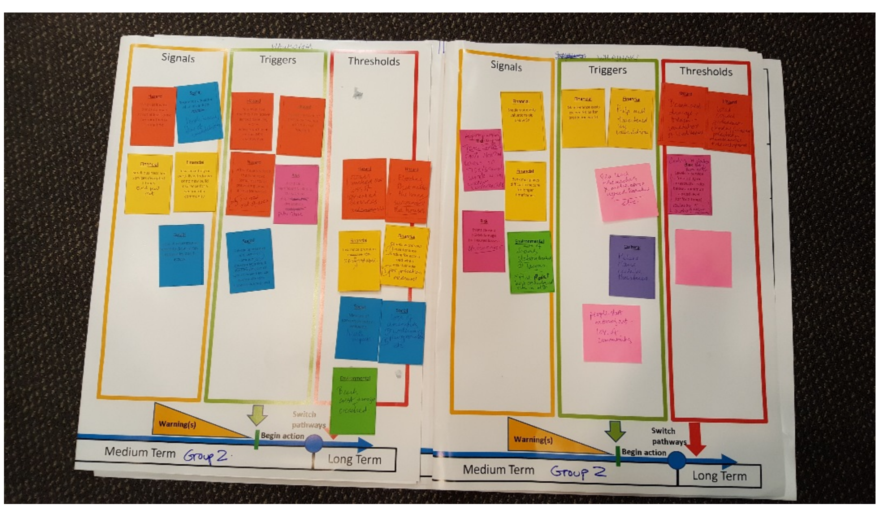



**Figure 14**: Pre-prepared worksheet and cards for defining thresholds, triggers, and thresholds at workshops.

This was followed by 'testing' the signals and triggers using a set of New Zealand-derived socio-economic scenarios (process set out in section 4.2).

### 4.1.3 What we learned

We learned the following:

1. Starting the process with the AT identification was important for enabling participants to conceptualise what sort of trigger would be needed and under what conditions, to avoid the threshold. This helped participants to focus on what they valued and the lead time it might take to implement new pathways.
2. That such an exercise could be conducted with community members within a three to four hour period (noting that the Hawke's Bay participants had already been primed to think about DAPP, having used it for developing the Strategy 2120, and that the GWRC staff had used DAPP in the Hutt River decision-making outlined in example 3.3).
3. To conduct such an exercise in other locations with less DAPP familiarity a briefing on what DAPP is and how to use it is essential. This could include a mock DAPP exercise and/or a Serious Game to give 'experience' in thinking long-term and receiving 'feedback' on decisions made.

### 4.1.4 Conclusion

Undertaking a deliberative process with a community elicits important information about what drives decision choices. Asking the participants what they didn't want to happen enabled a discussion of the objectives (e.g., what they wanted to avoid). This led to an understanding of what the community might tolerate and what might signal their concern, thus enabling the council to act early in anticipation of changing conditions in the environment and of longer-term considerations that might necessitate a shift of pathway. This understanding enables consideration of tolerability of change in the community and how this is influenced by specific conditions relevant to that community and acted upon by the council with greater confidence in advance of negative consequences.

The council participants recognised that signals and triggers also involve council-driven indicators relating to their statutory mandates and the requirements that flow from them for levels of service and community wellbeing, and the ability to monitoring the signals and triggers over long time-frames, including for public safety, health and wellbeing, planning, and building standards.

## 4.2 Use of scenarios for assessing the sensitivity of the signals and triggers

Nicholas Cradock-Henry and Judy Lawrence

### 4.2.1 Scenarios for testing the sensitivity of signals and triggers

The process outlined here introduces a set of New Zealand-specific scenarios and shows how they can be used in an adaptive planning process using DAPP for testing the sensitivity of signals and triggers to a range of futures. This enables credible, relevant, and thus legitimate signals and triggers to be developed and thereby assist decision makers, stakeholders, and communities to explore more robust pathways under a changing and uncertain world.

Scenarios are future possibilities, not predictions, and some will be more plausible than others. They can be expressed numerically as probabilistic projections of future conditions (where possible), or qualitatively as narrative storylines of how the future might unfold. Scenarios are increasingly being used in adaptation practice to “stress test” different options for their robustness under different futures that are changing and uncertain (Haasnoot et al., 2013). Use of scenarios also enable stakeholders and decision makers to visualise how their policy and adaptation choices are affected by changing risk (Cradock-Henry et al., 2018). By assessing adaptation options in the light of several possible futures, scenarios can help avoid locking decisions into a single path that cannot be changed readily and avoids giving a false sense of certainty about the future (Lawrence & Haasnoot, 2017).

### 4.2.2 Scenarios for adaptation pathways planning in New Zealand

While the effects of climate change are principally felt at the local level by communities, sectors, and decision makers, adaptation is required at national, regional, and local scales (Moss et al., 2013). To better understand climate change impacts and adaptation at national and sub-national (i.e., local and regional) scales, it is necessary to incorporate more locally-relevant characteristics of change processes into the global-scenario architecture, and to consider how local choices, trends, and policy decisions might change over time (Frame et al., 2018).

A unique set of scenarios for New Zealand has been developed based on a global set of scenarios that reflect different levels of greenhouse gas emissions (Representative Concentration Pathways (RCPs)), socio-economic development changes (Shared Socio-economic Pathways (SSPs)), and policy changes that limit the extent of warming (Shared Policy Assumptions (SPAs)) (Ebi et al., 2014). For New Zealand, the five global SSPs were scaled down to the national level initially making no assumptions about policy.

In New Zealand, national, regional, and local futures will be influenced in large part by policy choices relating to climate change mitigation (e.g., reducing GHG emissions) and adaptation to reduce risks and realise potential opportunities. National policy will have the effect of either ‘going with the flow’ and reinforcing global trends, or ‘swimming upstream’ and charting a different course in keeping with domestic values and priorities. The global SPAs were adapted to the local context through a suite of Shared Climate Policy Assumptions for New Zealand (SPANZ). The SPANZ use qualitative and quantitative indicators to describe ‘locally relevant’ policy characteristics and drivers of change in New Zealand, ranging from short-term incremental changes to wide-ranging systemic changes resulting in the transformation of existing decision-making processes and institutions.

The combination of SSPs, RCPs, and SPANZ provide the basis for a set of six national-scale socio-economic scenarios that can be used for vulnerability, impacts, and adaptation assessment (Figure 15).

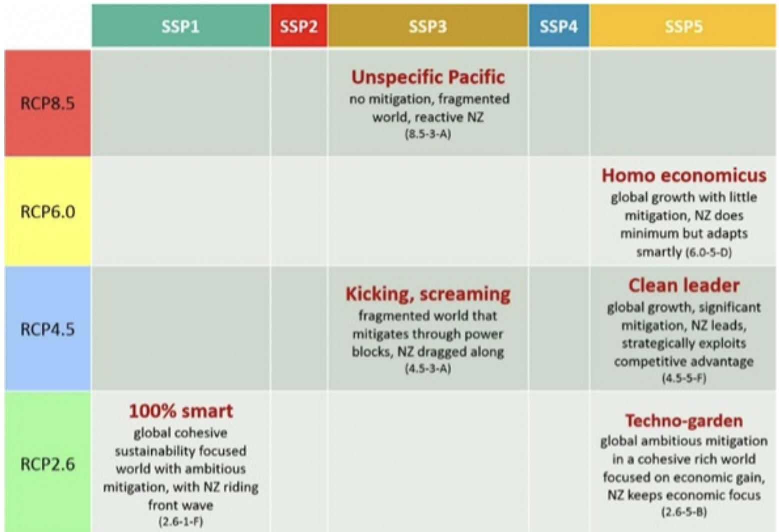



**Figure 15:** Six scenarios of New Zealand socio-economic futures, illustrating the potential impacts of climate change and need for adaptation. The scenarios provide a framework for exploring the likelihood of changes, the effects of policy choices, and the extent to which adaptation options might be suitable over time and under a range of circumstances. For local decision-making, adaptation planning, or vulnerability assessments, the scenarios can be tailored using input from stakeholders, desktop analysis, and/or expert elicitation to identify the ways in which these might influence conditions at the community, catchment, or regional scale (Frame & Reisinger, 2016).

### 4.2.3 What we did

The aim was to assess the viability of monitoring adaptive pathways long-term and to test the value of the derived signals and triggers using an elicitation process with local government experts (Wellington, Bay of Plenty, and Hawke's Bay) and communities (Hawke's Bay). To adapt effectively to climate change, pathways planning incorporating signals (warnings) and triggers (decision-points) are needed to guide decision makers on when to shift an option or pathway before reaching a threshold beyond which there are adverse consequences. For signals and triggers to be effective in local adaptation contexts, it is necessary for them to be credible, relevant, and legitimate (see Table 2 and Appendix 5).

**Table 2**. Characteristics of best practice decision processes (Cradock-Henry et al., 2018; Cash et al., 2003)

| | |
|---|---|
| **Credible** | Based on the best available scientific and technical information, in order to withstand scrutiny and expert and peer review. |
| **Relevant** | Meets stakeholders' and decision makers' needs and priorities, and sensitive to the local adaptation and planning context. |
| **Legitimate** | Information used in the process is transparent and respectful of the different values represented in any process using participatory approaches that provide opportunities for learning and provide a forum for different views and interests to be expressed. |

In the design of locally-sensitive ATs, signals for monitoring change for adaptive pathways, and triggers for action (see section 4.1), the six New Zealand scenarios were used to test the expert and community-derived signals and triggers (see Table 3 and Appendix 5) for their sensitivity to the different scenarios. This then enabled us to test whether the triggers were relevant (i.e., do the signals and triggers provide the necessary information for decision makers in a form and timing that they can use to monitor the performance of adaptation pathways?); credible (i.e., is the information provided of high scientific and technical quality, robust, defensible, and plausible?); and, therefore, legitimate (i.e., have the signals and triggers been identified and developed with stakeholders participating with the experts in the process?).

While the national scenarios (Figure 15) provide the overall architecture, local characteristics and drivers of change were added to ensure the relevance of the information generated. For example, in Hawke's Bay, local characteristics were identified before the workshop as shown in Table 3, column 5. The variables were identified using desktop analysis and review of local planning and strategy documents. Tourism (as a leading economic activity for the region and one that is dependent on the quality of ecosystem services in the area), roading and transportation (as an indicator of the vulnerability or resilience of infrastructure), economic development, and urbanisation (reflecting changes likely over the 100 years ahead - the focus of the scenarios) were all identified as significant influences on local conditions. Surveys and/or expert elicitation or other participatory qualitative or quantitative data could be added into the scenarios, or stakeholders themselves could identify what the relevant aspects of future 'worlds' might look like for their context or situation.

**Table 3**. New Zealand socio-economic scenarios and implications for Hawke's Bay

| Scenario | Regional Context | NZ climate policy dimensions | NZ non-climate policy dimensions | Local characteristics and future conditions |
|---|---|---|---|---|
| *Unspecific Pacific* | The Pacific region is becoming a backwater, sliding downwards economically. Breakdown of global trade, mounting refugees from Pacific Islands, and regional conflicts. | • Rampant exploitation of natural and physical resources<br>• Little consideration of environmental impacts<br>• Focus on short-term economic interests<br>• Change only occurs when forced, with little oversight of transition | • Economic values prioritised<br>• First come, first served for water rights. No water regulations<br>• Non-transparent and unfair trade relationships<br>• Immigration determined by economic interests | • Little emphasis on risk reduction in coastal areas<br>• Tourism in decline as environment degraded<br>• Roads poorly maintained<br>• Economic development slow<br>• Urban footprint in Hawke's Bay is stagnant |
| *Homo Economicus* | The region is dominated by changing powers dependent on economic ascendancy within a globalised trade regime. Strong regional migration based on maximising labour supply, which results in strong regional competition to attract business. | • Mitigation not NZ's primary concern<br>• Selective accounting<br>• No carbon charge on agriculture<br>• Only consider economic impacts and risks<br>• Use of market mechanisms<br>• Medium term economic focus | • Economic values prioritised<br>• Auctioning of water rights with limited regulation<br>• Global market requirements dominate trade<br>• No "clean green" premium available<br>• Immigration determined by economic interests<br>• Under-skilled local labour displaced<br>• Environmental conservation low priority | • Hawke's Bay is attractive for international labour, with attendant growth in urban and suburban areas<br>• With economic growth and growing wealth, Hawke's Bay is a popular domestic and international destination for visitors<br>• Highways developed to accommodate local population increase and visitor numbers |
| *Clean Leader* | The region is an important global player owing to its economic dominance within global markets. Technology, trade, and economic migration are resulting in increasing homogenisation of the region. | • NZ leading mitigation efforts<br>• Net CO2 neutral well before 2100<br>• Agricultural emissions fully priced and linked to international market<br>• Adaptation primarily serves to minimise economic risks<br>• Transformations facilitated where economic case can be demonstrated<br>• Ecological services accounted for | • Environmental and intangible social values monetised in accounting<br>• First come, first served for water rights<br>• Global market requirements dominate trade<br>• "Clean green" premium available<br>• Regulated immigration, protecting local labour<br>• Environmental conservation through business partnership | • Cost-benefit of risk reduction enables high-value properties and other assets to be protected<br>• Ecosystem-based adaptation prioritised<br>• Tourism development slow but steady as NZ's distance from key markets and costs of fossil fuels discourage long-haul travel<br>• Suburban growth and well-maintained roads connect bedroom communities with R&D hubs throughout Hawke's Bay |
| *Kicking, Screaming* | The region is one of several competing trade blocks, and countries within the region seek shifting alliances that serve their near-term interests. Some countries | • Bare-minimum action to ensure continued access to restricted markets<br>• Laggard adopting | • Economic values prioritised<br>• First come, first served for water rights. Minimum | • Economic growth piecemeal with no clear regional development strategy<br>• Coastal risk reduction |

| | | | | |
|---|---|---|---|---|
| | within the region remain in severe poverty while others, and urban elites within countries, rapidly gain wealth. | weak targets<br>• Selective accounting, agriculture remains exempt<br>• Piecemeal and reactive adaptation<br>• Ill-prepared transformations | water regulations<br>• Non-transparent and unfair trade relationships<br>• "Clean green" premium available but not pursued<br>• Regulated immigration, with limited consideration of demographic issues<br>• Environmental conservation low priority | not a priority<br>• Declining environmental conditions lead to lower visitor numbers, as agricultural production remains focus of local economy<br>• Declining rating base in marginal coastal areas, leads to delays in infrastructure (road) maintenance |
| *Techno-Garden* | The region is part of an effective global trade regime and seeks competitive advantages based on its cheap and abundant labour force to supply globally needed products and services. The region is becoming rapidly homogenised due to the near-universal spread of new technologies and economic migration. | • NZ is internationally compliant with stringent global efforts<br>• Opportunistic<br>• Focus on productivity and efficiency<br>• Limited adaptation required. When necessary, issues are addressed reactively<br>• Transformations made when business case adds up | • Environmental protection depends on economic value<br>• Limited consideration of intangible values<br>• Auctioning of water rights with environmental safeguards<br>• Global trade focus on efficiencies<br>• Innovative production and focus on high-value products<br>• Immigration based on recipient benefits rather than protecting refugees<br>• Environmental conservation through business partnership | • Public-Private Partnerships the model for investment in coastal risk reduction<br>• Local tourism caters to the small number of high-net worth/affluent market, both domestic and international. Emphasis on coastal retreats and luxury properties<br>• Critical roads are well maintained, secondary roads in poor condition.<br>• Hawke's Bay growing rapidly due to tele-commuting, tech firms, and generous tax relief for R&D |
| *100% Smart* | The region is part of an effective global trade regime and seeks competitive advantage based on a growing service industry and niche products that support local labour markets and sustainable use of local resources. Migration is seeking to balance economic advantages with protecting local and indigenous populations, retaining distinct cultural differences. | • NZ is leading stringent global mitigation efforts<br>• $CO_2$ neutral by 2050<br>• Aggressive efforts to reduce agricultural emissions<br>• Strategic adaptation despite high cost<br>• Active management of transition | • Strong environmental stewardship<br>• Auctioning of water rights with strong environmental safeguards<br>• Effective global trade with protections<br>• Market premiums available for exploitation<br>• Co-ordinated regional immigration (including refugees and voluntary migrants) | • Environmental ethos, strong emphasis on locally-appropriate mitigation and risk reduction options<br>• Strategic economic development, with Hawke's Bay a leading example of locally diversified economy, built on high-value horticulture and viticulture, technology, and service industries<br>• 'Smart Growth', and urban footprint expands, at the expense of commuter towns and suburbs<br>• Tourism a niche market<br>• Well-developed public transport network with roads in good condition |

After an introduction to the NZSSPs, participants worked through each of the scenarios, drawing on their own understanding of the relevant issues, referring to the derived signals, triggers, and threshold identified earlier in the workshop (section 4.1) and the characteristics of best practice decision-making criteria (credible, relevant, and legitimate; Table 2).

Participants were asked to evaluate their triggers against the following questions and record their results and rationale:

- What are the challenges for acting on the triggers in this scenario?
- What actions might start once the trigger is reached?
- Is the trigger still relevant; will it be acted on?
- How fast do you think these triggers might be reached (relative to the other scenarios, 1-6)?

Participants were then given the following instructions:

- Imagine yourself in each of the possible NZSSP future worlds. You will need to make some assumptions about that world beyond what you have been given.
- Think about how the coast (at the location given) may have adapted in each world. When might the triggers have occurred and what might have been done when each trigger was reached.
- Given each different world, what challenges might have arisen when implementing the strategy.
- Revisit the triggers and thresholds that you have described and think about whether they would be still relevant (or helpful) in each scenario/ future world and what sort of challenges, acting on the triggers, might be generated in this world.
- Would you alter the triggers? How and why?

### 4.2.4 What we learned

The global scenario architecture is a powerful tool for evaluating the intersection of climate change and societal responses. However, more specific context is required to explore and understand risks, drivers, and enablers of change at the sub-national scale. The set of scenarios for New Zealand can be used to derive new information on locally-relevant changes that communities are likely to experience, and then determine whether or not the signals and triggers for monitoring the performance of options and pathways are appropriate for decision making — relevant, credible, and legitimate.

Using scenarios to test signals and triggers provides a ‘safe space’ for learning and experimentation. However, trying to test signals and triggers against all six possible worlds in a workshop setting can increase the time to explore each scenario manually, due to participants’ finding it difficult to hold several scenarios in their heads. The use of fast modelling methods in workshops could address this issue (Kwakkel et al., 2015). Nevertheless, the differences between the futures were not sufficiently sensitive to reveal differences for signal and trigger design, particularly relative to the ‘noise’ of other changes. By ‘bookending’ the evaluations with scenarios at either end of a continuum, for example, ‘Unspecific Pacific’ and ‘100% Smart’, and a middle-of-the-range scenario, we provided sufficient range for sensitivity to reflect the long-term changes (see Table 4 used at Wellington workshop). Since the triggers and signals will be reviewed over time as the world changes, some scenarios may become less relevant in the real world. The signals and triggers were sensitive to scenarios and each trigger could lead to a different pathway.

**Table 4**. Bookended New Zealand socio-economic scenarios used at Wellington workshop

| | Scenario | |
|---|---|---|
| | **Unspecific Pacific (RCP 8.5, SSP3; High emissions, low adaptation)** | **100% Smart (Low emissions, high adaptation)** |
| *Regional Context* | • The Pacific region is becoming a backwater, sliding downwards economically. Breakdown of global trade, mounting refugees from Pacific Islands, and regional conflicts | • The region is part of an effective global trade regime and seeks competitive advantage based on a growing service industry and niche products that support local labour markets and sustainable use of local resources<br>• Migration is seeking to balance economic advantages with protecting local and indigenous populations, retaining distinct cultural differences |
| *Environmental and climatic trends* | • Significantly higher average temperatures (regionally)<br>• Increase in extreme rainfall events<br>• Sea-level rise exacerbates coastal erosion and inundation<br>• Dramatically increased risk/significantly reduced habitability/safety for populations living in coastal areas<br>• Saltwater intrusion affects household water supplies | • Higher average temperatures (regionally)<br>• Increased climate variability, problematic rainfall events<br>• Rates of coastal erosion increase, problematic flooding with tidal surges<br>• Coastal habitability declines due to increased risk |
| *NZ climate policy dimensions* | • Rampant exploitation of natural and physical resources<br>• Little consideration of environmental impacts<br>• Focus on short-term economic interests<br>• Change only occurs when forced, with little oversight of transition | • NZ is leading stringent global mitigation efforts<br>• $CO_2$ neutral by 2050<br>• Aggressive efforts to reduce agricultural emissions<br>• Strategic adaptation despite high cost<br>• Active management of transition |
| *Non-climate policy* | • Economic values prioritised<br>• First come, first served for water rights. No water regulations<br>• Non-transparent and unfair trade relationships<br>• Immigration determined by economic interests | • Strong environmental stewardship<br>• Auctioning of water rights with strong environmental safeguards<br>• Effective global trade with protections<br>• Market premiums available for exploitation<br>• Co-ordinated regional immigration (including refugees and voluntary migrants) |
| *Local conditions expressed in scenarios* | • Poor urban design exacerbates warm temperatures and urban heat island<br>• Low levels of 'community satisfaction', due to declining levels of service for infrastructure and amenities<br>• Flood hazard continues to increase with flood events a regular occurrence | • Environmental ethos, strong emphasis on locally-appropriate mitigation and risk reduction options<br>• Strategic economic development, with Greater Wellington Region acknowledged internationally for its advanced, diversified economy based on smart technology, and service industries<br>• 'Smart Growth' and urban footprint |

| | | |
|---|---|---|
| | • Transportation (road and rail) regularly disrupted due to flooding<br>• Slow decline in population size, especially young adults and families<br>• Decline in local services as workers leave or retire<br>• Increased cost of goods and services<br>• Reduced income for most households<br>• More accidents in coastal areas<br>• Economic development declines | expands. Increased jobs and infrastructure<br>• Influx of workers and families<br>• Increase in community services<br>• Local, regional, and central govt collaborate to invest money, build capital, and develop community services<br>• Enhanced cultural identity for local iwi, and diverse cultural values recognised in regional development/planning processes<br>• Increased expendable income<br>• Increased housing prices<br>• Reduced cost of food, goods, and services<br>• Well-developed public transport network with roads in good condition |

In the workshops, we introduced the scenarios and discussed the central issue (i.e., adaptation to climate change in the face of uncertainty) and the central question of the process: ''How can we identify signals and triggers that will be robust across a range of possible futures?"

In Hawke's Bay, for example (Table 3), road access was identified by the three groups as being a 'robust' signal across a number of scenarios. Reduced access – due to more frequent flooding or increased erosion – was a strong environmental signal that the effects of climate change were accelerating and impacting local communities; however, it was also a strong social and economic signal. Reduced road access might prevent people from getting to/from employment, for example. Regular disruption, in turn, was a warning of an impending threshold: complete loss of road access. By monitoring the signals, actions could be taken in advance (initiated at the pre-determined trigger) to limit further development and explore mitigation solutions. Furthermore, the signal was easily understood and directly relevant to local concerns because road access would also have effects on tourism and livelihoods.

### 4.2.5 Conclusion

Scenarios serve as a useful boundary object – shared by several different groups (e.g., scientists and researchers, policy and decision makers, and community groups or other stakeholders) – that helps focus discussions and explore options (Impedovo & Manuti, 2016). This presents an opportunity to view expert knowledge alongside quantitative modelling to validate model outputs in the 'real world'. Having qualitative inputs can also help make models manageable when applying them in complex situations where there is uncertainty over long time-frames, temporal and spatial dependence, multiple and changing hazards, and socio-economic conditions. Scenario-based evaluation of signals and triggers can also provide a trans-disciplinary forum for discussing adaptation options and to develop a more integrated set of pathways across types of signals and triggers that link to the range of complementary short-term action and future options in the pathways. Such evaluation will also enhance local capability and capacity for adaptation planning. By incorporating local characteristics into scenarios, stakeholders can readily express what the future might look like in ways they may not have done before, revealing new information and possible opportunities. Therefore, when used in participatory and collaborative settings, scenarios can raise awareness of the need for adaptation and how uncertainty can be addressed, without promoting delayed adaptation action. By modifying and applying the New Zealand scenarios to different contexts and local scales, they can be used in vulnerability analyses alongside adaptive planning, and for considering multiple interacting socio-economic and biophysical stressors.

In our work, scenarios were found to be a practical tool to support adaptive pathways planning and impacts and vulnerability assessments at a local level. Using participatory and non-technical planning methods and goals could be achieved in relatively short time-frames and on limited budgets through practitioners working closely with local communities. This approach added to the relevance, credibility, and legitimacy of decision-making processes under uncertain conditions.

# 5. Acknowledgements

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# Appendices

## Appendix 1. Illustrations of adaptive management and planning in different domains

### Background

Adaptive management was originally formulated by Holling (1978) in the context of resource management. It was devised as a concept for testing the resilience of a system while still managing its functionality. Adaptive management enables actions or policies to proceed in the light of uncertainties about effects, impacts, and future conditions and comprises an element of learning or improved understanding of the system (Holling, 1978). It requires identification of clear and measurable management objectives to enable progress towards agreed objectives (or when they can no longer be met, for example, in the case of coastal adaptation) to be measured and to indicate when a change in direction is necessary.

An adaptive approach often includes early-warning indicators or signals, which initiate further assessments, improved estimate of the time-to-trigger, pre-planning, and whether more intensive monitoring is required. An example in water-quality management is resource consent conditions for seabed dredging. These often comprise an upper threshold turbidity, when all operations should cease and be investigated, along with one or two pre-threshold levels or signals that may require further review of the cause and the implications while still operating. These are especially used in situations where there is substantial natural variability compared to the signal sought.

How precautionary the triggers should be, arises in conservation ecology for a rare species (to avoid extinction) vs cumulative climate-change/hazard risk or impact. Determining trigger points also requires social and political judgments to be made regarding acceptable levels of risk in each circumstance.

Nevertheless, adaptive management approaches work from a static plan that is monitored and then adapted. Similarly, adaptive policy making (Walker et al., 2019) or the transport example below, has a static plan, but added contingency actions as part of the plan to hedge against potential changes. DAPP, on the other hand, makes the whole plan adaptive, and implementation is based on adjustments as conditions start to change (Haasnoot et al., 2019; MfE, 2017; Lawrence et al., 2019c).

### Examples from different domains

Examples from ecological management, infrastructure planning, and transport policy illustrate that monitoring for signals and particularly triggers are widely used in other domains. Experience from these can be built on for managing changing climate risks.

#### *Ecological management (e.g., Nie & Schultz, 2012; Peters et al., 2014)*

In ecological management a trigger is a pre-negotiated commitment, within an adaptive management or mitigation (risk-reduction) plan, that specifies what actions will occur if monitoring reveals trends towards particular outcomes. The trigger identifies in advance the circumstances in which plans will be altered on the basis of monitoring information. The monitoring regime sits within the statutory framework (which can be constraining or provide bottom lines). The following issues are discussed:

- Is there a need for a cumulative damage/impact trigger over multiple events, or just a number of events above given criteria?
- There can be multiple triggers (but with a conditional outcome; for example, all triggers tripped, minimum of *x* triggers, or just 1 trigger tripped).
- Tying triggers to goals or objectives – triggers measure performance towards objectives, for example, an abundance of salmon (or when objectives fail) – resulting in the need for changes to management actions.
- Triggers also help with the design of a more-focused monitoring programme; however, the challenge of using triggers in ecology is in the uncertainty in establishing thresholds for triggering actions.

*Major infrastructure projects - Thames Estuary 2100 (e.g., Ranger et al., 2013)*

The Thames Estuary 2100 or TE2100 project was one of the early adopters of the DAPP approach. Triggers are defined decision-points where the plan is adjusted, refined, or changed, triggered by observations of ten key indicators, which include relative or local sea-level rise, closures of Thames barrage, an extreme water level (e.g., peak storm-tide level), peak river flow, condition of flood defences, developed area of floodplain and value affected, extent of erosion, and public attitudes to flood risk as listed in Table 4 of Ranger et al. (2013).

Preparations for actions that might be triggered later or earlier depending on the trajectory of change were included, including the range of uncertainty of the indicator value. This case used a nominal fixed lead time for planning, consenting, and construction at the outset, to fit with the institutional regime by estimating indicative time-frames to exceedance of the triggers, using a mid-range and a high-end sea-level rise scenario. The actual monitoring determines under what conditions the triggers will emerge as the changes in storms and sea-level rise unfold. Note: stress-testing of the options used more sea-level rise scenarios.

> *[Comment on the use of a trigger (decision-point) in ecological management (previous sub-section) compared with DAPP applications such as TE2100:*
>
> *The important distinction between the two cases is that a threshold value for the trigger for ecological/water-quality management relates specifically to the juncture where intervention is required quickly (or cessation of the activity), whereas a trigger (in the DAPP framework) is not directly tied to a specific level of risk or performance at the AT. Rather, the latter has an earlier lower-magnitude criterion that also comprises the lead time needed to implement a pathway or action before the AT is reached (which in time could be quite different, depending on the uncertainty range and the next agreed option or action).]*

*Transport Policy – Europe (e.g., Marchau, et al., 2008; 2010)*

Urban transport is facing an increasing number of problems in Europe. Innovative technological solutions have been proposed for many of these problems (e.g., intelligent speed adaptation, personal intelligent travel assistant, and putting freight transport underground in places). However, implementation is surrounded by many uncertainties (e.g., future developments in urban transport demand and supply, the possible consequences of these developments for urban transportation system performance, and the way stakeholders will value these consequences). In order to deal with these uncertainties, a flexible or adaptive policy is proposed that takes some actions immediately and creates a framework for future actions that allows for adaptations over time, as knowledge changes, by following critical steps as the new technologies are implemented.

As part of the policy design, critical values for the trigger indicators are specified, beyond which actions should be implemented to ensure that a policy progresses in the right direction and at a proper speed.

Once the policy is agreed upon, the final step involves implementation of the monitoring. In this step, the actions to be taken immediately are implemented, indicator information (related to the triggers) begins to be collected, and when the trigger is reached, policy actions are started, altered, stopped, or extended.

**Note:** after implementation of the initial policy actions, the next step of the adaptive policies is held off until a trigger event is reached as determined in the monitoring programme. As long as the original policy objectives and constraints remain in place, the responses to a trigger event have a defensive or corrective character — that is, they are adjustments to the basic policy that preserve its benefits or meet outside challenges.

Under some circumstances, however, neither defensive nor corrective actions will be sufficient. In that case, the entire policy will have to be reassessed and substantially changed or even abandoned. If this is the case, the next policy deliberations would benefit from the previous experience so the process is inherently a learning experience as well.

‘Triggers’ that are defined would implement corrective policy actions when certain pre-defined levels of risky driving behaviour develop, for example. Another uncertain vulnerability involves driver acceptance. Driver-education programmes that educate drivers on the potential and the risks of ISA (intelligent speed adaptation) might be undertaken to hedge against this vulnerability. In addition, a signpost that monitors driver acceptance can be defined together with a trigger related, for instance, to an ISA penetration level required to reach the intended decrease in fatalities and injuries.

However, for some trigger events, neither defensive nor corrective actions may be sufficient. In a malfunctioning technology case, resulting in a large accident, the entire policy might come under serious pressure. If so, however, the policy-making process would not have to start all over again. The experiences gained and knowledge gathered in the initial adaptive policy-making process would be available and would contribute to the new policy-making process.

> [*Comment: Illustrates that a large event could alter the policy/pathway, and also the need for good documentation of process in deriving pathways, triggers, and thresholds (e.g., out-comes, values, objectives, measures, preferences of stakeholders, etc.) to enable smooth pick-up of previous deliberations and analysis over time*.
>
> *This transport example of adaptive policy-making is nevertheless working from a static plan and learning along the way before making further changes, in contrast to DAPP, which makes the whole plan adaptive, with implementation based on pre-agreed adjustments as conditions start to change*.]

## New Zealand examples under the RMA

There are numerous New Zealand court cases where 'triggers' have been germane to a resource consent refusal or conditional approval under the RMA. The three examples provided here help illustrate how triggers might be designed based on DAPP under the existing legal framework. More extensive summaries for coastal cases are provided at: https://niwa.co.nz/natural-hazards/hazards/planning-for-coastal-adaptation.

### *Mahanga E Tu Inc v The Hawke's Bay Regional Council and the Wairoa District Council, [2014] NZEnvC*

In Hawke's Bay, where the Regional Coastal Environment Plan has policies and rules expressed through progressive hazard zones over a historic residential zoning, a subdivision was allowed by the Environment Court in the coastal hazard zone with a trigger for adaptive action. A condition was based on a spatial metric of when the foredune reach a point within seven metres of two of the lots that would trigger removal of the allowed 'removable' dwellings and capping and removal of wastewater systems. The court applied a bond, payable upfront to the council, to cover removal in the future. This was designed to avoid future council liability, cost shifting to future ratepayers, and moral hazard that would be created for subsequent owners of the land.

### *Gallagher v Tasman District Council [2014] NZEnvC 245 3 December 2014*

In this case, in a coastal subdivision consent the threat from sea-level rise, coastal flooding, and uncertainties around rising groundwater levels over the lifetime of proposal and its inconsistency with the New Zealand Coastal Policy Statement (NZCPS) led to the Court declining the subdivision. This case suggests that the NZCPS test could be used as a trigger for shifting to other options and pathways.

### *Carter Holt Harvey HBU Ltd v Tasman District Council W025/2013*

In this coastal subdivision case [s106 RMA – *since amended in Oct 2017*] the council could not guarantee that adequate access could be maintained as the sea level rose, as the cost to the local authority of maintaining the access road was already problematic and would become unsustainable, generating disproportionate costs of maintenance on the community within the next 50 years. This became a trigger for declining the appeal, along with several provisions of the NZCPS and the relevant Resource Management Plan. This illustrates that such triggers could be included in plans in advance of subdivision and building approvals for which consents are required.

### *Mason v Bay of Plenty Regional Council, NZEnvC A098, 30 November 2007*

This case in a coastal setting was concerned with the replacement of a sea wall to protect 84 houses, worth $64 million, that were at extreme risk erosion from the sea requiring relocation. The Court made a medium-term decision to allow the consent for 25 years and suggested the council build a fund for future costs for measures to protect properties, which could include managed retreat (Kenderdine, 2010, p. 59). This case appears to foreshadow adaptive planning for coastal development.

# Appendix 2. Types of Triggers

| Precursors | Hazards | Risk | Social/psychological | Financial/economic | Cultural | Environmental | Governance/ institutional |
|---|---|---|---|---|---|---|---|
| Average New Zealand 7-station air temperature reaches X degree C | Riverbank erodes to within X m of house(s), levee, or other infrastructure | Event causing >$XM damage (or insured losses) | Measure of concern/anxiety or wellbeing | Insurance withdrawn or no new build insurance for a section of a community | Taonga or sites (e.g., urupa) begin to be inundated or are regularly inundated | X% loss of wetlands/marshes/ bird numbers/riparian habitat | Regional or district plan controls for further development |
| Mean annual precipitation across the region or catchment reaches X mm/yr | When X flood events, exceeding Z% AEP or Y m3/s (historical), occur in a 10-year period. | Levels of service for a utility or infrastructure dip below a minimum agreed level (or for X times) | Health indicator arising from dampness, e.g., number of child hospital admissions for respiratory illnesses | Premium excesses >$X | Disruption of cultural events (incl. tangi, hui, celebrations) | | Reduction in LoS, e.g., flood control, wastewater, water supply |
| Peak storm intensities or durations reach X mm/ hr or mm/storm, both annually and during flood season | After X events flood an important road (or access road) preventing vehicle access (or worse) | Greater than X% of a defined area or town flooded or X times main access to a suburb closed for more than X hours | | Bank mortgages difficult to secure | Access to mahinga kai limited or lost | Sediment supply for gravel extraction is depleted | Central control taken by national level government |
| Mean soil moisture levels during the flood season rise to X% of field capacity | | Stopbanks damaged or breached X times | Aesthetic, e.g., river views – once protection works reach X m high | Small business, services and agriculture disrupted X times or for Y days/year | | % loss of riverbank area for recreation | Room made for river |
| Mean annual hurricane intensity (Pacific Ocean; Southern Hemisphere) reaches X | The 20-year Mean Annual Flood reaches X m3/s | The next catastrophic flood (define risk/impact, extent) | Tolerance measure, e.g., sense of community is threatened; people start moving out or cannot move because cannot afford to (resale value too low) | Maintenance costs exceed $X pa for protection works | | | A managed retreat strategy begins |
| Mean precipitation over the flood season reaches X mm | Maximum flood extent reaches an agreed extent | A critical or significant facility is threatened, e.g., school, hall, fire station, rest home | Coping capacity measure | Council withdraws maintenance funding for access road when unsustainable at $X | | | Central government roading support withdrawn |
| Global air temperature reaches X degrees C | After X floods overtop flood protection or land use assets | | Specific societal objective is no longer met | Median property valuations dip below $X | | | Central government adaptation law changes |
| Global CO2 concentration reaches X ppm | When sediment damage to water intakes exceed $X or becomes uneconomic to maintain | | Resident population of an area drops below X | Sediment deposited from flood flows exceeds $X clean-up | | | |

## Appendix 3. Statutory mandates for monitoring signals and triggers

### *Resource Management Act (RMA)*

Local authorities have responsibilities under the RMA that provide a strong mandate for managing signals and triggers and monitoring them. Primary amongst them are:

- Section 35(3) to maintain environmental information for understanding the environment and to help people to participate in RMA processes and outcomes;
- Section 79 which confers responsibilities to review RMA policies and plans at least every 10 years. Even if it is found that changes are not required, the provisions must be notified for public submissions and reviewed 10 years after they become operative;
- S35 which outlines the duties on local authorities to gather information or undertake research to carry out effectively their functions under the RMA. In particular, monitor the state of the whole or any part of the environment of its region or district and "… the efficiency and effectiveness of policies, rules, or other methods in its policy statement or its plan" [35(2)(a-b)]. Section 35(5)(j) includes records of natural hazards more broadly for a council's functions under section 35(2)(a); and
- Monitoring and five-yearly reporting on the efficiency and effectiveness of councils' policy statements and plan provisions [section 35(2A) RMA], including consents.

These monitoring and information provision functions of local government are carried out within the context of several other relevant RMA provisions:

- It is a matter of national importance that all agencies and persons exercising powers or functions under the RMA "provide for ... the management of significant risks from natural hazards" [6(h)] and other matters for decision makers to have particular regard to includes "the effects of climate change" section 7 (i); and
- It is a function of regional and district councils when controlling land uses to avoid or mitigate natural hazards [RMA section 30(1)(iv); section 31 (i)(b) & (ii)(a)].

### *Local Government Act (LGA)*

The LGA provides the mandate for local government to engage with communities around monitoring and responding to signals, triggers, and evolving climate change risks, in particular relating to the Long Term Plan (LTP), Annual Plans, infrastructure and asset plans, policies, and funding. Relevant sections include:

- Sections 78, 82, 82A, 87, 95A, and 95B consultation requirements for LTP and Annual Plans and policies;
- Section 97 is critical in the context of managing adaptive plans, which must be in the LTP if a decision to alter significantly the intended level of service provision for any significant activity undertaken by or on behalf of the local authority, including a decision to commence or cease any such activity, is made; and
- Section 125 requires local government from time to time to assess the provision of water and sanitary services, which is a monitoring provision that can be used for monitoring relevant signals and triggers.

*Civil Defence and Emergency Management (CDEM) Act*

The CDEM Act provides a mandate for linking monitoring in the context of uncertainty for informing CDEM Group Plans:

- Section 7 *Precautionary approach* gives a general mandate to all persons exercising functions in relation to the development and implementation of civil defence emergency management plans under the CDEM Act to be cautious in managing risks even if there is scientific and technical uncertainty about those risks.

## Appendix 4. Adaptive planning challenges: How serious games and knowledge brokers can address the challenges (based on the Hutt riverine flood example in section 3.3)

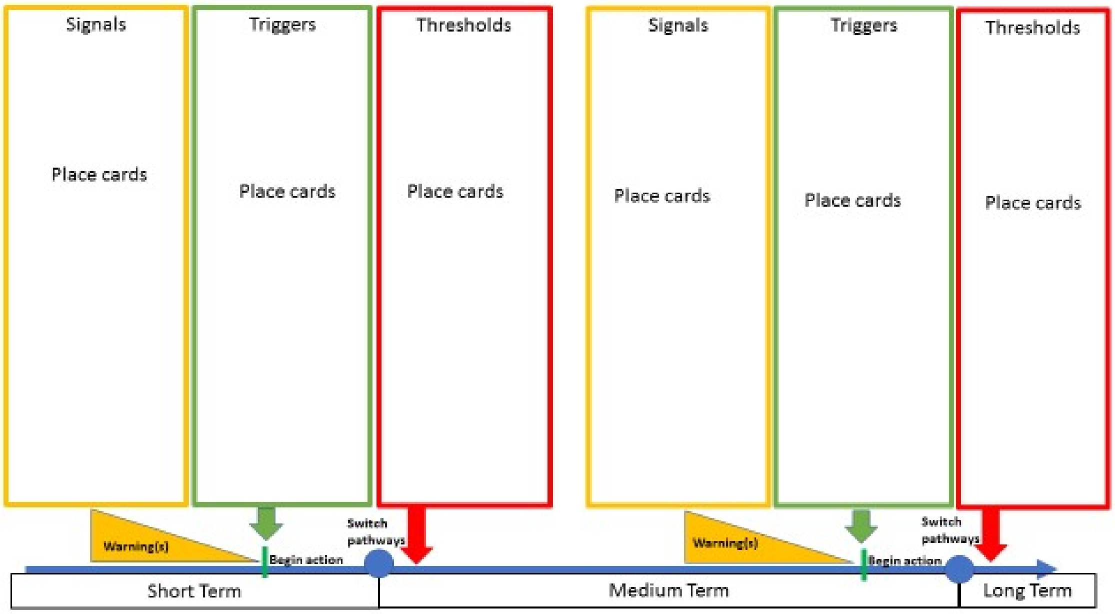
**Source:** Lawrence & Haasnoot (2017)

| Challenges to adaptive planning | The Game | Knowledge broker |
|---|---|---|
| **Decision making under uncertainty** | Participants need to make decisions on water management while not knowing how the future will unfold. The game raises awareness about path-dependency of decisions. Some actions close off later options as they become locked in, for example, city infrastructure in low-lying coastal areas exposed to sea-level rise. | Framing of climate change risks to emphasise how uncertainty and consequences matters, for example, a moving mean increases the consequences at the tail of the distribution, increased frequency and magnitude of rainfall, and use of scenarios across a range. |
| **Understanding and acknowledging different types of uncertainty** | Climate variability and climate change are included in the time series (transient scenarios that underpin the Game). Newspapers address socio-economic developments. Multiple scenarios are discussed. Two or three teams with different values decide – after negotiation - on what actions to take. Some actions have high path-dependency. Actions can only be implemented in case of social support. Some actions are uncertain in their efficacy. | Communicating now future risks cannot be predicted where deep uncertainty exists. Communicating how socio-economic change will influence exposure to climate change risks.<br>Introducing hitherto inaccessible new knowledge to participants. |
| **Making robust and adaptive decisions that can cope with uncertainties about the future** | During the course of the Game players receive simulated feedback on whether they are meeting objectives:<br>• 'Newspapers' on socio-economic development are circulated during the Game to simulate uncertainty and change; and<br>• Change of values/social support from citizens is scripted based on what is happening in response to policy actions. | Demonstrating, by being embedded in the DAPP assessment and decision process, how a range of options can be presented as adaptive pathways to influence the choices subsequently taken by the politicians. |
| **Explaining the need/benefit for a more dynamic approach to decision making under conditions of uncertainty and change** | The debrief after the Game reveals what was experienced during the Game and how participants can apply the experience and the thinking to assessing changing risk profiles in their real-life decisions that have uncertainty and change. | Facilitating discussion after the Games about the game experience and through demonstration in the DAPP assessment and decision process. |
| **Shifting planning practice from static to dynamic approaches.** | Experiential learning occurs during the Game. Debrief after the Game discusses how a shift from static to dynamic planning can be given effect. | The framing of the climate change risks. |

| | | |
|---|---|---|
| **Implementation of an adaptive plan** | Involvement of the elected politicians in Game sessions and briefings about the DAPP embedded adaptive thinking that influenced the pathways chosen. | Uptake of the DAPP in an adaptive plan. |
| **Contestation amongst affected interests** | The Game can be used in community settings to create experiential learning about how uncertainty can be addressed and legitimate decisions made, in advance of damaging impacts, thus enabling different values to be addressed and greater understanding fostered. | Advice on the communications strategy for the community consultation on options. |

## Appendix 5. Blank worksheets

### Signals Triggers Thresholds




### Scenarios

| Scenario | Challenges for acting on the trigger in this scenario | What actions might start once the trigger was reached? | Is the trigger still relevant? (will it still be acted on?) | How fast do you think these might be reached relative to the other scenarios? (rank in order 1-6) |
|---|---|---|---|---|
| 100% Smart | | | Y/N<br>Why? | |
| Unspecific pacific | | | Y/N<br>Why? | |

## Criteria for testing credibility, relevance, and legitimacy of signals and triggers against NZSSPs

| Scenario | Challenges for acting on the trigger in this scenario | What actions might start once the trigger was reached? | Is the trigger still relevant? (will it still be acted on?) | How fast do you think these might be reached relative to the other scenarios? (rank in order 1-6) |
|---|---|---|---|---|
| 100% Smart | | | Y/N<br>Why? | |
| Unspecific pacific | | | Y/N<br>Why? | |
| Kicking and Screaming | | | Y/N<br>Why? | |
| Homo-economics | | | Y/N<br>Why? | |
| Clean leader | | | Y/N<br>Why? | |
| Techno-garden | | | Y/N<br>Why? | |

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