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Strengthening Integrated Flood Risk Management

Managing Uncertainty in Integrated Flood Risk Management using Dynamic Adaptive Pathways Planning

Prepared by Deltares

For Asian Development Bank

Asian Development Bank

Managing Uncertainty in Integrated Flood Risk Management using Dynamic Adaptive Pathways Planning

Technical Note
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Abbreviations

ADB	Asian Development Bank
BCR	Benefit-Cost-Ratio
CAPEX	Capital Expenditure
CRIDA	Climate Risk Informed Decision Analysis
DAPP	Dynamic Adaptive Pathways Planning
DMC	Developing Member Countries
DMDU	Decision Making Under Deep Uncertainty
DS	Decision Scaling
EAD	Expected Annual Damages
EIRR	Expected Internal Rate of Return
IFRM	Integrated Flood Risk Management
IPCC	Intergovernmental Panel on Climate Change
MCA	Multi-Criteria Analysis
RDM	Robust Decision Making
RRP	Report and Recommendation of the President
SLR	Sea Level Rise
TA	Technical Assistance
TRTA	Transaction Technical Assistance

Glossary

Adaptation pathway

A specific type of strategy where sequences of interventions are formulated to ensure that planning objectives are continuously met as conditions change in time.

Adaptation tipping point / threshold

The point at which the existing system or intervention no longer performs acceptably or can be considered to 'fail'. Reaching this point indicates that a new intervention is required to maintain acceptable or 'successful' system performance.

Driver

Variables which influence levels of risk in the system, and which typically fall outside of planners' control. Examples include sea level rise, climate change, population growth, economic development.

Enabling actions

Actions that are required to prepare for implementation of the principal interventions included in the plan. Examples include land reservations, regulatory changes, governance arrangements, detailed planning and design work, compensation mechanisms.

Flexibility

The ability of a system to gradually adapt to changes in the future. This can refer to the capacity of interventions to be up- or down-scaled, combined with others, or to switch from one strategy to another.

Intervention/action/option/measure

Principal changes within the planner's control that are made to the system that directly impact the performance indicators. An individual intervention may consist of single or multiple actions.

Lock-in

A situation whereby short-term interventions impede the ability to carry out later interventions in the mid- to long-term.

Maladaptation

Interventions that are made to the system which (over time) lead to undesired outcomes or regret, for example, lock-ins, stranded assets, over- or under-investment.

Opportunity

Conditions under which the implementation of an intervention becomes feasible. This can refer to the completion of prior antecedent (principal) actions, or the emergence of a change in conditions outside the planner's control, for example public opinion or economic factors.

Path-dependency

The property whereby implementation of an intervention either facilitates or prevents the later implementation of other interventions.

Regret

An undesired outcome, typically taking the form of maladaptation.

Robust

The ability of a system to fulfil objectives (perform acceptably) across a wide range of plausible futures. A robust adaptation pathway or strategy can be made up of either/both flexible and robust interventions.

Scenario

Specified (sets of) plausible future conditions in the external environment (social, environmental) that are beyond the planner's control, but which impact the system performance indicators. Scenarios are comprised of drivers and typically anticipate the timing of the emergence of these conditions.

Scenario-dependency

The property whereby the emergence of particular conditions in the external environment (social, environmental) either facilitates or prevents the implementation of interventions.

Shock

A sudden or unpredictable event in the external environment (social, environmental) that affects the performance of the system. Examples of shocks include earthquakes, extreme weather events, and economic crises.

Signal

Measurable indicators that can be used to identify broader changes in the drivers of systemic change.

Stranded asset

An intervention that ceases its usefulness in achieving the planning objectives prior to reaching the end of its design life or achieving its investment return.

Strategy

A single or combination of interventions within the planner's control designed to achieve the specified planning objectives. A strategy can be expressed in the form of an adaptation pathway when the timing of interventions and their sequencing is included.

Transfer costs

Costs incurred in the transition from one intervention or strategy to another. For example, the cost of levee removal when switching to a subsequent strategy of floodplain lowering.

Trend

A gradual change in conditions in the external environment (social, environmental) that affects the performance of the system. Examples of trends include sea level rise, atmospheric CO¬2 concentrations, population growth, or urbanization.

1. Introduction

1.1. Overview

1. Planning for sustainable and resilient flood risk management is dominated by future uncertainty. For coastal areas, current estimates project that future sea levels may rise anywhere between 0.3 to 1m by 2100, before extending out to 1 to 3m by 2200 and even further beyond.[1] Similarly, expectations of future extreme weather suggest that more frequent, intense storms will occur, thereby generating additional uncertainty surrounding the magnitudes and frequencies of future storm surges, coastal erosion and peak river discharges. In the socioeconomic sphere, uncertain future changes in population growth and distribution, as well as the economic value of (protected) land also influence levels of risk. Integrated Flood Risk Management (IFRM) planners today are tasked with making infrastructural, spatial planning, land use, and disaster risk management investment decisions that recognize and respect these uncertainties. Decisions surrounding whether to protect or nourish vulnerable coastlines or riverbanks, whether to accommodate or resist the rising water levels or peak discharges, or even the elevation to which any interventions should ultimately be designed can no longer be made with the same degree of certainty previously possible. A new approach to planning is needed, and Dynamic Adaptative Pathways Planning (DAPP) offers an approach that is well suited to managing uncertainty in IFRM planning.

2. This document is intended to provide practical guidance for IFRM practitioners when applying the DAPP adaptive planning method. Many journal articles have been published about DAPP; this guidance serves to help fill the gap between the theory of DAPP and its application. In this chapter we briefly describe the DAPP method and when it is needed. The remaining content of this guidance note is as follows. Chapter 2 addresses uncertainty in risk drivers (like sea level rise) and their relevance to planning, Chapter 3 walks the reader through the steps of DAPP, focusing on the aspects that differ from more traditional approaches, Chapter 4 discusses different levels that DAPP can be applied depending on need and resources, Chapter 5 focuses on stakeholder engagement in the DAPP process, Chapter 6 walks the reader through an example application, and Chapter 7 summarizes the key take-home messages from this guidance for the reader.

1.2. Who is this guidance for?

3. This guidance is intended for ADB project officers and Developing Member Countries (DMC) partners who are faced with strategic IFRM planning questions exhibiting the features identified in the previous section. Specifically, the intention of the guide is to provide clarity on (1) under which conditions they should implement a DAPP analysis and develop an adaptive plan, and (2) the key activities and tasks which should occur during these analyses in the development of the plan. The information presented in this guide is intended to assist project officers and DMC partners to specify, manage, and actively participate in projects applying DAPP, and to engage and manage others to undertake these types of analyses. Where possible, references to additional resources have been provided as footnotes if additional details on specific tools or approaches are needed. These are all also collected at the rear of this guidance (see References).

[1] IPCC, 2019

1.3. What is DAPP?

4. The Dynamic Adaptive Pathways Planning (DAPP) approach[2] is a method for planning under uncertain future climatic or socioeconomic conditions that falls under the broader umbrella of decision making under deep uncertainty (DMDU)[3]. It is a generic and flexible planning approach that can be applied across a variety of problem domains, including coastal, river and urban IFRM. DAPP allows planners to identify short-term no-regret actions and be prepared for actions needed in the mid- to long-term as the future unfolds. A key feature of DAPP is adaptation pathways; they show possible sequences of actions over time which ensure planning objectives are continuously met as we move into the uncertain future. The timing when a new or additional action is needed is assessed by monitoring climate and socio-economic trends. There are generally multiple sequences of actions (pathways) that can achieve planning objectives over time; these are visualized in a pathways map, which is a metro-map-inspired infographic showing the shelf-life of actions as conditions (like sea levels or peak river discharges) change. A preferred pathway is selected through consultation with stakeholders and is elaborated by a suite of additional supporting (or enabling) actions. Figure 1 shows an example pathways map with scorecard. Box 1 gives guidance on how to read a pathways map.

5. An adaptive approach like DAPP has considerable advantages over more traditional planning approaches. The adaptation pathways are scenario-neutral, which means they are not tied to any specific scenario, which removes the difficulty surrounding which scenario to consider in the planning. Instead of planning for a specific scenario (or set of scenarios), DAPP works with adaptation tipping points; these indicate the shelf-lives of actions in terms of how much change they can handle while still achieving planning objectives. Essentially, it changes the approach from the more traditional 'will we meet objectives under scenario X or Y?' to 'under what conditions will we fail to meet objectives?' Scenarios are then used to estimate the timing of the tipping points. When a tipping point is reached, a new or additional action in the plan should be carried out. Should the trajectory of the scenarios (for example: sea level rise, population growth, or urbanization scenarios) change or be updated, the planner can adjust the timing of the tipping points but will not need to carry out a new vulnerability assessment. The consideration of decision-making through time offers another advantage of DAPP over more traditional methods. By planning for sequences of measures over time, decision-makers gain confidence that the choices they make today will work in harmony with the choices they may need to make in the future. This ensures no-regret short-term actions and avoids what is known as 'lock-in' situations whereby future options become constrained by short-term decisions or decision paralysis.

[2] Haasnoot et al., 2019

[3] For examples of other DMDU approaches, see Marchau et al (eds.), 2019

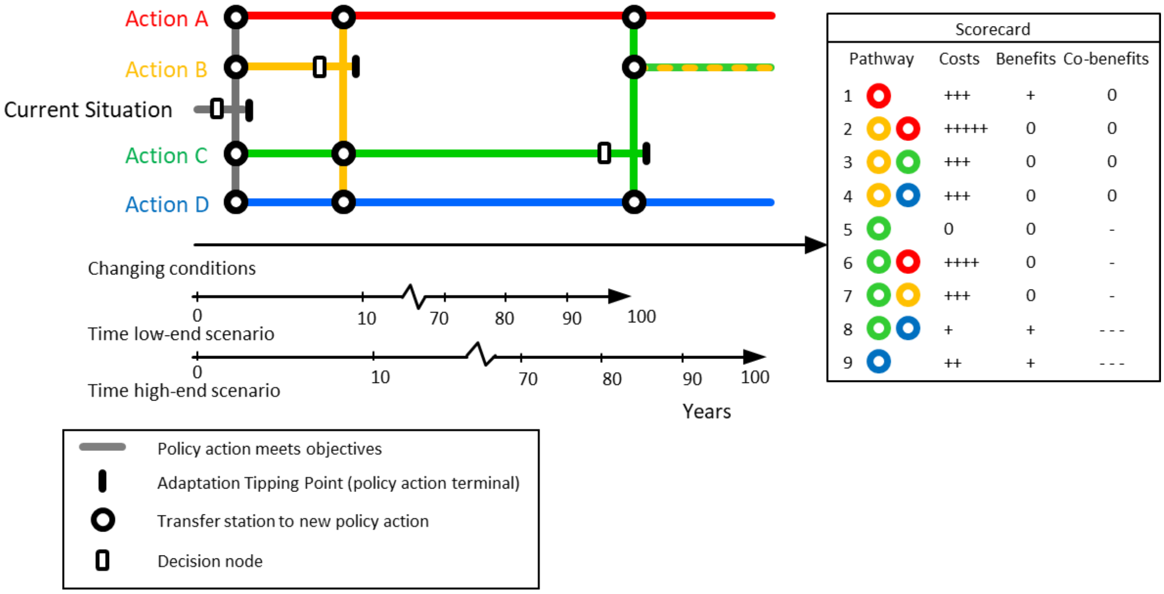


Figure 1: Example of adaptation pathways, illustrating transfer points, tipping points, decision nodes, and a pathway scorecard[4]

6. Adaptation pathways have been used in many adaptive flood risk planning projects, including the Bangladesh Delta Plan, the Dutch Delta Programme in the Netherlands, The UK Thames Estuary 2100 plan, the Hutt River City Centre Upgrade Project in New Zealand, the Assessment of alternative flood mitigation strategies for the C-7 basin in Miami-Dade County, Florida, and for planning and strategic analysis for the Calcasieu Parish-wide watershed in Louisiana. Adaptation pathways are included in the national climate adaptation guidelines in the Netherlands and New Zealand and were recently included in the Sea Level Rise guidance for California.

1.4. When is DAPP needed?

7. The DAPP method is most useful when planning for longer time-horizons (50+ years) and when there are large future uncertainties (like climate change) which have a substantial impact on community concerns (like flood risk). Decisions about which short-term actions to take to mitigate hazards in these cases have the potential to result in regret or maladaptation. This could be a so-called ‘lock-in’ situation, where short-term actions impede the ability to carry out actions that may be needed in the mid- to long-term. Or it could refer to the ‘stranding’ of assets, where the limits to the usefulness of the short-term intervention are reached well before the end of its design life. Short-term actions which are expensive or long-lived, or which are difficult to transition out of, have a greater potential to cause regret in the future. While these types of actions may not necessarily result in undesired outcomes, such potential negative impacts must be duly considered during planning activities and decisions taken with proper justification.

8. DAPP is a strategic planning approach that assists in the comparison of alternatives, and can best be applied during early strategic planning phases, when there are still choices to be made about the various strategic directions to achieve objectives (example: to protect vulnerable assets from flooding, to accommodate flood effects, or to relocate vulnerable assets). DAPP is less suited to later phases of conceptual or detailed design, once a strategy has already been decided. In terms of the ADB project cycle, a DAPP analysis would therefore best initially be completed as part of the TA Concept Paper.

9. To assess whether DAPP is needed in the development of an adaptation plan, four aspects should be considered:

[4] Adapted from Haasnoot et al., 2019

(1) the time horizon of the plan;

(2) the sensitivity of planning objectives (e.g. flood risk) to changing conditions (e.g. sea level rise, peak discharge);

(3) the impact of not meeting objectives (i.e. failure impact);

(4) the potential for lock-in situations or other path-dependencies to emerge.

10. When the time horizon is greater than 50 years, the uncertainty in the future is generally large enough to warrant the use of an adaptive planning approach like DAPP. However, its usefulness also depends on how impactful those future changes could be. For example, if future sea level rise or peak river discharges will have only a minor impact on the flood risk of the community, then the uncertainty present in these parameters is less important to confront. Similarly, it depends on how impactful a failure to meet objectives would be for the community. If it is imperative that the objectives are met, then a method like DAPP – which ensures that objectives are continuously met

Box 1: How to read a pathways map

How to read a pathways map

A pathways map should be thought of as a transit map, showing how to navigate into the future while maintaining objectives. Figure 1 shows an example of a pathways map. The vertical axis shows the ‘transit lines’: these are the options (or actions) that have been assessed. An action may consist of either a single intervention or a portfolio of multiple interventions, which could include both hard and soft infrastructure options. The horizontal axis shows a changing condition (like rising sea levels). In the absence of an overarching single condition, for example when applying scenarios of sets of uncorrelated conditions, the condition axis can be omitted, and time used instead. The small vertical black lines show the end terminal of a line; this is the adaptation tipping point, beyond which objectives are no longer met. At this point, you must transfer to another line. The open circles indicate a transfer from another line onto the current line. For example, in Figure 1, consider a coastal example where Action A is the implementation of a sea wall, Action B is sandbagging vulnerable households during high tide events, Action C is beach replenishment, and Action D is the enforcement of set-back lines. Action A receives three potential transfers. The first would be a transfer from the current situation (grey line), the second would be a transfer from Action B (yellow line) once its tipping point is reached, and the third would be a transfer from Action C (green line) once its tipping point is reached.

There are two types of transfers: one in which the subsequent intervention replaces the first, and one in which it augments the first. A replacement is indicated on the map by a solid color transfer. For example, in the pathway in which Action C transfers to Action A, the solid red color indicates that Action A has replaced Action C. In contrast, in the pathway in which Action C transfers to Action B, the combined yellow/green color indicates that Action B has augmented Action C, which is still in use.

Underneath the pathways map you often see multiple timing axes. This shows the uncertainty in the timing of different scenarios. The conditions at which transfers are needed are relatively certain; the timing is the uncertain aspect. The pathways map helps to clarify and make explicit which information is known, and which is uncertain.

over time – is useful. Finally, if any considered interventions have a high potential to result in future lock-ins or other such path-dependencies, planners may prefer to use a method like DAPP to gain greater insight into lock-in situations and how to avoid them. Figure 2 outlines a decision aid that planners may apply to help in determining the usefulness or otherwise of applying DAPP for adaptation planning.

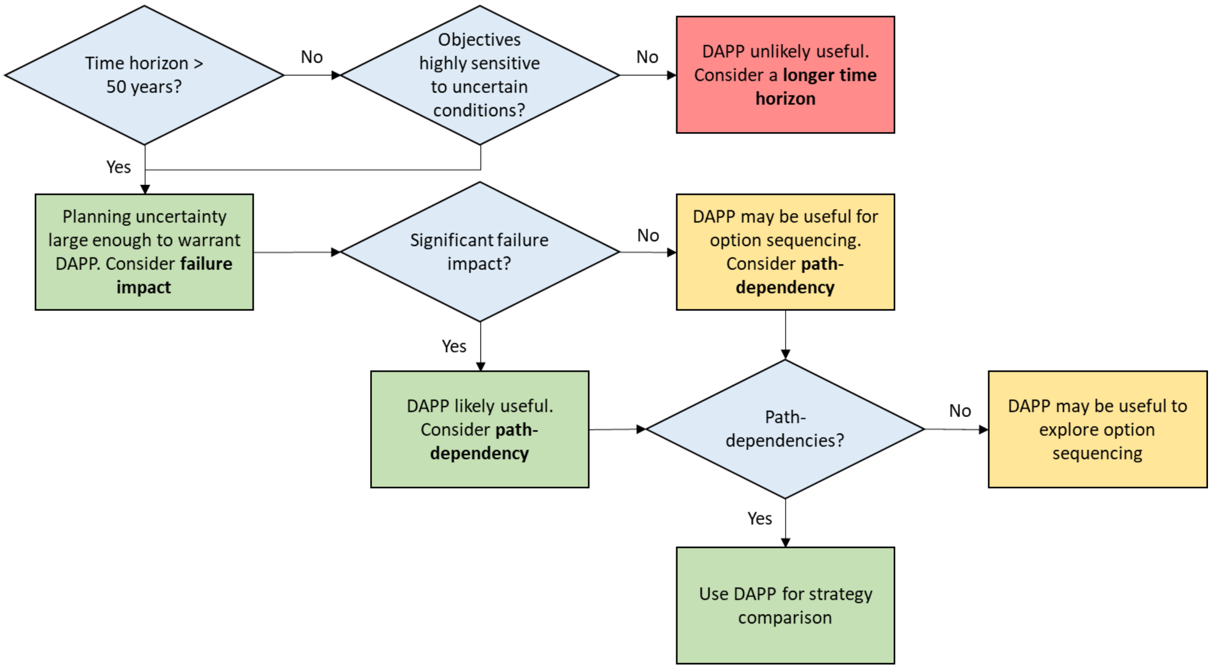


Figure 2: Decision aid to determine the usefulness of applying DAPP for adaptation planning

11. Further guidance on determining whether DAPP is the right approach is provided in the following chapter (Chapter 2).

2. Uncertainty and the Relevance to Planning

12. There are many uncertainties involved in flood risk analysis and adaptation planning. Some of these uncertainties are related to incomplete knowledge and may be remedied through additional research, like establishing the roughness of a riverbed or the ground-floor elevation of houses. Some uncertainties are irreducible and relate to natural variability, like the maximum annual rainfall or water level for a given year. While other uncertainties are more ambiguous, like those regarding how the future will develop in terms of its climate, sea level rise, economic growth, population growth, or land use. Uncertainties also manifest as either shocks (as in the case of tsunami, cyclones/typhoons or extreme rainfall) or stresses (like sea level rise, population growth).

13. In the early phase of the planning process, it is important to consider all potential sources and types of uncertainty that may affect planning objectives. Where possible and practical, the task of reducing any reducible uncertainties can then be undertaken should these factors be expected to significantly influence the planning decision. The type of planning approach will depend on the level and impact of the identified uncertainties. Figure 3 shows an uncertainty-impact matrix, which can be used to organize the different sources of uncertainty according to their level of uncertainty and the impact they have on planning objectives. The matrix can then be used to help determine what type of planning approach is needed. Each quadrant of the matrix is associated with a different type of strategic planning approach. A description of which types of strategies are recommended for the different quadrants can be found following Figure 3.

14. Preparing the uncertainty-impact matrix can be done using a qualitative rating system, where the uncertainty and the impact of future drivers are rated on a simple scale. Here it is important to apply a scale that sufficiently highlights the main differences between the various drivers, while not becoming too unwieldy (for example, a scale of 1-6 may be sufficient). Drivers exhibiting greater uncertainty or increased impacts are rated higher than their more certain or lower impact counterparts. Figure 4 shows how qualitative scores ranging from 1 to 6 are used to assign uncertain factors to the different quadrants of the matrix.

15. In cases where uncertain factors have a high impact and are also highly uncertain, adaptive planning methods like DAPP are particularly recommended. A common example of such a factor is sea level rise for future climate, for which future projections (timing and magnitude) are very uncertain, and which often has a large impact on flood risk. Adaptive planning methods are appropriate in these situations because they are designed to develop adaptation plans that are both flexible and robust. Flexible means that a plan can adapt to changing conditions and robust means that it will be effective under a wide range of future conditions (Box 2).

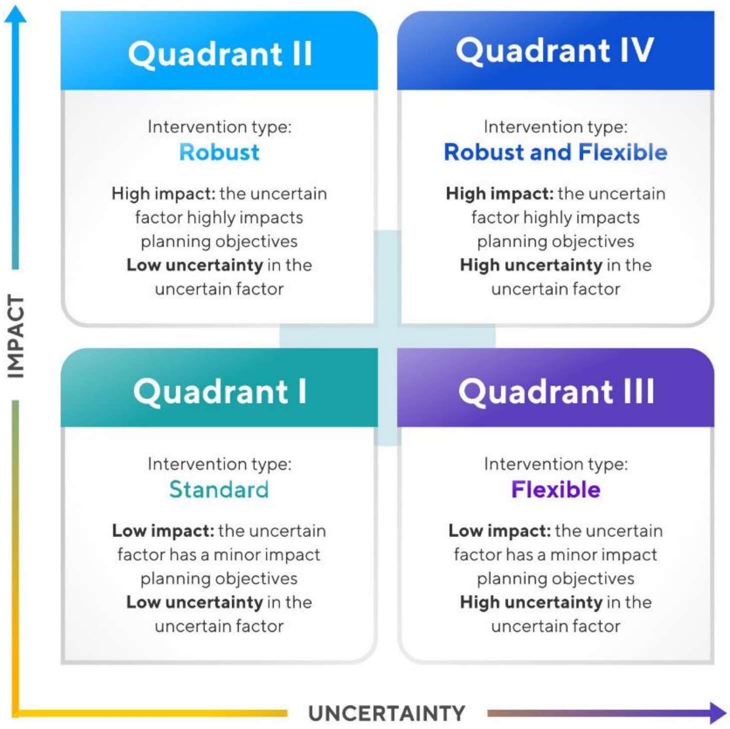


Figure 3: An uncertainty-impact matrix is used to analyze and prioritize uncertainties and help determine the type of planning approach needed.[5]

16. The four quadrants of the matrix are used to indicate broad strategic directions for potential interventions. A general guideline is:

- **Quadrant I: standard interventions** following existing planning and design guidelines will typically apply, as both the potential impacts and degree of uncertainty in outcomes is low.
- **Quadrant II:** typically, **robust interventions** will be needed due to the relative confidence in the occurrence of future high impact events (particularly shocks).
- **Quadrant III:** the low to moderate potential impacts from system stressors suggest that more **flexible interventions** are required. These will allow gradual changes to be made to the system in line with the conditions as they emerge.
- **Quadrant IV:** a mixture of both **robust** and **flexible interventions** needs to be considered. The overarching strategies will need to be robust enough to mitigate future high impact shocks or trend-based stresses, but also flexible enough to permit potential changes in strategic direction given the deep uncertainty surrounding the emergence of these conditions.

[5] Figure adapted from CRIDA. Mendoza et al., 2018

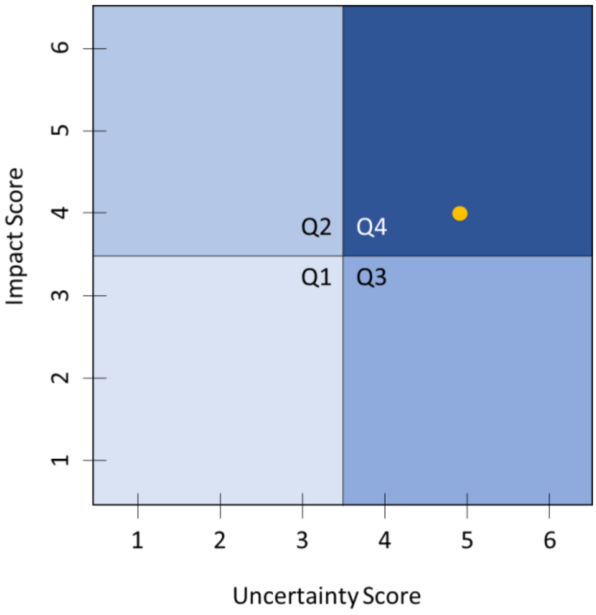


Figure 4: Uncertainty-impact matrix using qualitative uncertainty and impact scores. In the illustration, a driver with an uncertainty score of 5 and an impact score of 4 is plotted and falls within the fourth quadrant (Q4).

17. DAPP is well-suited for situations where there are highly uncertain drivers which have a large impact on the planning objectives, which is indicated by **Quadrant IV** and (to a lesser degree) by **Quadrant III** in Figure 3. This type of situation requires a plan that is flexible/adaptive, robust, and avoids regret in short-term solutions.

Box 2: Flexibility and robustness of adaptive plans

Flexibility and robustness of adaptation plans

Flexibility is the ability to adapt to changes in the future. Within the pathways, this refers to the ability to easily up- or downscale interventions, combine interventions, or switch from one intervention to another. Some interventions may be particularly well suited for this, such as nature-based solutions, which can also dynamically grow and adapt to changing conditions. Similarly, a coastal or river embankment that is constructed with a wide berm to facilitate its later raising of the crest (if needed) is another example of building future flexibility into our present-day solutions.

Robustness is the ability of the plan to achieve the planning objectives for the entire range of plausible futures. A robust adaptation pathway or strategy can be made up of either/both flexible and robust interventions.

3. The Stepwise Approach of DAPP

3.1. The DAPP methodology

18. The DAPP methodology is broken down into seven steps, which are shown in Figure 5. This chapter walks the reader through these steps, focusing on aspects that are different from traditional planning approaches.

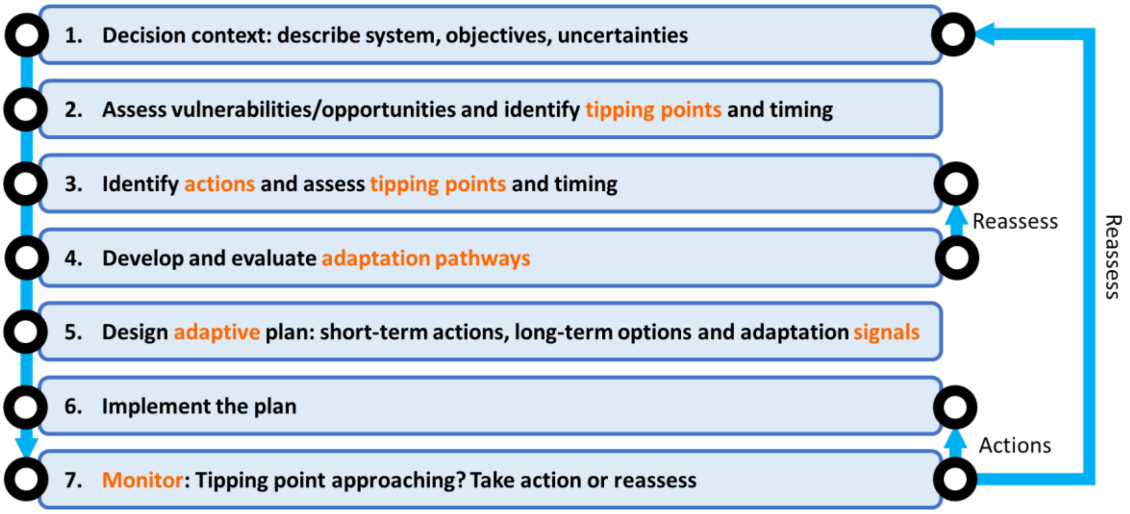


Figure 5: The steps in the DAPP methodology[6]

3.2. Decision context

19. The decision context step is concerned with gaining an understanding of the system and the context, as well as identifying **key uncertain drivers, planning objectives, and pathways evaluation criteria**.

20. The key uncertain drivers are those that are highly uncertain and have a high impact on planning objectives. During the decision context phase, the range of values to be considered for these drivers in the analysis should be selected, based on future scenarios. The ranges should be chosen so that they sufficiently cover both the observed historical record and any future projections (for example from climate models). Extreme drivers should exceed the magnitude of most forecast data, provided they remain theoretically possible. A range that extends some way beyond the highest projection is advised, to accommodate future changes in the projections. For example, if the planning period is 100 years, and the highest projected sea level rise in 100 years is 1.5 m sea level rise, it would be advisable to take the range out to 2 or 2.5 m sea level rise. In the future, when new projections come out, the highest 100-year projection may increase beyond 1.5 m. Taking the range out far enough ensures that no new analysis will be required when projections shift in the future.

21. Specifying planning objectives is the act of defining 'success' and makes explicit what the adaptation plan is trying to achieve. The objectives are essential for assessing the effectiveness and longevity of potential actions in building system resilience. Outcome objectives are often lofty and qualitative ('we want to keep our community safe') but need to be made concrete so that they can be formulated into quantifiable **output objectives**. For example, an output can be a desired maximum flood risk or maximum inundation frequency. These are further elaborated with relevant

[6] Adapted from Haasnoot et al, 2019

performance indicators, which is what will be calculated in the vulnerability assessment. Examples of performance indicators are expected annual damage (for risk-based outputs), or number of houses flooded within a specified period (for inundation frequency-based outputs).

22. Evaluation criteria encompass all important considerations outside of the key outputs. For example, the key output objective may be to keep flood risk below a certain threshold. This objective will be used to develop adaptation pathways that ensure this objective is always met. Other important criteria, such as (i) economic (CAPEX, EIRR, BCR), (ii) safeguards (environmental, involuntary resettlement and indigenous peoples), and (iii) gender elements, are considered in the final evaluation of the different adaptation pathways. In the decision context phase, stakeholders can be engaged to come up with the set of potential criteria to be used later to evaluate the pathways.

23. The remainder of the tasks that fall under this step have to do with gaining understanding of the system and context, including any constraints (such as regulatory limits) that may impact the feasibility of adaptation options. Questions that should be answered in this process are given below, with examples.

    - What are the core problems we are trying to address?
        - Example: stormwater flooding, flash flooding
    - What do we know about the problem?
        - Example: what is the current frequency of flooding? Where is flooding most problematic? What are the main causes and consequences of the flooding?
    - How do we measure when our system is performing acceptably? What are the thresholds for acceptable performance?
        - Example: maximum 1/10 year peak water level; maximum allowable frequency of on-street flooding; maximum allowable flood risk (expressed in terms of expected annual damage)
    - What uncertainties/drivers will exacerbate the core problem?
        - Example: sea level rise, extreme weather (magnitude and frequency), population increase, subsidence
    - How uncertain are these drivers?
        - Example: how much spread is there in potential future states of these drivers? How best can we establish this? Is there lack of consensus on the future state of these drivers?
    - What other criteria will we use to evaluate the available options/pathways?
        - Examples: cost, environmental impacts, impacts on gender or other safeguards, other co-benefits or negative externalities
    - Are there any outside influences on the problem?
        - Example: are there larger or nearby initiatives that may impact the flooding or raft of mitigation measures available, like a nationwide sediment management plan, or an upstream solution that impacts local flooding?

24. These questions are best answered in a stakeholder engagement workshop with representatives from all relevant agencies that are knowledgeable on either the system, the context, or the uncertain drivers influencing the problem.

25. The information collected in this step will feed into Step 2. In that step, scenarios will be developed to assess the timing of the most relevant uncertain drivers that were collected in Step 1. Further, the vulnerability assessment will determine at which point in the future the planning objectives defined in Step 1 will no longer be met if no action is taken.

3.3. Scenario development & vulnerability assessment

26. The vulnerability assessment in the DAPP method shares many similarities with traditional methods. The key difference is that it assesses how the system's resilience, vulnerability or risk changes as the uncertain driver(s) change, and under which conditions the planning objectives are no longer met. This is called an adaptation tipping point or adaptation threshold. This is the point beyond which a new action is needed to ensure the planning objectives continue to be met. The timing of tipping points is derived through scenario analysis.

27. There are different levels at which system resilience, vulnerability and risk can be assessed, depending on resources. DAPP can accommodate both qualitative and quantitative assessments. Most simply, it can be done qualitatively in stakeholder workshops, during which information is elicited from knowledgeable stakeholders. This section describes more quantitative methods, which can be performed following the stakeholder-driven qualitative assessment. Different levels of qualitative/quantitative analysis for the DAPP method are described in more detail in Chapter 4.

28. Figure 6 shows an example of a tipping point analysis. In the example, the changing condition that is being considered is sea level rise, and the objective is a risk threshold that should not be exceeded. The illustration shows the risk increasing as sea level rises; the red star indicates the sea level rise at which the risk threshold is exceeded. This sea level rise is the adaptation tipping point. In this case, it is a tipping point based on a condition (sea level rise). Scenarios can then be used to determine the potential timing range for these conditions to occur.

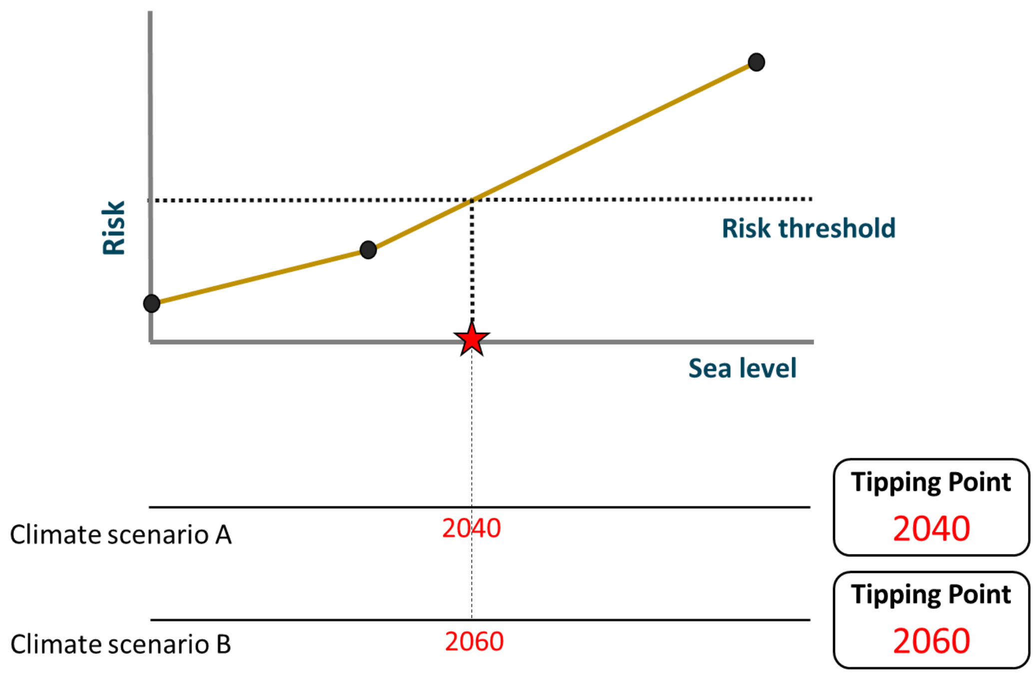


Figure 6: Illustration of a tipping point analysis

29. There are various approaches available to undertake the vulnerability assessment. For example, stress tests can be performed to gradually stress the system with incremental changes in the uncertain drivers until failure conditions are reached. Alternatively, semi-static assessments can be

carried out for (limited) sets of future conditions with tipping points derived through interpolation (example Figure 6). Fully transient analyses using continuous time series are also possible; however, these rely on the availability of (multiple) scenario time series for the development of the uncertainty condition.

30. When more than one uncertain driver is important, the analyst needs to consider how best to include these in the tipping point analysis. Several approaches to include multiple drivers are available. One way to understand the combined impact of multiple drivers on planning objectives is using response surfaces. These are often applied in climate studies where impacts of both temperature and precipitation changes must be considered[7], but they can also be used for other drivers. In this approach, the analyst calculates the output indicator (example flood risk) for multiple combinations of the drivers to identify which combinations lead to ‘failure’ (or unacceptable system performance). Figure 7 shows an example of a two-driver assessment of risk, with the risk threshold indicated in the form of a simple contour plot. Scenarios can then be overlaid on the response surface to determine/estimate the timing of the combinations for which the threshold is exceeded.

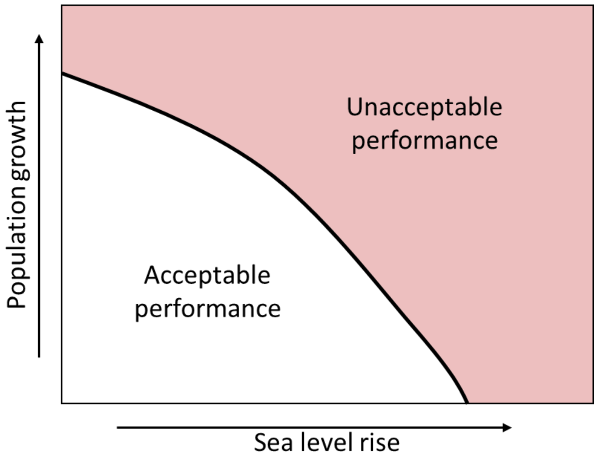


Figure 7: Example of a decision-scaling approach in which the failure to meet objectives are assessed for multiple drivers. Shown is an example for sea level rise and population growth as drivers, and 'risk threshold' as a tipping point threshold.

31. A second option is to identify and select the most impactful driver to estimate tipping points and use the other driver(s) to derive bounds on those tipping points. Figure 8 shows an example where both sea level rise and precipitation are considered. The main driver is sea level rise, but tipping points are calculated for three precipitation scenarios. In this example, higher precipitation levels will stress flood defenses further. The lower plot shows how this translates into bounds on the tipping points in a pathways map. Such an approach can indicate how important non-primary driver(s) can be to the tipping point estimate.

[7] Refer to Brown et al, 2019

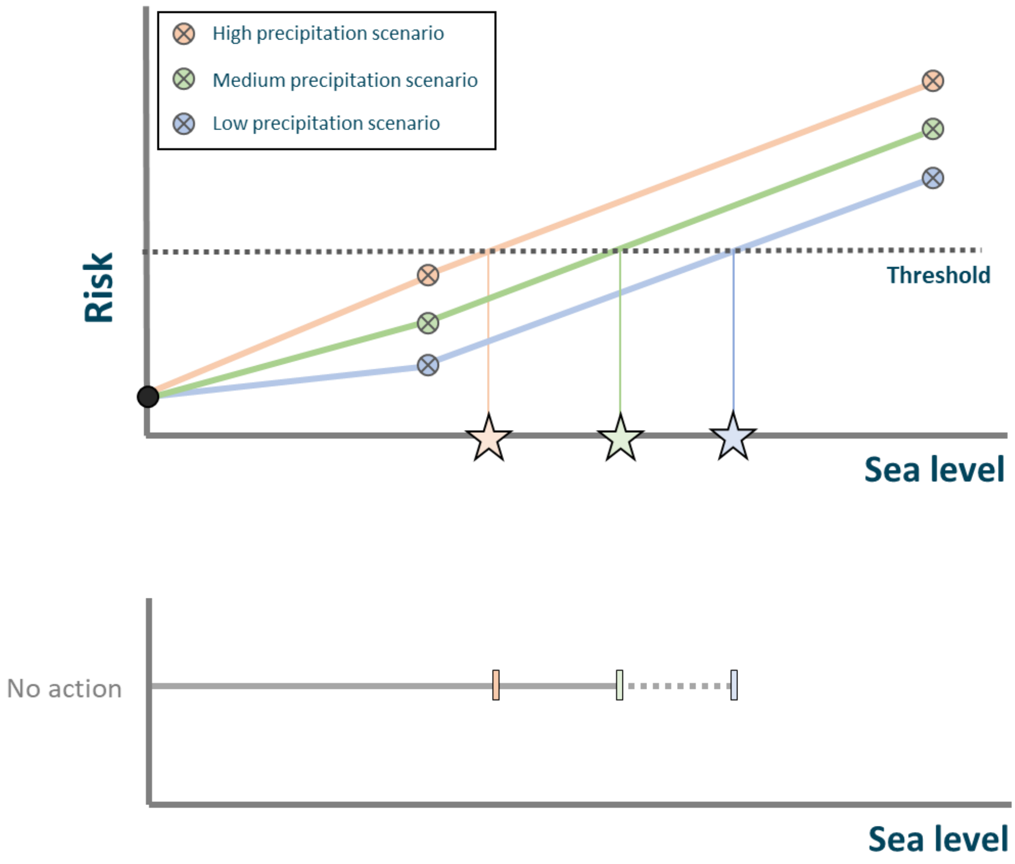


Figure 8: Illustration of a tipping point analysis with more than one driver – bounded tipping points

32. Another approach is to consider combinations of drivers and use the timing estimate for these combinations (based on scenarios) to derive combined tipping points. The example in Figure 9 shows combined sea level rise and population growth. In the example, the risk with a low population growth projection and a low sea level rise projection is calculated for different time steps (blue line), and similarly for the high sea level rise and population growth projections (orange line). The advantage of this approach is that it is generally more intuitive to combine drivers to determine adaptation thresholds, and it is easier to manage when there are more than two drivers.

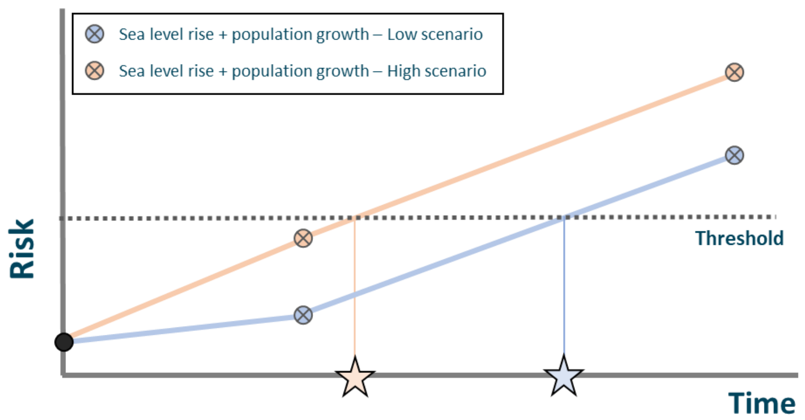


Figure 9: Illustration of a tipping point analysis with more than one driver – combining drivers.

3.4. Options identification and assessment

33. In this step, an inventory is made of possible adaptation interventions that can help meet objectives and build system resilience in the immediate and short-term, as well as in the mid- to long-term as conditions change. It is important to explore a wide range of interventions that represent the diversity of stakeholder perspectives, include both structural and non-structural actions, and address any impacts from cascading effects. The inventory should also include some out-of-the-box and long-term options to ensure that shorter-term interventions do not prevent the potential long-term options from being implemented later. Adaptation interventions can meet planning objectives by addressing the hazards (example installing upstream retention) or the exposure and vulnerability of the population (example early warning systems or home elevations). Once possible interventions have been inventoried, these can (if desired) be grouped into portfolios (or programs), which represent a set of interventions. This is useful when interventions are to be implemented concurrently, or when many (smaller) interventions of a similar type are being considered. For example, a flood risk mitigation program may consist of both ‘hard’ and ‘soft’ interventions including flood barriers, early warning systems, land use controls and/or nature-based solutions. Various programs could be assembled for assessment that consist of different configurations of constituent interventions.

34. Once an inventory is made, the interventions need to be assessed for their effectiveness over the planning horizon. There are two main metrics for the effectiveness of an intervention. One is the benefit of the intervention over time, often in terms of risk reduction. This metric is important for carrying out benefit-costs analysis to ensure a return on the investment in the intervention. The second metric is specific to the DAPP method and relates to the satisfactory fulfilment of the output objective(s). It is the adaptation tipping point of an intervention (or combination of interventions), which indicates how far into the future the intervention(s) will continue to meet planning objectives. The tipping points of interventions are assessed using the same qualitative or quantitative methods as were applied in the vulnerability assessment in the preceding step.

35. In addition to assessing the relative effectiveness of each of the interventions, it is also useful to consider the following when cataloguing available options, either to serve as initial screening criteria or for use in pathways formulation and evaluation (step 4):

    - Cost of intervention
    - Any implementation/lead time considerations which could impact their delivery or ongoing performance
    - Any potential ancillary benefits or costs (negative impacts) resulting from the proposed intervention.

36. Some interventions may also be dependent on favorable conditions (or opportunities) emerging before it becomes possible to implement the intervention. In some cases, these are the completion of prior path-dependent actions, such as the removal/relocation of vulnerable households in floodplains that then offer the potential for future floodplain works like floodplain lowering. In other cases, they refer to a change in conditions outside the planner’s control, such as public opinion or economic factors, that render previously less-feasible interventions more feasible. An example could be a flood event, whereby previously complacent homeowners come to see the value in relocating their properties from vulnerable areas. Or the economic value of vulnerable land and assets reaching levels that warrant investment in more-expensive, robust options. For opportunities outside the planner’s control, it is important to be aware of the conditions that may lower implementation barriers so that these can be monitored and planners can capitalize on the opportunities when they arise.

3.5. Developing and evaluating adaptation pathways

37. The main ingredients in the development of adaptation pathways are the interventions and their adaptation tipping points. Each potential adaptation intervention should be plotted in the pathways map (see Figure 10, and Box 1), with the length of each path indicating the amount of time (or changing condition) before a tipping point is reached. Implementation lead times or (known) opportunity points can be expressed by delaying the start of any paths until the necessary pre-conditions such as preceding interventions are met (not shown). Figure 10 illustrates an example of the individual interventions to manage flood risk in a pathways map for a fictitious drainage basin, with the tipping points expressed in terms of sea level rise.

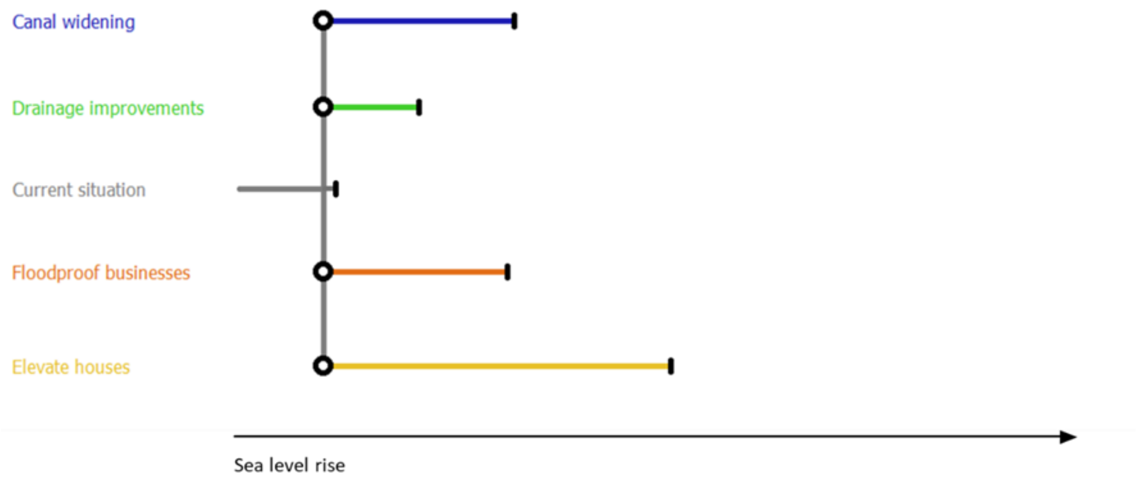


Figure 10: Example of individual interventions in a pathways map; the length of the path indicates how long the intervention will meet planning objectives before reaching the tipping point (in this example in terms of sea level rise).

38. Developing a pathway means combining and sequencing the considered adaptation options into logical arrangements, which is best achieved with the involvement of stakeholders. As each additional intervention is included in a pathway, the new tipping point is ascertained either via: (1) replacement, when an intervention is directly substituted for a new one, or (2) determining the combined effects of two (or more) interventions, when previous interventions are augmented with new ones. In the latter case, new tipping points can be estimated via expert elicitation or more accurately derived from additional model simulations of the intervention combinations. In Figure 11, a simple process of adding tipping points has been used, but it is important to note that this will not apply in all situations.

39. Different factors can affect the sequencing. Some key considerations include: (1) implementation time, (2) permitting requirements, and (3) available financing. These considerations guide the development of feasible sequences of interventions as well as determining if there are any (known) opportunities that can be exploited. The mechanics of how to draw the pathways map, with transition nodes (or transfer stations) and tipping points, is explained in Box 1 (see Chapter 1). Figure 11 illustrates an example pathway composed of the measures shown in Figure 10. In this example, drainage improvements are first implemented, followed by canal widening. Once the combination of those two hazard-reducing measures reach their tipping point, local businesses are floodproofed, after which residential houses are elevated. Such a pathway might be based on considerations of the need to allow time to build consensus and arrange the necessary financing for the floodproofing and elevation measures.

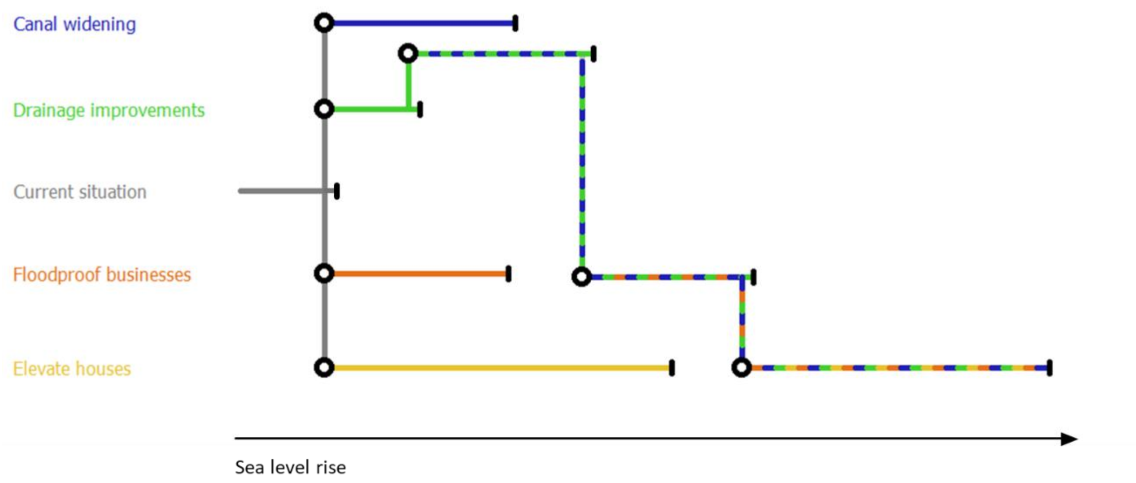


Figure 11: Example of a single adaptation pathway, made by sequencing the individual measures.

40. In addition to transition nodes and tipping points, the pathways map can be used to indicate when a decision must be made so that the implementation of the next action occurs before a tipping point is reached. This ensures that the planning objectives are continuously met. A decision point (Figure 1) can be determined by estimating the necessary lead-times for any permitting, financing, and implementation considerations for each option.

41. Creating pathway maps can be performed with any drawing software but is greatly assisted by making use of the freely-available Pathways Generator tool[8]. This tool allows the user to specify measures, tipping points, and sequences in a simple user interface, and then draws the pathways using a consistent visual symbology. Alternatively, pathways can be developed and explored directly using models (e.g. agent-based or multi-objective robust optimization models[9], serious games[10]), or more qualitatively during stakeholder focus group discussions[11] or a combination of model-based and group discussions. These different approaches again reflect different levels of analysis, which are described in more detail in Chapter 4.

42. Evaluating adaptation pathways can also be performed at different levels of analysis, from a qualitative scorecard (Figure 1) or multi-criteria analysis (MCA) to more quantitative methods such as cost-effectiveness or cost-benefit analysis. In addition to evaluating the relative costs and benefits of the pathways, additional benefits can also be considered in the evaluation, such as safeguards (environmental, involuntary resettlement and indigenous peoples) and gender elements. Other considerations that are important in the evaluation of the pathways are: path-dependencies that could result in lock-ins, the relative flexibility and robustness of the pathways, any transfer costs (to transfer from one intervention to another)[12], and the potential for maladaptation. (see Box 3).

[8] Pathway generator available from https://publicwiki.deltares.nl/display/AP/Pathways+Generator

[9] Kwakkel et al., 2015

[10] For relevant examples, refer to Lawrence and Haasnoot, 2017, and Lawrence et al, 2019.

[11] For relevant examples, refer to Campos et al, 2016

[12] Haasnoot et al, 2020

Box 3: Maladaptation

Maladaptation

Maladaptation is when an adaptation action that is intended to reduce vulnerability has the effect of increasing vulnerability or reducing opportunities for future adaptation, despite potentially appearing both technically and financially attractive in the present. Common effects of maladaptation are the transfer of risk to other communities or different sectors within the community and the (unintentional) stimulation of development in flood-prone areas. For example, building high levees around rivers encourages people to build in the floodplains, which are perceived to be protected. As climate conditions worsen and river levels rise, the potential for damages to life and property become much higher. The ability to lower the floodplain also becomes more difficult in the future if the floodplain is more developed. Another example is a drainage pump for upstream areas in a coastal system, to help alleviate stormwater as sea levels rise. However, this can create more risk for the areas downstream of the pump, essentially transferring risk from one area to another. When evaluating adaptation pathways, care must be taken to identify any potential maladaptive pitfalls in the pathways and to properly account for these in the evaluation (for example through the inclusion of transfer costs).

43. Table 1 gives guidance on which type of evaluation method is appropriate for various stages of the planning process, levels of data and time availability, as well as the number of evaluation criteria being considered.

Table 1: Guidance on which type of evaluation method to choose based on time and data availability[13]

	Scorecard	Multi-criteria analysis	Cost-effectiveness	Cost-benefit analysis
Planning phase	Options inventory (e.g. TA Concept Paper)	Options inventory Policy evaluation (e.g. TA Concept Paper, TRTA)	Options inventory Policy evaluation Financing decision (e.g. TA Concept Paper, TRTA)	Policy evaluation Financing decision (e.g. TRTA)
Time requirement	Low	Low-Medium	Low-Medium	High
Data requirement	Low-Medium	Low-Medium	Medium	High
# Evaluation criteria	Low-High	Low-High	Low	Low-High

44. During the earliest planning phases when extensive risk and economic data are likely to be scarce, costs and benefits can be evaluated using qualitative scorecards or MCA with knowledgeable stakeholders. Later, when more data and resources become available and financing decisions need to be made, more quantitative methods can be applied. When applying ‘best-practice’ approaches towards cost-benefit analysis, the benefit is often taken to be the risk reduction. Risk-reduction benefits can be calculated either over time (if the tipping point axis is in terms of time) or over a changing condition like sea level rise. For cost-benefit analysis, typically annual risk reduction benefits are needed. When risk reduction has been calculated over a changing condition like sea level rise, scenarios of how the driving condition changes in time are used to obtain the coincident risk-reduction benefits over time.

[13] Adapted from Schasfoort and van Aalst, 2017

3.6. Action planning

45. Action planning refers to identifying and specifying the necessary preparations for the implementation of the adaptive plan. These can be thought of as the necessary enabling or contingency activities to ensure the viability of the plan in the future. Common activities that could fall under this step in the process include:

- Identifying additional studies, planning or design work to refine the selected interventions in the pathways (e.g. further research, environmental or social impact assessments)
- Identifying needs for any land reservations (for both short- and longer-term infrastructure)
- Identifying needs to update or change regulations or legislation
- Devising clear governance mechanisms and sustainable institutions to implement and monitor the plan into the future
- Planning public outreach, particularly around any contentious elements in the plan
- Establishing funds for (future) compensation to those negatively affected by implementation of the plan.

46. In addition to identifying and planning the necessary enabling actions, an implementation plan is formulated for the short-term actions. This includes determining lines of responsibility for the interventions, including design, construction, ownership and ongoing management oversight. Likewise, (flexible) financing arrangements must be worked out, including any (future) assurance implications.

47. A monitoring plan should also be established[14]. This should specify timely, reliable and measurable indicators to be evaluated on a regular basis that identify when a subsequent action in the plan is needed (adaptation threshold) or can feasibly be implemented (opportunity threshold). These indicators are often referred to as signals, because they signal change in the uncertain drivers (like sea level rise, peak river discharge) or broader system context that indicate implementation of the next action in the adaptive plan must/can occur. There are broadly three different types of signals:

- Trends or events in the physical environment. For example, mean annual sea level, annual incidence of flash floods, annual number of sunny-day inundation events, or the changing composition of shoreline or riverine ecosystems.
- Human-induced trends or events that impact the flood risk. For example, an increase or reduction in population that increases or reduces exposure.
- Changing societal perspectives about the future creating new opportunities for action. For example, acceptance and expectations about future sea levels, peak river discharges and inundation frequency, or a desire to protect and preserve natural environments.

48. It is not always easy to identify the most appropriate parameters to monitor. Stakeholder workshops can be used to suggest relevant signals across the broader system context, while quantitative analyses can test a range of potential signals to identify those that provide the clearest indications of change and potential tipping point timing. Figure 12 (bottom) shows that annual mean dry-season flow is an effective signal for future extreme river discharges. This contrasts with the 1/10-year low flow (top plot), which is a much noisier signal. Effective signals will often be different depending on

[14] Haasnoot et al, 2018

the uncertain driver. Good signals should give an indication of the direction and speed with which a driver is changing.

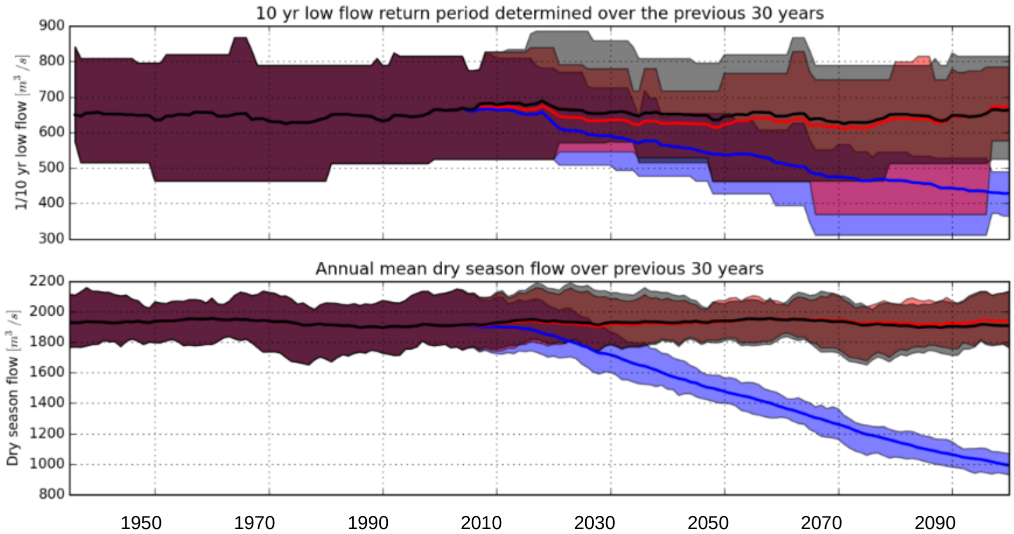


Figure 12: Searching for the right signals using model-based sensitivity analysis. The black line refers to present day conditions, the blue line to a high climate change future and red line to a low climate change future. The shift towards a high or low climate change future is evident much earlier in the bottom figure than the top[15]

49. The preceding information and the earlier steps is then collated together to comprise the complete adaptive plan. This will typically contain the following elements[16]:

(1) A preferred adaptation pathway, including both short- and long-term actions/strategies.

(2) Organizational, financial, and legal directives to implement the actions.

(3) A monitoring plan to keep track of implemented actions and to trigger future action.

(4) An implementation agenda, including budget, project lead-, and preparation times.

(5) An assignment of institutional responsibilities for implementing the components of the plan as well as scheduled updates of monitoring processes.

3.7. Implementation and monitoring

50. With the conclusion of the preceding step, the plan is ready for implementation and can proceed to the next phase of its realization. Short-term interventions can be further detailed and designed, their financing arranged, governance relationships established, and the implementation and monitoring plans enacted. Any supporting actions are also implemented at this time, or subjected to further preparation, as required. Signaling information begins to be collected, and actions are started, altered, stopped, or expanded in response to this information.

[15] Adapted from Haasnoot et al, 2015

[16] Mendoza et al, 2019

4. Levels of Analysis

4.1. Overview

51. The DAPP framework is flexible in its application and is often referred to as ‘fit for purpose’. It can support communities with different needs, budgets, and availability of data and models. DAPP can provide a strong framework for adaptive planning for the case of both scarce and plentiful resources.

52. Levels of analysis refer to a tiered approach to DAPP planning, starting with the most qualitative problem scoping assessments and progressively moving (if desired and possible) towards more quantitative and sophisticated analyses. Figure 13 presents key features of the three levels of analysis; more description follows the figure. In addition to these levels, there is a preliminary ‘Level zero’ which refers to awareness raising. Adaptive planning is still a novel concept, and engagement activities can help stakeholders and the community to better understand and ultimately be more receptive to the adaptive planning approach. Tools to help in awareness raising are addressed further in Chapter 5 about stakeholder engagement.

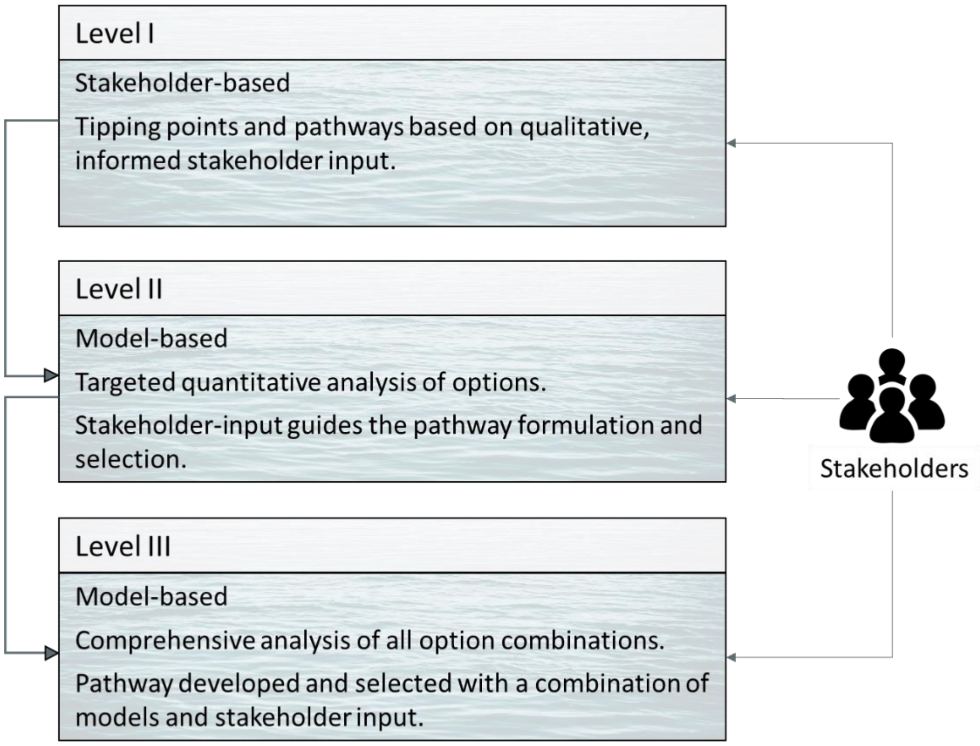


Figure 13: Three levels of analysis, to meet different needs, budgets, and data/modeling resources.

4.2. Level I

53. A ‘Level I’ analysis is a qualitative, stakeholder-driven approach to the steps of DAPP (excluding action planning and implementation) and is highly recommended even when ultimately carrying out Level II or Level III-type analyses. The process may require multiple stakeholder engagement sessions; for example, a first session to elicit information about context, goals and uncertainties, and a second session to elicit information on vulnerabilities, tipping points, adaptation options, and evaluation criteria.

54. Information about the context, goals, and uncertainties is best explored in stakeholder engagement settings. These provide opportunities to explore the different drivers of flood risk and discuss their uncertainty and impacts, having participants identify where on the uncertainty-impact matrix different drivers should be categorized (see Figure 3 for the uncertainty-impact matrix). They also offer an opportunity to discuss and try to reach consensus on potentially differing ideas about the objectives of the plan and how to quantify the objective(s) with indicators. Contextual information such as projects that are already in the planning phase or national plans that may influence the planning objectives and otherwise impact the resilience of the system can also be discussed in this stakeholder setting.

55. A (second) stakeholder engagement session can be organized to explore vulnerabilities, tipping points, and potential adaptation options. If available, previous studies and data like current and future flood or vulnerability maps are very useful for participants to visualize the impacts of future conditions. This can help elicit ideas about when (under what conditions) the identified objectives would fail, and what kind of interventions could be implemented to address the future conditions, improve system resilience and ensure objectives are met. The following information is important to elicit:

    - Which intervention or action should be taken?
    - Where should the intervention or action be implemented?
    - What is the (relative) cost of the intervention?
    - What is the (relative) implementation time of the intervention?
    - For how long (relatively) will this intervention achieve planning objectives?
    - What are any additional benefits/consequences of the intervention?
    - What are potential long-term implications for the sustainability of the intervention (in terms of e.g. resourcing, operations and maintenance)?

56. The questions that ask ‘relative’ information are qualitative and can be performed with simple scoring systems. For example, the participants could be asked “On a scale of 1-5, how expensive is this measure, with 1 being very inexpensive, and 5 being very expensive?”

57. It is important to encourage participants to think of any measure that might be effective in the area, and to consider measures that will work far into the future when hazard conditions might be much worse. Having hazard maps that show such extreme future conditions can be helpful to elicit more long-term solutions. These long-term solutions are imperative to have in consideration to ensure that shorter-term solutions do not prevent them from being implemented later.

58. Figure 14 shows an example of a very preliminary example of a qualitative pathway that was drawn up immediately following a Level I stakeholder engagement workshop.

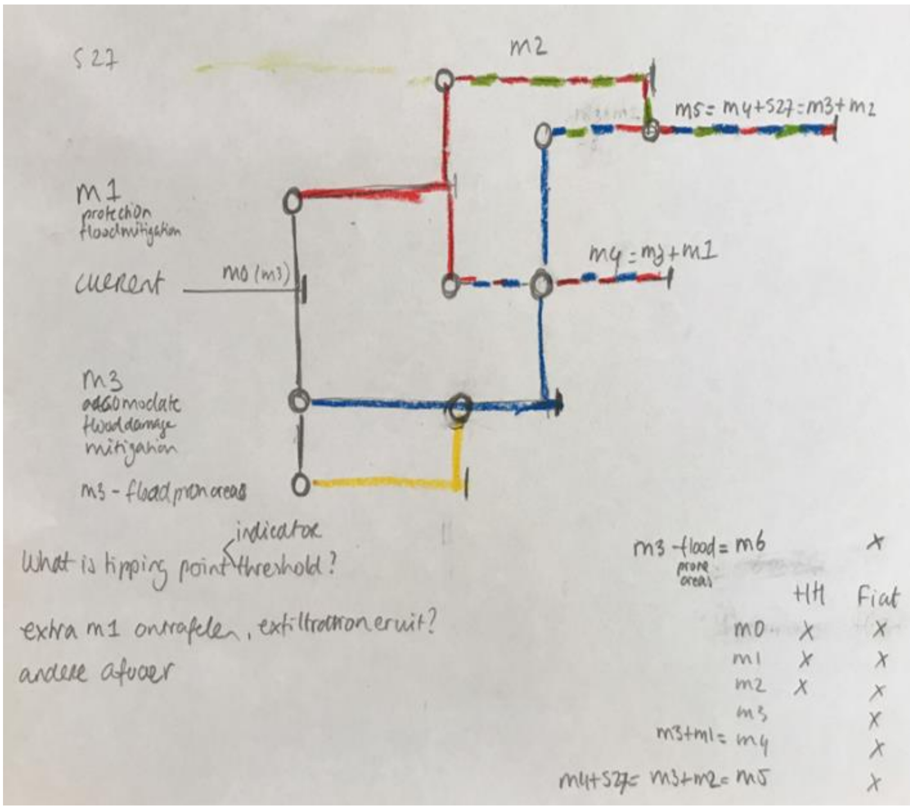


Figure 14: Example of a Level I qualitative pathways map resulting from a stakeholder engagement session

59. The advantage of developing a qualitative pathway, even when ultimately moving towards a more quantitative analysis, is that it scopes the required modeling work. For example, the qualitative pathways will identify combinations of measures that do not need to be considered (for example, because they are not feasible or desirable). This keeps the modeling effort efficient and targeted.

4.3. Level II

60. A ‘Level II’ analysis is the most common level. It refers to a quantitative, model-based approach using existing modelling tools, but one which is typically limited in scope in terms of the number of scenarios and combinations of interventions that it considers, and which does not seek to optimize the selection of adaptation pathways. Level II analyses take the more qualitative outputs from the Level I assessment and quantify and refine the analysis using models. The future vulnerability or risk due caused by drivers (like sea level rise, flash floods) are calculated to determine adaptation tipping points, both with and without (combinations) of interventions. This data is then used to manually develop the adaptation pathways and action plan. Pathways evaluation processes during this level of analysis can blend both qualitative and quantitative data sources. Costs and benefits may be formally calculated based on quantitative data, while the determination of any additional benefits or consequences may remain more qualitative in nature. Hence, the development and evaluation of the pathways is still performed in close collaboration with stakeholders in a Level II analysis.

61. Figure 15 shows an example of a computational framework for a Level II analysis. In this example, a hazard and damage model are set up to evaluate flood risk for different adaptation options under different climate and socio-economic projections.

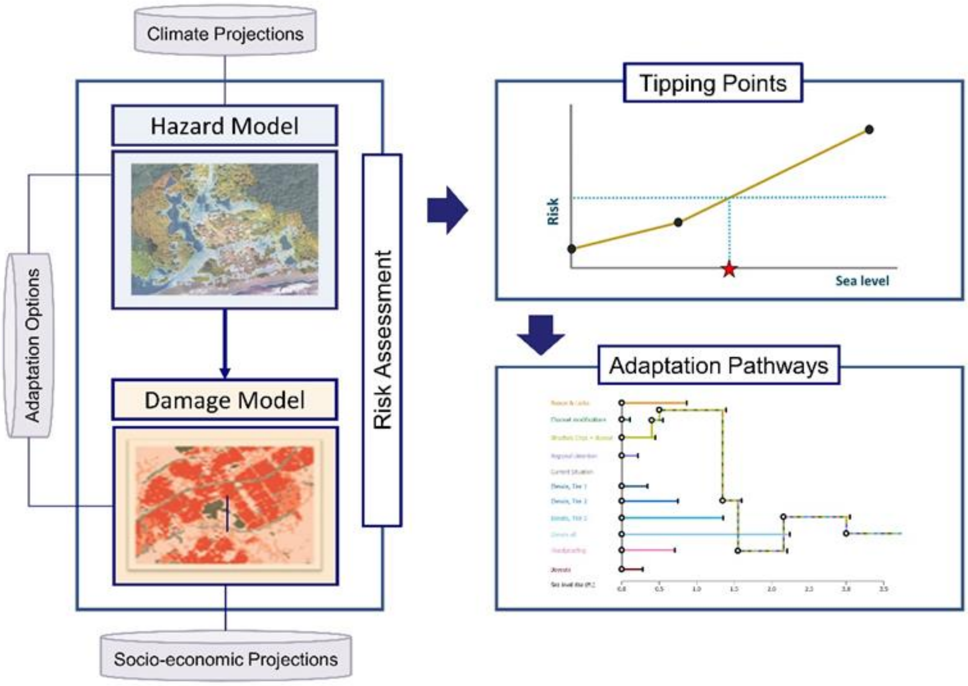


Figure 15: Schematization of a Level II quantitative approach to developing a pathways map

62. In many cases, the outputs from a Level II type analysis will be sufficient to proceed with the remaining planning activities and implementation. This is particularly the case in instances when the complexity of the problem is not too great and the outputs from the models provide clear indication of the strategic interventions to implement. Two exemplary applications of DAPP, the Dutch Delta Programme[17] and the Thames Estuary 2100 study[18], are examples of Level II-type analyses.

4.4. Level III

63. 'Level III' analyses are necessary for complex planning questions for which specialized modelling tools are typically required. In these types of analyses, the aim is to capture the full dynamics of the system and the uncertainties present. This often calls for the development of customized, integrated modelling tools or metamodels that can explore large numbers of scenario parameter combinations, interventions and pathway arrangements against complex, multi-objective algorithms. Some models can even assist in the (automated) development and evaluation of 'optimal' adaptation pathways through application of optimization functions to determine the most robust pathways against specified evaluation criteria. This is the level of analysis that provides the strongest intersection with other approaches to decision making under deep uncertainty, such as Robust Decision Making[19] and Decision Scaling[20].

64. Note that there is a gradual transition from Level II- to Level III-type analyses that proceeds in line with the level of complexity needing to be represented. Ideally, Level III analyses build upon the outputs from the Level II analysis and are implemented in those instances when the more conventional modelling assessments provide insufficient planning clarity; for example, if any key uncertain drivers or integrated impacts were left unexplored. Level II outputs should nevertheless be used to improve the efficiency of the Level III analysis, for example by defining constraints such that unnecessary or infeasible scenario parameters or pathways may be omitted. Similarly,

[17] Haasnoot, 2013
[18] Ranger, Reeder and Lowe, 2013
[19] Lempert, 2019
[20] Brown et al, 2019

stakeholder engagement retains an important role in this level, as it is important that stakeholders understand and agree to the rationale for the specialized modelling analysis, have helped to define the objectives and assumptions present within it, and possess a level of trust in its outputs to render them credible for planning purposes.

5. Stakeholder Engagement

65. DAPP is intended to be carried out with high levels of stakeholder engagement. This is to not only facilitate participatory decision-making, but also provide important opportunities for capacity building and risk awareness-raising.

66. Initiating a planning process with a Level I analysis ensures that the first five steps of the DAPP procedure are performed collaboratively and with full stakeholder awareness and engagement. The participatory process also provides avenues for ongoing stakeholder involvement throughout subsequent levels of analysis, through to implementation, operation, monitoring and maintenance activities. It thereby serves to foster long-term stakeholder engagement in the management of adaptation interventions. Figure 16 shows potential types of engagement for the different steps of the DAPP approach. Note that these activities can occur during all three levels of analysis.

Figure 16: Stakeholder engagement throughout the DAPP approach

67. There are many types of participation embedded in the DAPP approach. Stakeholder workshops typically include informed members of relevant agencies, such as stormwater, floodplain, or coastal managers, nature conservancy groups, equity groups, local government, regional government, developers and business representatives, as well as community members and organizations. It is important to get a wide cross section of the community to make sure that all perspectives and insights are represented, particularly during activities of problem definition and actions assessment. In addition to stakeholder engagement workshops which aim to involve wide cross sections of the community, smaller focused groups with specialized experts are useful when trying to elicit more technical or specific information, or during the development and application of Level II and Level III modelling tools. Technical working groups and/or advisory groups serve as important mechanisms for both data and planning validation and verification, providing both quality-control and contributing to community confidence in the process.

68. Serious gaming is a playful and engaging approach to learn (or teach) new concepts. Adaptive planning is a new concept for many people, and they may not understand the utility or be receptive to a new planning approach. *Sustainable Delta*[21] is a serious game that has been developed to address this by providing an entertaining and engaging approach to introducing adaptive planning.

[21] Further details on Sustainable Delta can be found at https://www.deltares.nl/en/software/sustainable-delta-game/

6. Example Application

69. This section is intended to walk the reader through an example application of DAPP, from the Level I phase through to the Level II analysis of tipping points and the development and evaluation of an adaptation pathway.

6.1. Background

70. Haikon District is a (fictitious) flat, low-lying coastal area of about 300,000 residents, with increasingly strong economic activity related to the petrochemical industry and shipping. The area also serves as a recreational and ecological magnet, with tourism as one of its main industries. The district has experienced three devastating cyclones in the last half century, but flood risk is also sensitive to more frequent storms due to increases in rainfall, subsidence and rising sea levels. The area has seen a 13% increase in rainfall, and a 25 cm increase in relative sea level rise (sea level + subsidence) over the last 30 years. Furthermore, the area is experiencing rapid urbanization, with a population increase of 15% over the last 10 years and an annual 5% growth in economy. The increase in population and economic activity is increasing exposure to flooding in the district, while the increasing precipitation, sea level and subsidence is increasing the hazard. The increasing development also exacerbates the hazard because it reduces the capacity of the land to infiltrate rainwater.

71. The area is bordered by the Hinghong River, and divided by the Latsou River, both of which are tidally influenced. These two rivers are commercially significant but represent only a fraction of the 2750 km channel network draining the area. These channels all drain into one of the two rivers and represent a source of flooding for residents in the area. When tidal water levels in the two rivers are high, the rivers are unable to properly drain the channel system, leading to backwater flooding.

72. The Haikon District water management council wishes to prepare an adaptive stormwater management plan to both alleviate the current strain on the stormwater drainage system and prepare the area for the future as climate change, subsidence, and urban and economic growth increase the frequency and impacts of flooding against a 2070 planning time horizon. They are particularly interested in applying methods that will allow them to undertake actions to build resilience in the short-term that will not result in later regret, but which also provide a roadmap for future actions depending on how the future unfolds. Given the council's recognition of its long planning time horizon, system sensitivity to the uncertainty drivers, significant impacts of failure and potential path-dependencies present, the council has engaged a consultant to undertake a DAPP planning analysis for the stormwater management plan.

6.2. Awareness-raising and Level I analysis

73. As the governing bodies in the Haikon District are not familiar with the DAPP planning method, a two-day awareness-raising and problem-scoping stakeholder workshop is organized to facilitate stakeholder understanding and acceptance of the method and scope out the parameters of subsequent analysis activities. A serious game, *Sustainable Delta*, is played on the first day to introduce DAPP concepts to the participants as well as serve as an icebreaker for the multidisciplinary group.

74. The second day commences with a Level I assessment. The problem context is discussed in general to ascertain the key policymaking concerns and objectives of the stakeholders in relation to flood risk management. Uncertain drivers are discussed, including both those that impact the

hazard (precipitation intensity and frequency, subsidence, sea level rise, urban development) and exposure (economic growth and population growth) components to flood risk. Stakeholders share their available information on these drivers, pointing to sources of available data from which scenarios of their potential impacts and timing can be later developed. A qualitative assessment is undertaken of the relative level and impact of the uncertain drivers to confirm the appropriateness of DAPP to the decision-making context, and to determine the overarching strategic direction to follow (Figure 17). The outcomes of this assessment suggest that both planning robustness and flexibility will likely be required.

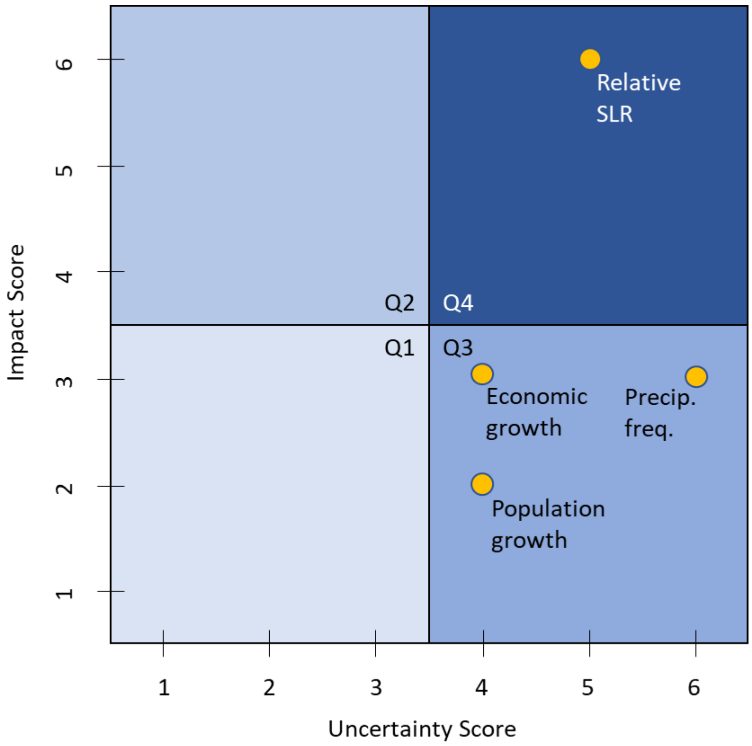


Figure 17: Uncertainty-Impact matrix developed for the example DAPP application

75. Possible adaptation interventions are also discussed during the workshop, with simple pre-prepared flood hazard maps for several potential combined sea level, precipitation, and subsidence futures used to stimulate the discussion. For each intervention, the stakeholders are asked to qualitatively estimate using a score card: (1) how much climate change it can accommodate, (2) its costs, (3) its additional benefits, (4) any enabling conditions (preparatory actions) needed, and (5) its implementation time.

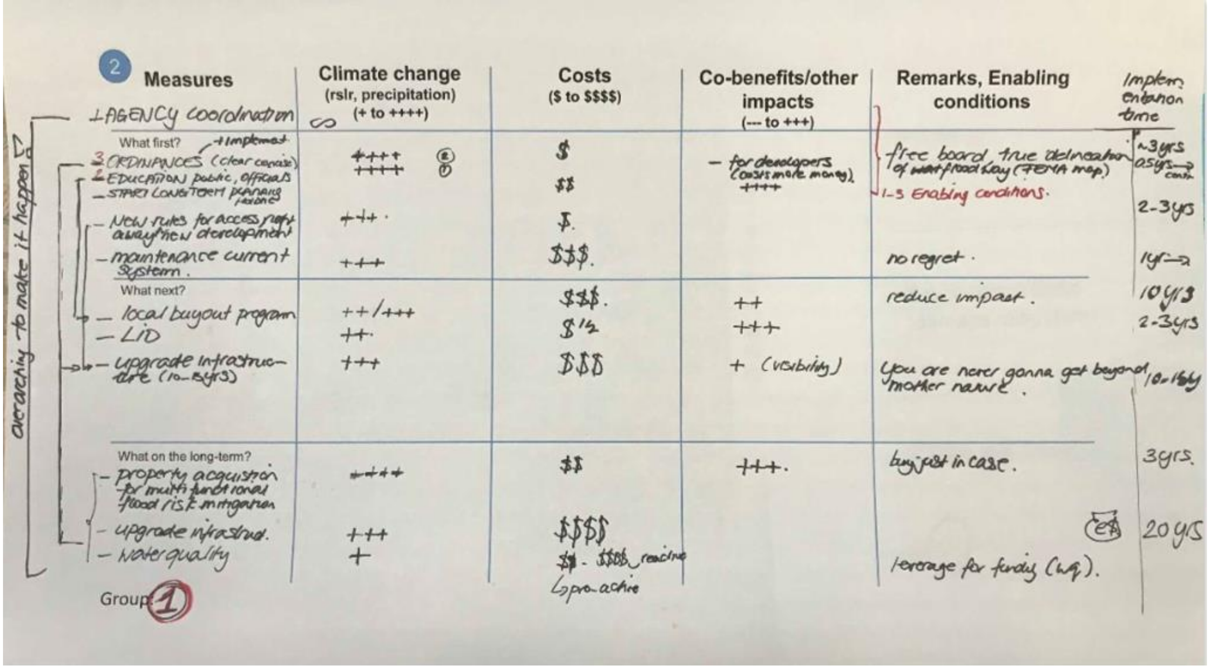


Figure 18: Assessing potential adaptation options in a Level 1 analysis based on stakeholder knowledge. The figure illustrates example outputs from a single group in a multi-group setting.

76. This information is then used to develop a qualitative adaptation pathways map, with the capacity for each intervention and pathway to reduce flood risk expressed relatively on a scale of 1-100 (Figure 19).

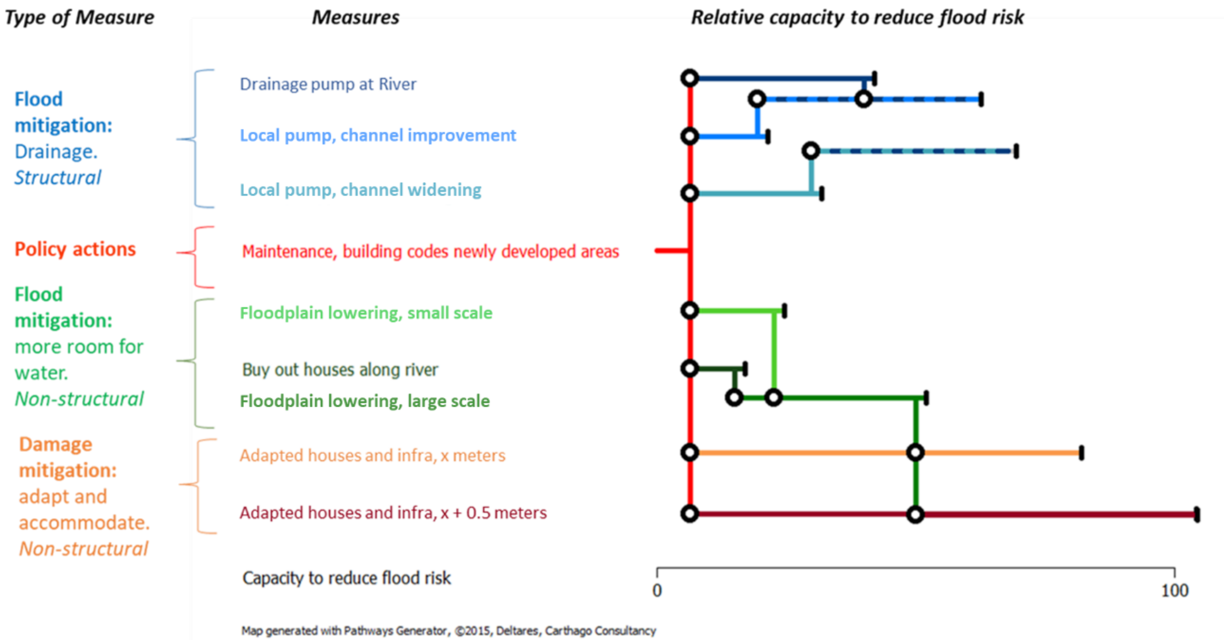


Figure 19: Example of a Level I qualitative pathways map, based on expert elicitation of adaptation options and discussion with stakeholders. The pathway map is an amalgamation of the information in Figure 18 along with that gained from other stakeholder groups.

77. Discussions with focus groups then refine the qualitative pathways into a selection of promising options to be evaluated using an agreed modelling framework. Figure 20 specifies the interventions selected for further analysis.

Figure 20: Set of measures considered in the example DAPP application

6.3. Level II analysis

78. The Level II analysis requires quantitative indicators to measure system performance in terms of meeting its objective. An initial objective is set that 'flood risk should not get worse than it is today' as many stakeholders believe the frequency of flooding is already at a 'tipping point'. The agreed key indicator of this objective is set as Expected Annual Damages (EAD) from flood events. However, this objective and indicator can be fine-tuned at a later stage, if required.

79. A computational framework is formulated and agreed upon, with an example framework relevant to the current application presented in Figure 21. In this example, the analysis consists of a probabilistic flood risk assessment using a hydrodynamic model and a flood damage model and includes a compound flood analysis (storm surge + precipitation). Hazard-reduction actions are represented in the hydraulic model and exposure/vulnerability-reduction actions in the damage model.

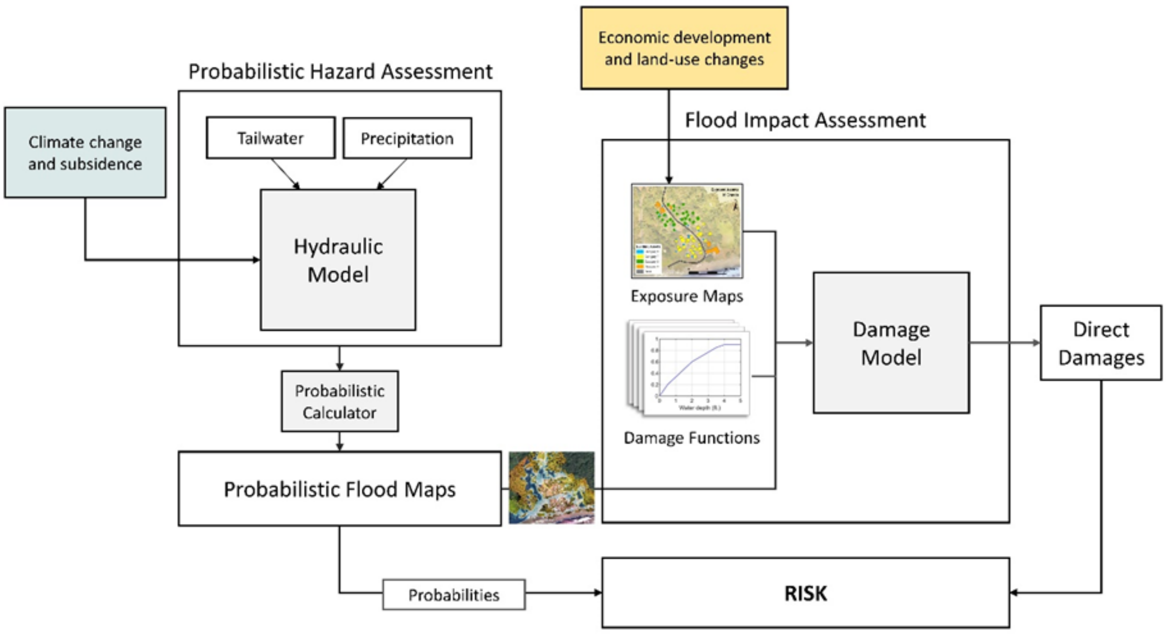


Figure 21: Level II computational framework for the example DAPP application

80. A combination of sea level rise and subsidence (i.e. relative sea level rise) are taken together to be the key uncertain driver in the district. Other uncertain drivers acting on the system include precipitation frequency, population growth and economic growth. Previous studies are used to

ascertain their relative impacts and levels of uncertainty. Relative sea level rise is found to exhibit the greatest potential impact on system performance and, as such, is prioritized in the analysis.

81. Flood risk is then calculated using the computational framework for several values of (increasing) relative sea level rise in the form of a stress test. Present-day risk is taken as the adaptation threshold. The model results are used to determine the relative sea level at which flood risks (with each adaptation intervention) exceed current-day risk. Figure 22 shows the tipping point analysis for the intervention ‘pumps and locks’, and how the tipping point translates to the ‘end terminal’ of the measure in the pathways map. A similar procedure is followed for each of the remaining interventions.

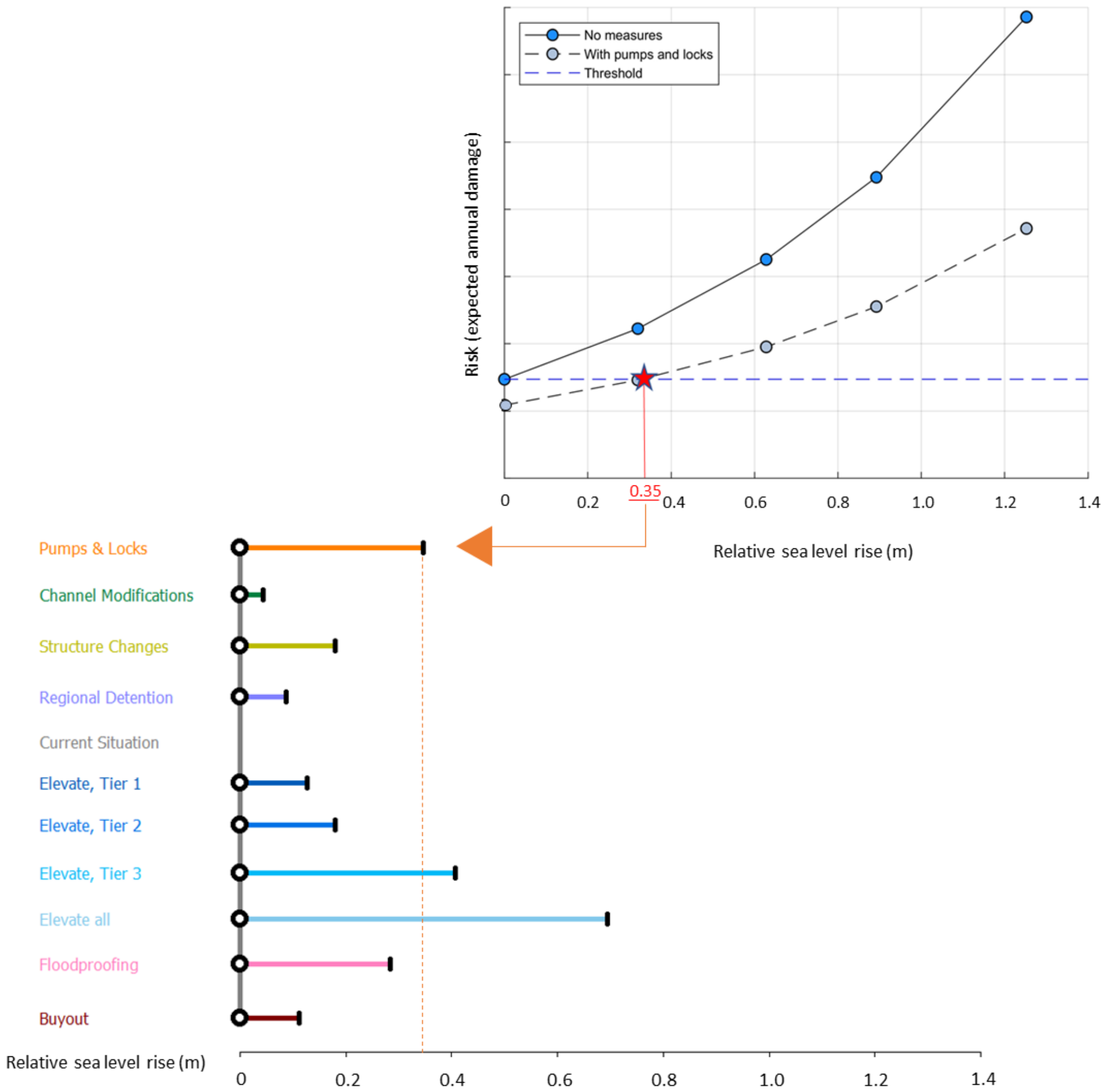
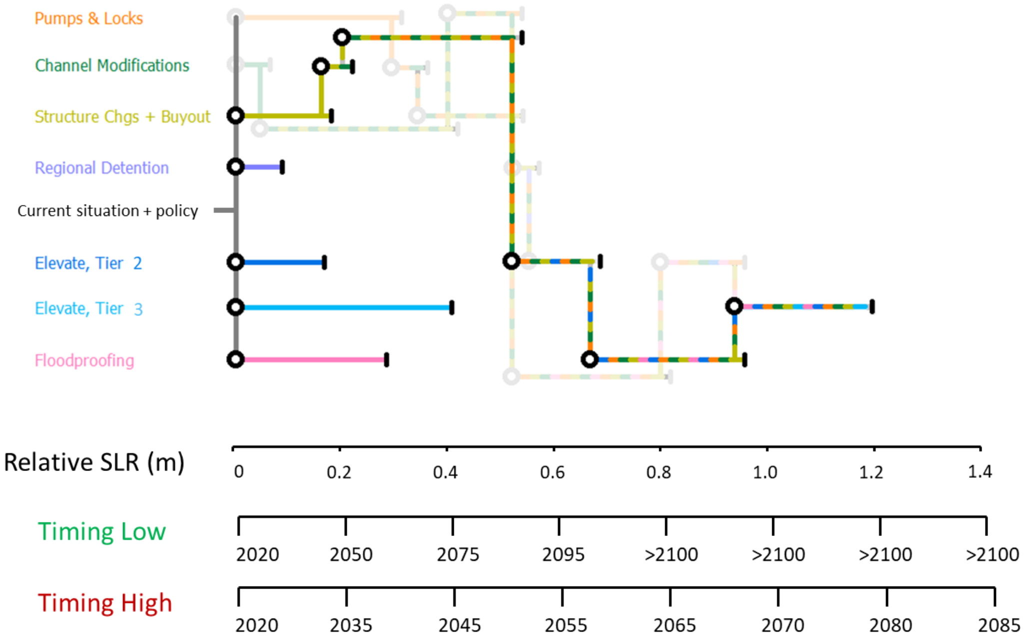


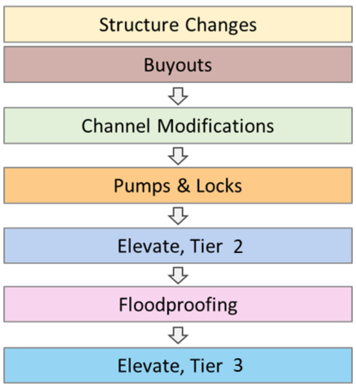
Figure 22: Tipping point analysis for the example application

82. Adaptation pathways are then formulated through focus group discussions together with stakeholders. Implementation time, permit requirements, and financing are taken as key informing considerations when developing logical sequences from the initial interventions. These considerations also form a foundation for the selection of a preferred pathway. Additional considerations are public buy-in, enabling conditions, additional benefits/consequences, and costs. Figure 23 illustrates numerous pathways that were considered in this example, with the preferred pathway shown in the foreground. Below the adaptation pathways map, its sequenced interventions are laid out explicitly along with a quantitative scorecard. This is populated by data on the costs and benefits for each measure, achieved through an initial cost-benefit analysis. In this example,

benefit-cost ratios are calculated for each individual measure if it is applied today. Note this is not equivalent to the benefit-cost ratio of the entire pathway, which would require discounting the costs and benefits of measures to be implemented at a future point in time.

83. In this example, almost all the identified interventions will be required in the event of conditions like the high relative sea level rise scenario. For the low scenario conditions, only either the hazard reduction or exposure reduction interventions would likely be needed. As such, pathways sequencing most relates to which measures will deliver the greatest benefits along with which are most feasible from a financing and implementation perspective. While the pumps and locks intervention is notionally the most cost-effective, its (eventual) implementation would benefit from an initial delay to carry out the necessary preliminary planning and design work. Hence the preference of stakeholders to first implement changes to existing drainage infrastructure (maintenance work, replacing culverts), vulnerable property buyouts (limited in number) and channel modifications. Then if needed, the more expensive (less cost-effective) and socially impactful exposure reduction measures (property elevation, floodproofing) can be implemented.





Measure	Costs	BCR	Environmental	Resettlement	Indigenous people	Gender
	30M	2.7	0	0	0	0
	40M	2.3	0	--	--	0
	20M	1.6	-	--	--	0
	40M	4.8	--	-	--	0
	60M	1.8	0	0	0	0
	200M	1.1	0	0	0	0
	250M	1.2	0	0	0	0

Figure 23: Adaptation pathways for the example application (with preferred pathway highlighted). The top part of the figure shows the pathways, set against a condition axis (relative sea level rise), with two timing estimates given as additional axes. The bottom part of the figure shows the sequencing of the measures in the preferred pathway, coupled with a score card which shows the costs of the measures and the benefit cost ratio (BCR).

84. The preferred pathway is then elaborated with the specification of relevant enabling activities. In this example, governance for all measures remains the responsibility of the District Water Management Council. Initially, extensive public consultation is required in relation to the compulsory acquisition of properties along the channels, as well as the additional planning and design work pump stations and locks. For the longer-term elevation and flood-proofing options, seed funding is allocated and invested in low-risk government bonds in order to provide future subsidies to property owners for the elevation and floodproofing measures. Table 2 summarizes the key enabling activities identified.

Table 2: Key enabling activities to facilitate implementation of the preferred pathway

Interventions	Enabling actions	Trigger
General		
• Establish monitoring program	• Further study into relevant monitoring signals to indicate magnitude of future relative SLR	• Immediate
Short-term		
• Structure changes & buyouts	• Commence existing structures maintenance and upgrade program • Launch public consultation processes • Allocate funds for property acquisition	• Immediate • Immediate • Immediate
Mid-term		
• Channel modifications • Pumps and locks	• Launch public consultation processes • Channel modification location selection & design • Pump station location selection & design • Environmental Impact Assessment channel modifications and lock installation (e.g. aquatic migration, breeding; saline water quality regulation, etc.) • Arrange permits	• Immediate • Preliminary design work commencing after 5 years • Preliminary design work commencing after 5 years • Following completion of preliminary designs • Following completion of preliminary designs
Long-term		
• Elevation & flood-proofing	• Further study to refine selection of houses falling in relevant tiers following installation of pumps/locks • Incentivize homeowners to upgrade existing insurance coverage • Establish and invest seed funding in future subsidy fund	• Immediate • Immediate • Immediate (no-regret as funds can be repurposed if not needed)

7. Summary and Key Take-home Messages

85. The DAPP adaptive planning method offers advantages to policy-makers and planners when there are large uncertainties in important flood risk drivers, when the planning horizon is long, or when adaptation options have the potential to create situations of ‘lock-in’ in the future.

86. DAPP can be applied at different levels, with a Level I qualitative analysis always recommended as a first approach taken together with stakeholders. Level II is generally an appropriate level of complexity for many applications, being based on fit-for-purpose quantitative modelling of a targeted set of (combinations) of adaptation interventions using existing tools. Level III is reserved for the most complex of problem contexts where specialized custom modelling tools are required and the potential for regret is great enough to justify the investment in these types of analysis.

87. The key difference between DAPP and other (more traditional) planning methods is that it looks at the ability to meet objectives over time through consideration of adaptation tipping points and adaptation pathways. This contrasts with the planning for a specific scenario in traditional methods. The fundamental question posed by the DAPP approach is ‘how much change can the system handle before objectives are no longer met?’ Adaptation tipping points can be described in terms of a changing condition, like ‘0.5 meters of sea level rise’ or in terms of time (or a time range), for example ‘2045 in the high scenario, 2065 in the low scenario’.

88. There are two freely available tools that greatly support the DAPP approach. For awareness-raising, the Sustainable Delta Game is a playful way to help stakeholders experience the need for adaptive planning. When developing pathways, the Pathways Generator pathways-drawing tool greatly reduces the effort in drawing up and exploring different pathways.

89. Stakeholder engagement is a critical part of the process, and stakeholders should be involved in determining objectives, identifying and assessing the uncertain drivers, identifying and selecting options to evaluate, composing pathways, and ultimately selecting the preferred pathway(s).

90. Planning for IFRM is dominated by long-term, highly impactful and deeply uncertain potential future conditions that have the potential to result in disaster or considerable regret. DAPP provides a useful and flexible framework for infrastructure planning that both recognizes and respects this uncertainty and helps to build system robustness, flexibility and resilience.

Appendix 1: Example Terms of Reference

Introduction

Planning for sustainable and resilient flood risk management is dominated by deep uncertainties in the magnitude and timing of future climatic and socioeconomic conditions. Decisions can no longer be made with the same degree of certainty previously possible. Dynamic Adaptive Pathways Planning (DAPP) provides an analytical framework for Decision Making under Deep Uncertainty (DMDU) that formulates adaptive plans that are both robust against a wide range of plausible future conditions and can flexibly adapt to these conditions as they emerge.

Objective

The objective of this TA is to, together with key institutional stakeholders, develop a dynamic adaptive plan to build system resilience and adapt to current and (uncertain) future flood risks in <*PLACE*> against a planning time horizon of <*TIME HORIZON*>. The plan will be used to inform later project proposals for ADB funding, and will undergo a continuous adaptive process of monitoring, review and (periodic) revision.

Scope

The scope of this TA includes the following:

- Undertake an iterative, collaborative, strategic DAPP assessment of current and future plausible flood risks according to a schedule of agreed planning objectives and key performance indicators (to be determined during the TA). Consideration should be given to both uncertain biophysical and socioeconomic drivers of current and future flood risk, to be prioritized for scenario development and analysis.
- Assess quantitatively current and future technical performance of existing IFRM infrastructure and potential project concepts under a range of plausible future conditions to establish the conditions and potential timing when unacceptable system performance thresholds are exceeded. Potential project concepts should:
  - include structural and non-structural interventions
  - include short- and longer-term options
  - target each of the hazard, exposure and vulnerability aspects of flood risk, and
  - address any impacts from cascading effects.
- Organize promising project concepts into robust and flexible strategic adaptation pathways to ensure planning objectives continue to be met into the future. The pathways should specify those interventions to be implemented in the immediate short-term, along with those to be left as flexible options for the longer-term depending on the system changes experienced.
- Evaluate project concepts and adaptation pathways against a set of integrated criteria. These should include (i) economic (e.g. CAPEX, EIRR, BCR), (ii) safeguards (environmental, involuntary resettlement and indigenous peoples), and (iii) gender elements as a minimum. Quantitative evaluations are preferred, however in the absence of reliable quantitative data, qualitative assessments may be undertaken.
- Elaborate the adaptive strategy through a robust process of action planning to identify and resolve potential implementation, ongoing management and monitoring issues.
- Develop a fit-for-purpose computational framework to be applied during the assessment. It is anticipated this will employ existing flood risk modelling tools and instruments (open source

preferred); however, tenders must ensure the proposed framework represents a level of complexity appropriate to the decision context. Tenders are free to apply other DMDU tools as appropriate (e.g. decision scaling, robust decision making, real options analysis), provided these tools inform the overarching process of pathways formulation.

- Effective collaboration with key institutional stakeholders throughout the TA is expected. Tenders are to indicate how they propose to achieve this specifying relevant activities, modes and moments of participation. As a minimum, four collaborative planning workshops are anticipated to be needed, however tenders are free to specify alternative schedules:
  - Session 1: Initial scoping workshop
  - Session 2: Decision context, scenario development and options identification
  - Session 3: Vulnerability assessment and initial options assessment and pathways formulation
  - Session 4: Final options assessment and pathways, evaluation and action planning.

Activities

DAPP is organized according to five key steps: (1) decision context specification, (2) scenario development and vulnerability assessment, (3) options identification and assessment, (4) adaptation pathways formulation and evaluation, and (5) action planning. Suggested activities for each step falling under this TA are outlined below. Co-development of all activity outputs together with key institutional stakeholders is expected.

1. Decision Context
   a. **Specify/verify** critical boundary conditions for the strategic analysis, including:
      i. Key drivers of system uncertainty, prioritized through a ‘level of concern’ analysis or similar
      ii. Relevant (prioritized) planning objectives and performance indicators for flood risk, including any unacceptable threshold conditions
      iii. Integrated assessment evaluation criteria
   b. **Design** and **develop** the fit-for-purpose computational modelling framework for quantitative assessment
2. Scenario development & vulnerability assessment
   a. **Specify** reference scenario conditions
      i. Establish plausible range(s) of future conditions for key (prioritized) uncertainty driver(s)
      ii. Develop scenarios of how these conditions will develop in the future. Either semi-static or fully transient scenario approaches are acceptable
      iii. Multiple drivers may be dealt with either separately or in combination
   b. **Undertake** vulnerability assessment by applying the computational modelling framework
      i. Undertake system stress tests of uncertainty drivers to establish (combinations of) conditions leading to unacceptable system states according to performance indicators
      ii. Through scenario analysis, establish points in time at which unacceptable system states occur
3. Options identification and assessment
   a. **Catalogue** inventory of possible (combinations of) IFRM interventions to address system vulnerability and improve resilience. Both short- and longer-term interventions are to be considered
   b. **Specify** any implementation lead-times for interventions as well as any un-/favorable conditions that may raise/lower barriers to implementation as applicable

   c. **Assess** interventions for effectiveness in meeting planning objectives into the future through scenario analysis and by applying the computational modelling framework. Establish performance limits to potential adaptations
   d. **Assess** interventions for any impacts against integrated evaluation criteria
4. Developing and evaluating adaptation pathways
   a. **Arrange** interventions into logical adaptation pathways to mitigate (uncertain) flood risks as conditions change
      i. Pathways should **consider** any implementation lead-times, opportunities and/or barriers
      ii. Pathways should be used to **identify** 'low-regret' interventions, path-dependencies and key decision moments as applicable
   b. **Evaluate** possible pathways against integrated evaluation criteria
      i. Economic evaluations should **consider** transfer cost implications
      ii. Together with stakeholders, select a limited number of preferred pathways for action planning
5. Action planning
   a. **Recommend** further actions to further refine and develop the concepts presented in the preferred pathways, including indicative timings for these
   b. **Recommend** institutional arrangements or reform needed to facilitate the implementation and ongoing custodianship of the plan, including establishing clear lines of responsibility
   c. **Recommend** regulatory or legislative reforms needed, including indicative timings for these
   d. **Recommend** project financing arrangements and mechanisms to be applied over the lifetime of the plan
   e. **Formulate** public consultation plan for plan dissemination
   f. **Identify** appropriate schedule of monitoring parameters to signal changes in the system drivers as well as changes in the broader system context that may facilitate or hinder plan implementation
   g. **Formulate** terms of reference for subsequent TRTA(s) to design and implement initial projects/programs in the short-term

Deliverables

The following list of deliverables are expected

1. Inception report, including stakeholder engagement protocol
2. Current and future vulnerability assessment report
3. Options assessment and strategy building report
4. Final adaptive strategy report, including implementation and monitoring plans

Expertise and Inputs

The scope of work requires an **interdisciplinary team** of skilled **experts** with compatible qualifications and previous experience in developing adaptive plans for similar flood risk management/water resources/environmental projects. Team members will possess excellent relevant technical skills to successfully implement the assignment and will include the mandatory areas of expertise in the table below. Individual experts may service the requirements of one or more areas of expertise, with the (International) Team Leader having expertise in Integrated Flood Risk Management and/or Adaptive planning/climate change adaptation. Prospective teams should also clearly nominate a (national) Deputy Team Leader. Anticipated levels of effort are provided as a guide only; tenders are free to deviate from these to properly service the requirements of this TOR. Tenders should indicate which members of the project team are international/national personnel, with preference given to project teams that include national team members.

Area of expertise	**International / National expert**	**Approximate level of effort (days)***
Integrated flood risk management	I	30
Adaptive planning / Climate change adaptation	I	30
Hydrological and hydraulic modelling	I/N	As required*
Flood risk modelling	I/N	30
Stakeholder engagement and co-development	I/N	15
Socio-economic analysis	I/N	15
Ecology / water quality	I/N	10
Indigenous peoples	N	10
Gender	I/N	10
TOTAL		**150***

* The stated level of effort provides an estimate for the completion of the DAPP-specific aspects of the assignment only and excludes any associated hydrological and hydraulic modelling to underly the assessment. These are excluded since they are highly context-specific and dependent on many factors, e.g. data availability, existence of pre-existing models, and the complexity of the modelling to be applied (e.g. 1D/2D/3D). It is expected that the requirements listed under this TOR will complement and provide coordination to the necessary biophysical modelling effort.

References

Brown C., Steinschneider S., Ray P., Wi S., Basdekas L., Yates D. (2019) Decision Scaling (DS): Decision Support for Climate Change. In: Marchau V., Walker W., Bloemen P., Popper S. (eds) Decision Making under Deep Uncertainty. Springer, Cham. https://doi.org/10.1007/978-3-030-05252-2_12

Campos, I. S., Alves, F., Dinas, J., Truninger, M., Vizinho A., & Penha-Lopes, G. (2016) Climate adaptation, transitions, and socially innovative action-research approaches. Ecology and Society, 21(13).

Haasnoot M., Warren A., Kwakkel J.H. (2019) Dynamic Adaptive Policy Pathways (DAPP). In: Marchau V., Walker W., Bloemen P., Popper S. (eds) Decision Making under Deep Uncertainty. Springer, Cham. https://doi.org/10.1007/978-3-030-05252-2_4

Haasnoot, M. (2013). Anticipating change—Sustainable water policy pathways for an uncertain future. Ph.D. dissertation, Twente University, Enschede, Netherlands. https://doi.org/10.3990/1.9789036535595

Haasnoot, M., Schellekens, J., Beersma, J. J., Middelkoop, H., & Kwadijk, J. C. J. (2015). Transient scenarios for robust climate change adaptation illustrated for water management in the Netherlands. Environmental Research Letters. https://doi.org/10.1088/1748-9326/10/10/105008

Haasnoot, M., van Aalst, M., Rozenberg, J. et al. (2020). Investments under non-stationarity: economic evaluation of adaptation pathways. Climatic Change 161, 451–463. https://doi.org/10.1007/s10584-019-02409-6

Haasnoot, M., van Klooster, S., & van't Alphen, J. (2018). Designing a monitoring system to detect signals to adapt to uncertain climate change. Global Environmental Change, 52, 273–285. https://doi.org/10.1016/j.gloenvcha.2018.08.003

IPCC (2019). IPCC Special Report on the Ocean and Cryosphere in a Changing Climate [H.-O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, N.M. Weyer (eds.)]. In press.

Kwakkel, J. H., Haasnoot, M., & Walker, W. E. (2015). Developing dynamic adaptive policy pathways: A computer-assisted approach for developing adaptive strategies for a deeply uncertain world. Climatic Change, 132, 373–386. https://doi.org/10.1007/s10584-014-1210-4

Lawrence J., Haasnoot M., McKim L., Atapattu D., Campbell G., Stroombergen A. (2019) Dynamic Adaptive Policy Pathways (DAPP): From Theory to Practice. In: Marchau V., Walker W., Bloemen P., Popper S. (eds) Decision Making under Deep Uncertainty. Springer, Cham. https://doi.org/10.1007/978-3-030-05252-2_9

Lawrence, J., & Haasnoot, M. (2017). What it took to catalyze uptake of dynamic adaptive pathways planning to address climate change uncertainty. Environmental Science & Policy, 68, 47–57.

Lempert R.J. (2019) Robust Decision Making (RDM). In: Marchau V., Walker W., Bloemen P., Popper S. (eds) Decision Making under Deep Uncertainty. Springer, Cham. https://doi.org/10.1007/978-3-030-05252-2_2

Marchau V., Walker W., Bloemen P., Popper S. (eds) (2019) Decision Making under Deep Uncertainty. Springer, Cham. https://doi.org/10.1007/978-3-030-05252-2

Mendoza, G., Jeuken, A., Matthews, J.H., Stakhiv, E., Kucharski, J., Gilroy K (2018). Climate Risk Informed Decision Analysis (CRIDA): Collaborative Water Resources Planning for an Uncertain Future. UNESCO and ICIWaRM. Available from: https://agwaguide.org/docs/CRIDA_Sept_2019.pdf

Ranger, N., Reeder, T., & Lowe, J. (2013). Addressing 'deep' uncertainty over long-term climate in major infrastructure projects: four innovations of the Thames estuary 2100 Project. EURO Journal on Decision Processes, 1, 233–262. https://doi.org/10.1007/s40070-013-0014-5

Schasfoort, F., & van Aalst, M. (2017). Guideline for Economic Analysis of Adaptation Investment Decisions under Uncertainty in the Philippines. Deltares Report