



Dynamic adaptive policy pathways: A method for crafting robust decisions for a deeply uncertain world

Marjolijn Haasnoot^{a,b,d,*}, Jan H. Kwakkel^c, Warren E. Walker^c, Judith ter Maat^d

^a Utrecht University, Department of Geosciences, P.O. Box 80115, 3508 TC Utrecht, The Netherlands

^b Twente University, Department of Water Engineering & Management, P.O. Box 217,7500 AE Enschede, The Netherlands

^c Delft University of Technology, Faculty of Technology, Policy and Management, P.O. Box 5015, 2600 GA Delft, The Netherlands

^d Deltares, P.O. Box 177, 2600 MH Delft, The Netherlands

ARTICLE INFO

Article history:

Received 15 June 2012

Received in revised form 3 December 2012

Accepted 18 December 2012

Keywords:

Uncertainty
Policymaking
Adaptation pathways
Adaptive policies
Water management
Rhine delta

ABSTRACT

A new paradigm for planning under conditions of deep uncertainty has emerged in the literature. According to this paradigm, a planner should create a strategic vision of the future, commit to short-term actions, and establish a framework to guide future actions. A plan that embodies these ideas allows for its dynamic adaptation over time to meet changing circumstances. We propose a method for decisionmaking under uncertain global and regional changes called 'Dynamic Adaptive Policy Pathways'. We base our approach on two complementary approaches for designing adaptive plans: 'Adaptive Policymaking' and 'Adaptation Pathways'. Adaptive Policymaking is a theoretical approach describing a planning process with different types of actions (e.g. 'mitigating actions' and 'hedging actions') and signposts to monitor to see if adaptation is needed. In contrast, Adaptation Pathways provides an analytical approach for exploring and sequencing a set of possible actions based on alternative external developments over time. We illustrate the Dynamic Adaptive Policy Pathways approach by producing an adaptive plan for long-term water management of the Rhine Delta in the Netherlands that takes into account the deep uncertainties about the future arising from social, political, technological, economic, and climate changes. The results suggest that it is worthwhile to further test and use the approach.

© 2012 Elsevier Ltd. Open access under [CC BY-NC-ND license](http://creativecommons.org/licenses/by-nc-nd/4.0/).

1. Introduction

Nowadays, decisionmakers face deep uncertainties about a myriad of external factors, such as climate change, population growth, new technologies, economic developments, and their impacts. Moreover, not only environmental conditions, but also societal perspectives and preferences may change over time, including stakeholders' interests and their evaluation of plans (Offermans, 2010; van der Brugge et al., 2005). Traditionally, decisionmakers in many policy domains, including water management, assume that the future can be predicted. They develop a static 'optimal' plan using a single 'most likely' future (often based on the extrapolation of trends) or a static 'robust' plan that will produce acceptable outcomes in most plausible future worlds (Dessai and Hulme, 2007; Dessai and Van der Sluijs, 2007; Hallegatte et al., 2012). However, if the future turns out to be

different from the hypothesized future(s), the plan is likely to fail. McInerney et al. (2012) liken this to "dancing on the top of a needle". But, as the future unfolds policymakers learn and usually respond to the new situation by adapting their plans (*ad hoc*) to the new reality. Adaptation over the course of time is not only determined by what is known or anticipated at present, but also by what is experienced and learned as the future unfolds (Yohe, 1990) and by the policy responses to events (Haasnoot et al., 2012). Thus, policymaking becomes part of the storyline, and thereby an essential component of the total uncertainty – in fact, Hallegatte et al. (2012) include the adaptation of decisions over time in an updated definition of 'deep uncertainty'.

To address these deep uncertainties, a new planning paradigm has emerged. This paradigm holds that, in light of the deep uncertainties, one needs to design dynamic adaptive plans (Albrechts, 2004; de Neufville and Odoni, 2003; Haasnoot et al., 2011; Hallegatte, 2009; Hallegatte et al., 2012; Ranger et al., 2010; Schwartz and Trigeorgis, 2004; Swanson et al., 2010). Such plans contain a strategic vision of the future, commit to short-term actions, and establish a framework to guide future actions (Albrechts, 2004; Ranger et al., 2010). The seeds for this planning paradigm were planted almost a century ago. Dewey (1927) argued

* Corresponding author at: Deltares, P.O. Box 177, 2600 MH Delft, The Netherlands. Tel.: +31 88 335 81 75.

E-mail addresses: Marjolijn.Haasnoot@deltares.nl (M. Haasnoot), J.H.Kwakkel@tudelft.nl (J.H. Kwakkel), W.E.Walker@tudelft.nl (W.E. Walker), Judith.TerMaat@deltares.nl (J. ter Maat).

that policies should be treated as experiments, with the aim of promoting continual learning and adaptation in response to experience over time. Early applications of adaptive plans can be found in the field of environmental management (Holling, 1978; Lee, 1993; McLain and Lee, 1996), and involve the ability to change plans based on new experience and insights (Pahl-Wostl et al., 2007). Collingridge (1980) argues that, given ignorance about the possible side effects of technologies under development, one should strive for correctability of decisions, extensive monitoring of effects, and flexibility. Rosenhead (1990) and Rosenhead et al. (1972) presented flexibility, in terms of keeping options open, as an indicator to evaluate the robustness of strategies under uncertainty.

This planning paradigm, in one form or another, has been receiving increasing attention in various policy domains. Dynamic adaptive plans are being developed for water management of New York (Rosenzweig et al., 2011; Yohe and Leichenko, 2010), New Zealand (Lawrence and Manning, 2012), and the Rhine Delta (Delta Programme, 2011, 2012; Jeuken and Reeder, 2011; Roosjen et al., 2012), and have been developed for the Thames Estuary (Lowe et al., 2009; McGahey and Sayers, 2008; Reeder and Ranger, online; Sayers et al., 2012; Wilby and Keenan, 2012). Such applications are also arising in other fields (see Swanson and Bhadwal, 2009; Walker et al., 2010 for examples).

A large number of approaches and computational techniques exist to support decisionmaking under deep uncertainty (see e.g. Dessai and Van der Sluijs, 2007; Hallegatte et al., 2012; IISD, 2006; Metz et al., 2001; Swanson et al., 2010; Walker et al., accepted for an overview of a strand of approaches). With respect to approaches, the Thames2100 project used decision trees to analyze sequential decisions for preparing the Thames Estuary for future sea level rise. In the Netherlands, Real Options Analysis has been used to assess optimal costs and benefits of pathways for fresh water supply of the Southwestern Delta (van Rhee, 2011) and for studying how flexibility can be built into flood risk infrastructure (Gersonius et al., 2013). To show dependencies of choices for shipping, a decision tree has been used in the Dutch Delta Programme (Delta Programme, 2011). Roadmaps have been used to illustrate a sequence of actions in water management studies (e.g. for the lakes IJsselmeer (unpublished) and Volkerak Zoommeer (Projectteam Verkenning oplossingsrichtingen Volkerak-Zoommeer, 2003)). The Backcasting approach aims at describing a desirable future, and then looking backwards from that future to the present to develop a pathway of actions needed to realize this future (Höjer and Mattsson, 2000; Lovins, 1976; Quist and Vergragt, 2006). Assumption-Based Planning begins with an existing plan and analyzes the critical assumptions in this plan (Dewar et al., 1993). It uses signposts to monitor the need for changes. Robust Decision Making is an approach that uses many computational experiments to create an ensemble of scenarios against which candidate actions are evaluated in order to develop robust actions (Groves and Lempert, 2007; Lempert et al., 2006). Several planning approaches consider reassessment and the ability to change policies based on new insights in a planning circle (Loucks and Van Beek, 2005; Pahl-Wostl, 2007; Ranger et al., 2010; Swanson et al., 2010; Willows and Connell, 2003). The Panel on America's Climate Choices (2010) refers to this as 'iterative risk management' that 'is a system for assessing risks, identifying options that are robust across a range of possible futures, and assessing and revising those choices as new information emerges.' Among the computational techniques are Scenario Discovery (Bryant and Lempert, 2010; Lempert and Groves, 2010), Exploratory Modeling and Analysis (Bankes, 1993; Bankes et al., 2013), and Info-Gap decision theory (Hall and Harvey, 2009; Korteling et al., 2012).

These approaches and computational techniques, although developed for different purposes, have been found valuable for

designing adaptive policies (Bankes, 2002; Hall et al., 2012; Hallegatte et al., 2012; Hamarat et al., 2012; Lempert et al., 2000, 2002). They differ in terms of the concepts employed, and provide different kinds decision support information (Hall et al., 2012). Consequently, they have different strengths and limitations. This situation calls for research into comparing the various approaches and techniques, providing an understanding of their relative strengths and weaknesses, and identifying the contexts within which each of the approaches and techniques is most appropriately employed (Hall et al., 2012; Hallegatte et al., 2012; Ranger et al., 2010). In addition, we argue that it is worthwhile to assess the extent to which the different terminologies used signify real differences in the underlying concepts, for this can contribute to harmonizing the field.

In this article, we analyze two existing adaptive planning approaches and show how the employed concepts are partially overlapping and partially complementary, resulting in an integration of the two approaches. We look at *Adaptive Policymaking* (Kwakkel et al., 2010a; Walker et al., 2001) and *Adaptation Pathways* (Haasnoot et al., 2012). Adaptive Policymaking provides a stepwise approach for developing a basic plan, and contingency planning to adapt the basic plan to new information over time. Adaptation Pathways provide insight into the sequencing of actions over time, potential lock-ins, and path dependencies. An example of a family resemblance between concepts used by these two approaches is the concept of an *adaptation tipping point* (Kwadijk et al., 2010) used in Adaptation Pathways and the notion of a *trigger* from Adaptive Policymaking. An adaptation tipping point is the point at which a particular action is no longer adequate for meeting the plan's objectives. A new action is therefore necessary. A trigger specifies the conditions under which a pre-specified action to change the plan is to be taken.

A fundamental challenge in planning research is the assessment of the efficacy of new planning methods and concepts. The problem is pointedly summarized by Dewar et al. (1993, p. 58) "nothing done in the short term can 'prove' the efficacy of a planning methodology, nor can the monitoring, over time, of a single instance of a plan generated by that methodology, unless there is a competing parallel plan". With respect to how a planning concept is tested, the planning research literature tends to look toward controlled real world application (Dewar et al., 1993; Hansman et al., 2006; Straatemeier et al., 2010). However, analogous to other design sciences (Frey and Dym, 2006), the evaluation of a planning concept can also utilize other sources of evidence (Kwakkel and Van Der Pas, 2011; Kwakkel et al., 2012). Evidence can come from planning practice, from virtual worlds that represent the world of practice but are not the world of practice (Schön, 1983), and from theoretical considerations. In this paper, to assess the efficacy of the outlined integration of Adaptive Policymaking and Adaptation Pathways, we use such a virtual world in the form of applying the presented planning concepts to a real world decision problem currently faced by the Dutch National Government. This application serves to illustrate the concept, describes how it could be used to develop a dynamic adaptive plan, and offers a first source of evidence of its efficacy through a critical reflection on the application.

The paper ultimately proposes a method for decisionmaking under deep uncertainty called *Dynamic Adaptive Policy Pathways*, which is a combination of Adaptive Policymaking and Adaptation Pathways. We first provide short introductions to each of the underlying approaches, and then explore how the two approaches can be integrated into a single approach based on the strong elements of both to produce a dynamic adaptive plan. We demonstrate the approach by producing a dynamic adaptive plan for water management of the Rhine Delta region of the Netherlands that takes into account the deep uncertainties associated with global climate change.

2. The two underlying approaches

2.1. Adaptation Pathways

The Adaptation Pathways approach is summarized in Figs. 1 and 2 (Haasnoot et al., 2011, 2012). Central to adaptation pathways are adaptation tipping points (Kwadijk et al., 2010), which are the conditions under which an action no longer meets the clearly specified objectives. The timing of the adaptation point for a given action, its sell-by date, is scenario dependent. After reaching a tipping point, additional actions are needed. As a result, a pathway emerges. The Adaptation Pathways approach presents a sequence of possible actions after a tipping point in the form of adaptation trees (e.g. like a decision tree or a roadmap). Any given route through the tree is an adaptation pathway. Typically, this approach uses computational scenario approaches to assess the distribution of the sell-by date of several actions across a large ensemble of transient scenarios. This distribution can be summarized in box-whisker plots, and the median or quartile values are used in generating an adaptation map. The exact date of a tipping point is not important; the moment should be roughly right – for example, “on average the tipping point will be reached within 50 years, at earliest within 40 years, and at latest within 60 years”. The effects of sequences of actions can be assessed in the same way as individual actions. To cope with the presence of different stakeholders, values, and worldviews, cultural perspectives can be used to map these out (Hoekstra, 1998; Middelkoop et al., 2004; Offermans et al., 2011; Van Asselt and Rotmans, 1997).

The Adaptation Pathways map, manually drawn based on model results or expert judgment, presents an overview of relevant pathways (see Fig. 2 for an example). Similar to a Metro map (see, for example, <http://www.wmata.com/rail/maps/map.cfm>), the Adaptation Pathways map presents alternative routes to get to the same desired point in the future. All routes presented satisfy a pre-specified minimum performance level, such as a safety norm (a threshold that determines whether results are acceptable or not). They can, thus, be considered as ‘different ways leading to Rome’ (as is true of different routes to a specified destination on the Metro). Also, the moment of an adaptation tipping point (*terminal station*), and the available actions after this point, are shown (via *transfer stations*). Due to unacceptable performance of some actions in a selection of scenarios, some routes are not always available (dashed lines). Decisionmakers or stakeholders may have a preference for certain pathways, since costs and benefits may differ. An overview of such costs and benefits for each pathway can be presented in a scorecard (e.g. Walker, 2000). With the

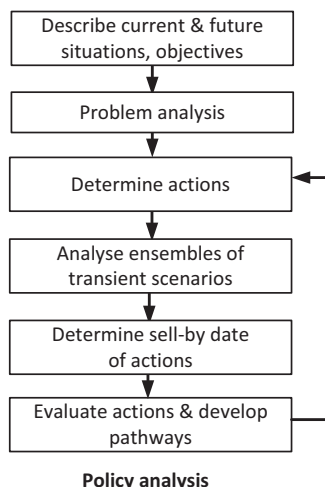


Fig. 1. Stepwise policy analysis to construct Adaptation Pathways.

adaptation map, decisionmakers can identify opportunities, no-regret actions, lock-ins, and the timing of an action, in order to support decisionmaking in a changing environment. That is, the adaptation map can be used to prepare a plan for actions to be taken immediately, and for preparations that need to be made in order to be able to implement an action in the future in case conditions change. The example of Fig. 2 shows that actions are needed in the short-term. Choosing action B may be ineffective as soon additional actions are needed. Choosing option C involves taking a risk, as additional actions may be needed in case scenario X becomes reality. In combination with a scorecard of the costs and benefits for the pathways, a decisionmaker could make an informed decision.

2.2. Adaptive Policymaking

Adaptive Policymaking is a generic structured approach for designing dynamic robust plans (Kwakkel et al., 2010a; Marchau et al., 2009; Ranger et al., 2010). Conceptually, Adaptive Policymaking is rooted in Assumption-Based Planning (Dewar et al., 1993). Fig. 3 shows the steps of the Adaptive Policymaking approach for designing a dynamic adaptive plan (Kwakkel et al., 2010a). In Step I, the existing conditions of a system are analyzed and the objectives for future development are specified. In Step II, the way in which these objectives are to be achieved is specified by assembling a basic plan. This basic plan is made more robust through four types of actions (Step III): *mitigating actions* (actions to reduce the *likely* adverse effects of a plan); *hedging actions* (actions to spread or reduce the *uncertain* adverse effects of a plan); *seizing actions* (actions taken to seize likely available opportunities); and *shaping actions* (actions taken to reduce failure or enhance success). Even with the actions taken in Step III, there is still the need to monitor the plan's performance and to take action if necessary. This is called contingency planning (Step IV). *Signposts* specify information that should be tracked in order to determine whether the plan is meeting the conditions for its success. In addition, critical values of signpost variables (*triggers*) beyond which additional actions should be implemented are specified. There are four different types of actions that can be triggered by a signpost, which are specified in Step V: *defensive actions* (actions taken to clarify the basic plan, preserve its benefits, or meet outside challenges in response to specific triggers that leave the basic plan unchanged); *corrective actions* (adjustments to the basic plan); *capitalizing actions* (actions to take advantage of opportunities that can improve the performance of the basic plan); and a *reassessment* of the plan (initiated when the analysis and assumptions critical to the plan's success have clearly lost validity).

Once the complete plan has been designed, the actions to be taken immediately (from Step II and Step III) are implemented, and a monitoring system (from Step IV) is established. Then time starts running, signpost information related to the triggers is collected, and actions are started, altered, stopped, or expanded in response to this information. After implementation of the initial actions, the implementation of other actions (from Step V) is suspended until a trigger event occurs.

2.3. Comparison of the approaches

Table 1 compares the features of Adaptive Policymaking and Adaptation Pathways. Both approaches aim at supporting decisionmakers in handling uncertainty in long-term decisionmaking and emphasize the need for adaptivity in plans in order to cope with deep uncertainty. More specifically, they both offer support in choosing near-term actions, while keeping open the possibility to modify, extend, or otherwise alter the plans in response to how the future unfolds.

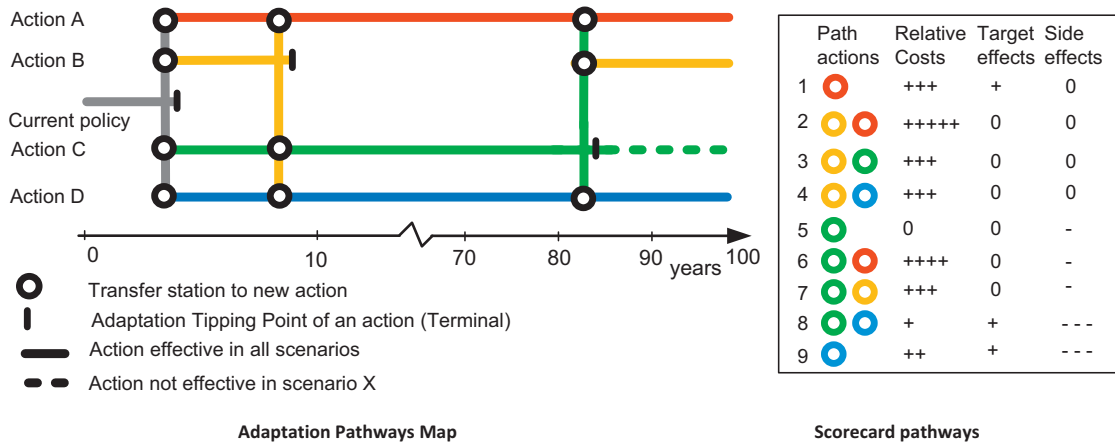


Fig. 2. An example of an Adaptation Pathways map (left) and a scorecard presenting the costs and benefits of the 9 possible pathways presented in the map. In the map, starting from the current situation, targets begin to be missed after four years. Following the gray lines of the current policy, one can see that there are four options. Actions A and D should be able to achieve the targets for the next 100 years in all climate scenarios. If Action B is chosen after the first four years, a tipping point is reached within about five years; a shift to one of the other three actions will then be needed to achieve the targets (follow the orange lines). If Action C is chosen after the first four years, a shift to Action A, B, or D will be needed in the case of Scenario X (follow the solid green lines). In all other scenarios, the targets will be achieved for the next 100 years (the dashed green line). The colors in the scorecard refer the actions A (red), B (orange), C (green), and D (blue).

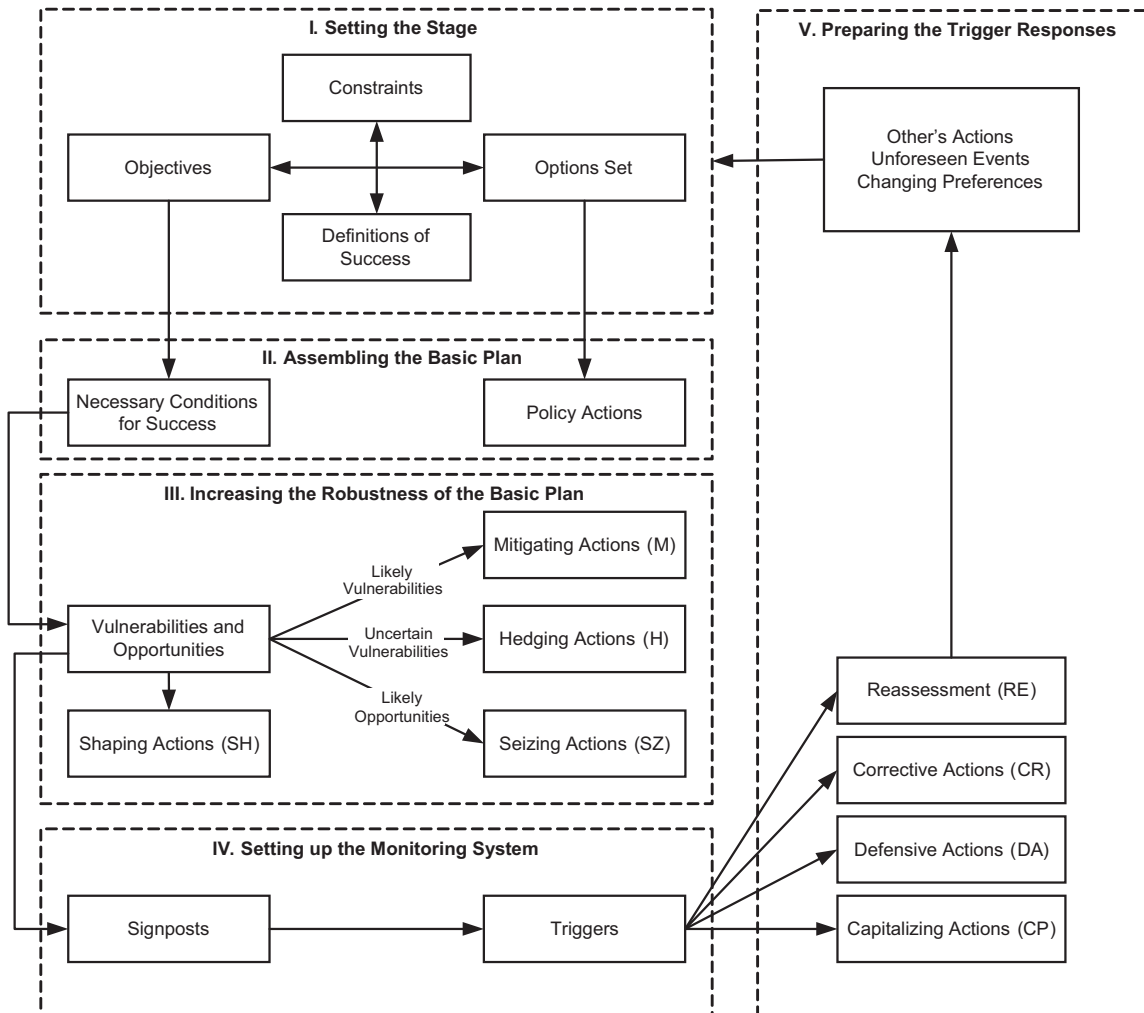


Fig. 3. The Adaptive Policymaking approach to designing a dynamic adaptive plan (Kwakkel et al., 2010a).

Table 1
Comparison of the approaches.

Aspect	Adaptive Policymaking	Adaptation Pathways
Focus	Starts from a vision of the decisionmaker and creates a plan for realizing this vision and protecting it from failure.	Explores actions for achieving objectives over time by including dynamic interaction between the system and society.
Consideration of the multiplicity of futures Planning process	Indirectly via vulnerabilities and opportunities. Comprehensive stepwise approach for designing a plan.	Explicitly via transient scenarios. Short stepwise approach for designing Adaptation Pathways.
Clarity on how to design a plan	Limited; a high level framework that can be translated into a specific plan in many different ways.	Application oriented, with a clear link to the use of models to develop a specific plan.
Types of actions that can be taken	Distinguishes many different types of actions that can be taken (e.g. hedging, mitigating, and shaping).	No specific categorization of actions is used. Several actions and pathways are presented. A variety of actions are identified based on different societal perspectives.
Desirable plan	One basic plan is developed. No clear guideline on how develop the basic plan.	Several pathways are presented. Different perspectives result in different preferred pathways. No focus on how to identify promising pathways when confronted with a large number of possible actions.
Consideration of types of uncertainties	In principle, any uncertainty can be accounted for.	In principle, any uncertainty can be accounted for. Explicit attention is given to social uncertainty.
Flexibility of resulting plan	Flexibility is established through the monitoring system and associated actions.	The Adaptation Pathways map clearly specifies when a policy should be changed, and what the next action should be.
Dynamic robustness of resulting plan	Dynamic robustness results from the monitoring set up in Step IV and the actions taken in Step V.	Dynamic robustness is produced indirectly via the idea of a 'sell-by date' and the shift to another action.

The ways in which the two approaches offer decision support are quite different. Adaptation Pathways provides insight into the sequencing of actions over time, taking into account a large ensemble of transient scenarios. The transient scenarios allow for a wide variety of uncertainties about future developments to be taken into account in the planning process. Not only trends and system changes are included, but also uncertainty due to natural variability. The use of a fast and simple model allows for exploring a wide variety of pathways over the ensemble. These results can be used to sketch an Adaptation Pathways map. Dynamic robustness of the resulting plan is indirectly handled through the identification of an adaptation tipping point, the sell-by date, and the shift to other actions. The pathways map provides information to the decisionmaker, but gives no guidance on how the decisionmaker can translate this into an actual plan.

Adaptive Policymaking supports the decisionmaker in a different way. It specifies a stepwise approach to designing a plan. First a basic course of action is developed in light of well specified objectives. Then, the vulnerabilities and opportunities of this course of action are identified, and different types of actions to be taken now or in the future to either cope with the vulnerabilities or capitalize on the opportunities are specified. Through the identification of opportunities and vulnerabilities, a wide variety of uncertainties can be accounted for. The specification of a monitoring system and associated actions results in a dynamically robust plan. However, Adaptive Policymaking offers no clear guidance beyond these concepts. That is, questions, such as how can one identify vulnerabilities, how should the actions be sequenced, or how does one decide whether to hedge against a vulnerability or to specify a monitoring system with actions to handle the vulnerability in the future if and when it arises, are not addressed explicitly.

3. A new approach: dynamic adaptive policy pathways

The combination of Adaptive Policymaking and Adaptation Pathways, which we call Dynamic Adaptive Policy Pathways, results from using the strengths of both approaches. In short, this integrated approach includes: *transient scenarios* representing a variety of relevant uncertainties and their development over time;

different types of *actions* to handle vulnerabilities and opportunities; *Adaptation Pathways* describing sequences of promising actions; and a *monitoring system* with related *contingency actions* to keep the plan on the track of a preferred pathway. The steps in the approach are presented in Fig. 4.

The first step is to *describe the study area*, including the system's characteristics, the objectives, the constraints in the current situation, and potential constraints in future situations. The result is a definition of *success*, which is a specification of the desired outcomes in terms of indicators and targets that are used in subsequent steps to evaluate the performance of actions and pathways, and to assess the 'sell-by dates' of the actions. The description of the study area includes a specification of the major uncertainties that play a role in the decisionmaking problem. These uncertainties are not restricted to uncertainties about the future,

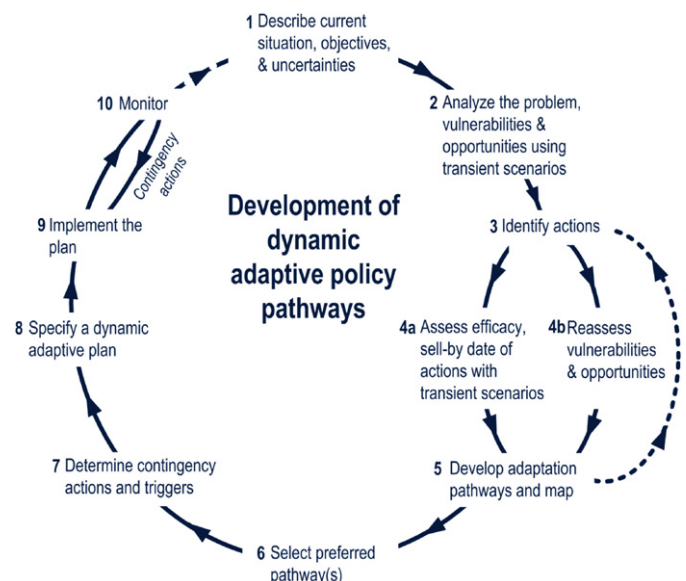


Fig. 4. The Dynamic Adaptive Policy Pathways approach.

but can also cover uncertainties related to the data or models that are being used (Kwakkel et al., 2010b).

The second step is the *problem analysis*. In this step, the current situation and possible future situations are compared to the specified objectives to identify whether there are any gaps. The possible future situations are 'reference cases' assuming no new policies are implemented, and consist of (transient) scenarios that span the uncertainties identified in step one. A gap indicates that actions are needed. Both opportunities and vulnerabilities should be considered. Opportunities are developments that can help in achieving the objectives, while vulnerabilities are developments that can harm the extent to which the objectives can be achieved. The identification of opportunities and vulnerabilities can be based on the analysis of the reference cases, which can best be accomplished using a computational model.

In the third step, one identifies *possible actions* that can be taken to meet the definition for success. These actions can thus be specified in light of the opportunities and vulnerabilities previously identified and can be categorized according to the types of actions specified in the Adaptive Policymaking framework (i.e. shaping, mitigating, hedging, and capitalizing actions). The aim of this step is to assemble a rich set of possible actions. An identification of actions for different perspectives could enforce this (e.g. done by Offermans et al., 2011).

The fourth step is to *evaluate the actions*. The effects of the individual actions on the outcome indicators are assessed for each of the scenarios and can be presented using scorecards. The results are used to *identify the sell-by date* for each of the actions. Furthermore, the vulnerabilities and opportunities need to be reassessed. Was the action able to reduce or remove a specified vulnerability? Was the action able to utilize a specified opportunity? Does the action create new opportunities and/or vulnerabilities? Ineffective actions are screened out (Walker, 1988), and only the promising actions are used in the next steps as the basic building blocks for the assembly of Adaptation Pathways.

The fifth step is the *assembly of pathways* using the information generated in the previous steps. It is conceivable that the reassessment of the vulnerabilities and opportunities in the previous step triggers an iterative process (back to step 3) wherein new or additional actions are identified. Once the set of actions is deemed adequate, pathways can be designed. A pathway consists of a concatenation of actions, where a new action is activated once its predecessor is no longer able to meet the definition of success. Pathways can be assembled in different ways. For example, analysts could explore all possible routes with all available actions. Each of these routes can then be evaluated on its performance. However, some actions may exclude others, and some sequences of actions may be illogical. In addition, fundamental criteria, such as the urgency of actions, the severity of the impacts, the uncertainty involved, and the desire to keep options open, could be used to develop a set of *promising pathways*. The result is an adaptation map, which summarizes all logical potential pathways in which 'success' (as defined in step 1) is achieved. Note that actions need not be a single action, but can be a portfolio of actions, constructed after iteration of steps 3–5.

The sixth step is to develop a manageable number of *preferred pathways*. Preferred pathways are pathways that fit well within a specified perspective. It can be useful to specify two to four pathways that reflect different perspectives. This will result not only in the identification of physically robust pathways, but also 'socially robust' pathways (Offermans et al., 2011). The preferred pathways will form the basic structure of a *dynamic adaptive plan* (like the basic plan in the Adaptive Policymaking framework).

The seventh step is to improve the robustness of the preferred pathways through *contingency planning* – in other words, to define actions to get and keep each of the pathways on track for success.

In general, these are actions to anticipate and prepare for one or more preferred pathway (e.g. keep options open), and corrective actions to stay on track in case the future turns out differently than expected. We distinguish three types of contingency actions from Adaptive Policymaking: corrective, defensive, and capitalizing actions, which are associated with a monitoring system and trigger values. The monitoring system specifies what to monitor, and the triggers specify when a contingency action should be activated.

The eighth step is to translate the results from all of the previous steps into a *dynamic adaptive plan*. This plan should answer the following question: Given the set of pathways and the uncertainties about the future, what actions/decisions should we take now (and which actions/decisions can be postponed)? The plan summarizes the results from the previous steps, such as targets, problems, and potential and preferred pathways. The challenge is to draft a plan that keeps the preferred pathways open for as long as possible. Thus, the plan specifies actions to be taken immediately, actions to be taken now to keep open future adaptations, and the monitoring system.

Finally, the actions to be taken immediately are implemented and the monitoring system is established. Then, time starts running, signpost information related to the triggers is collected, and actions are started, altered, stopped, or expanded in response to this information. After implementation of the initial actions, activation of other actions is suspended until a trigger event occurs.

4. Case study: Rhine Delta in the Netherlands

We illustrate and test the approach of Dynamic Adaptive Policy Pathways for the lower Rhine Delta in the Netherlands, and focus on the IJsselmeer area. In 2007, the Government established the Second Delta Commission for identifying actions to prevent future disasters (Deltacommissie, 2008; Kabat et al., 2009), since the expected future climate change and sea level rise 'can no longer be ignored' (Deltacommissie, 2008, p. 5). The Commission's advice resulted in the enactment of a Delta Act, and is presently being elaborated in a Delta Programme. The chair of the Delta Programme summarized their main challenge as follows: "One of the biggest challenges is dealing with uncertainties in the future climate, but also in population, economy and society. This requires a new way of planning, which we call adaptive delta planning. It seeks to maximize flexibility; keeping options open and avoiding 'lock-in'" (Kuijken, 2010). This corresponds well with our integrated approach, and thus provides an appropriate case to use as an illustration. However, we have made many simplifying assumptions. So, what follows can be used only for illustrative purposes and a first tentative test of our approach. The steps we mention refer to the steps in Fig. 4.

4.1. Steps 1 and 2: current situation and problem analysis

The Netherlands is a densely populated country, two-thirds of which is vulnerable to being flooded by the sea or large rivers. A sophisticated and comprehensive water management system satisfies the water system requirements for living in a delta. But, for coping with future changes such as global climate change, adaptation may be needed. Having the right amount of water for users, at the right time, in the right place, and at socially acceptable costs is a key target for the Ministry of Transport, Public Works and Water Management (Rijkswaterstaat, 2011). The objective of the Delta Programme is "to protect the Netherlands from flooding and to ensure adequate supplies of freshwater for generations ahead." (Delta Programme, 2011). Accordingly, we define 'success' as follows: "The plan will be successful if no floods occur, and if there is enough fresh water during the next 100 years. The frequency of water shortage will be at least similar to the present situation (once in 10 years a

water shortage may occur.’ Constraints would include the various EU Directives that the Dutch Government must follow. For example, the Water Framework Directive implies that ecological and water quality objectives have to be met. These Directives imply that we need to add another target to our definition of success: *‘the plan will be successful if it does not result in negative impacts on nature’*.

4.1.1. The water system and its functions in the current situation

There are several key water characteristics that need further explanation for our case (see Fig. 5). After the Rhine enters the country, the water is distributed over three branches – the Waal, Nederrijn, and IJssel – by means of a weir at Driel. The IJssel supplies the IJsselmeer and Markermeer lakes with fresh water. The Afsluitdijk dam protects the adjacent areas from flooding and enables water storage in the lakes. The levels of the IJsselmeer and Markermeer are carefully maintained with sluices, to ensure safety in the winter and enough fresh water in the summer. Safety from flooding is expressed in standards of a probability per year that a critical water level will occur – e.g. 1:1250 years (Rijkswaterstaat, 2011). These standards (also called ‘norm frequencies’) are laid down by law for every dike ring area, and depend largely on the economic activities, the number of inhabitants, and flood characteristics associated with the dike ring. The Haringvliet sluice gates and the Maeslantkering protect the Rhine estuary from (mainly coastal) flooding. The Haringvliet sluices also limit salt intrusion into the river.

The IJsselmeer and Markermeer are the main water reservoirs in the lower Rhine Delta. During dry periods, water from these lakes is used to supply large parts of the Netherlands. Despite the extensive network of ditches and canals and the large amount of water storage, the water supply is insufficient to fulfill the fresh water demands during dry periods. During such periods, a priority list is used to distribute fresh water for different uses. The major uses of water are for agriculture (for irrigation), for flushing (to mitigate adverse impacts for agriculture and drinking water from the upward seepage of salt water and salt intrusion in the waterways near Rotterdam), and for water management itself (to maintain water levels in the lakes and canals). Drinking water and industry are also important uses, although the quantity used for these is negligible compared to the other uses.

4.1.2. The water system and its functions in the future

Future socio-economic developments, climate change, and sea level rise, may require changes to the water management system. Recently, four water-related scenarios were developed for the Netherlands (Bruggeman et al., 2011; Te Linde et al., submitted). These ‘Deltascenarios’ cover two representations of future climate (based on Van den Hurk et al., 2007) and two sets of socio-economic developments in the Netherlands. The climate scenarios cover a range from moderate increases in temperature and precipitation (1 °C, 3.6% precipitation in the winter, and 2.8% in the summer; used in the scenario ‘Crowd’) to a large temperature increase (2 °C in 2100; used in the scenario ‘Warm’), a large

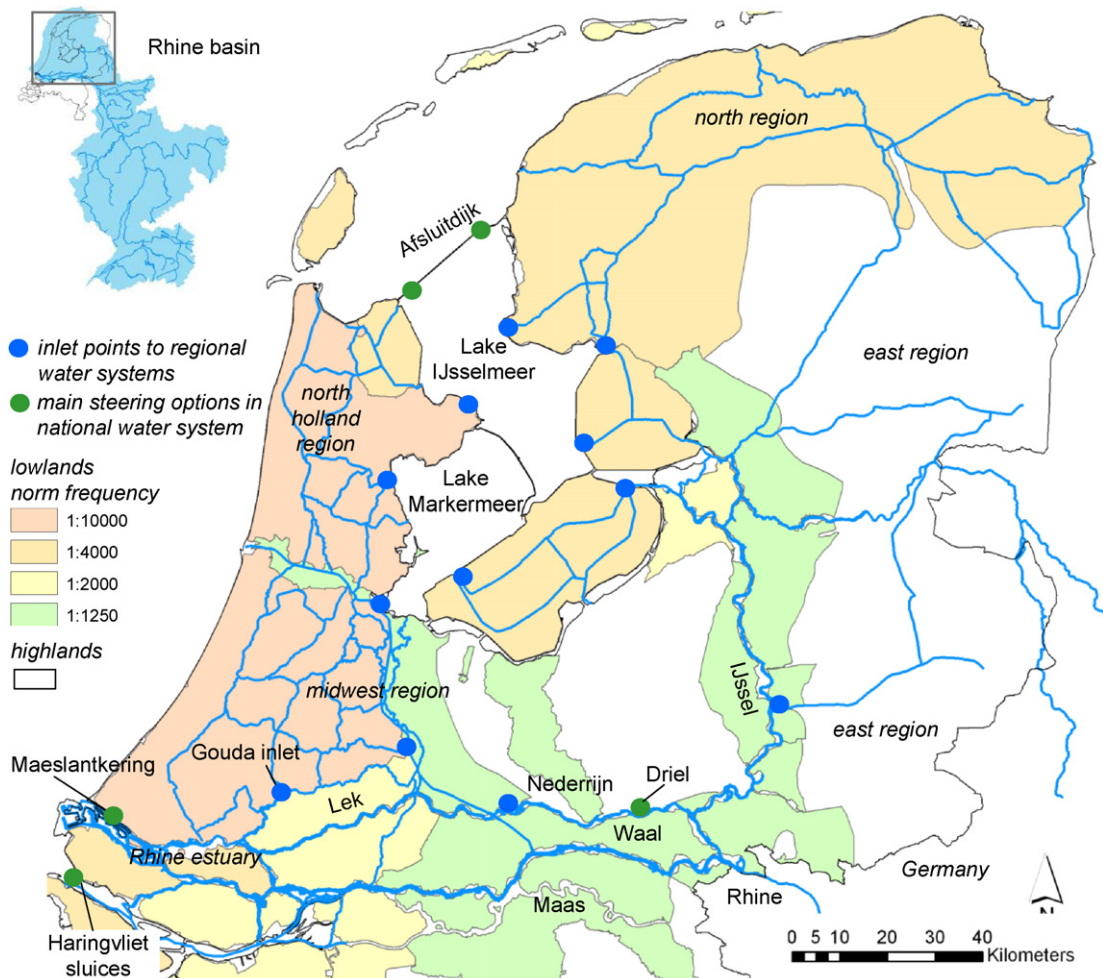


Fig. 5. Case study location: Lower Rhine Delta in the Netherlands, with focus on the IJsselmeer area.

precipitation increase in winter (14.2%), and a large precipitation decrease in the summer (19%). The sea level can increase (35–85 cm in 2100). The socio-economic scenarios describe a population change from the current 16 million to 12 million or 24 million in 2100, together with major changes in agricultural land use. These scenarios would result in an increase in water demands from the regional areas to the national water system due to less rain and lower river discharges, more salt intrusion, and/or agricultural changes; and an increase in flood risk due to sea level rise, higher river discharges, and population and economic growth.

4.2. Step 3: determine actions

For illustrative purposes, we focus on the IJsselmeer area, and consider in our analysis only the main alternative actions, whereas in reality the entire Rhine Delta and all kinds of combinations of actions are possible. As a result of our problem analysis, it is clear that the IJsselmeer area will become even more important as a storage basin for providing fresh water in times of drought. Either the water storage capacity needs to be increased, or the (growth in) water demand needs to be reduced. To increase the water storage, the water level of lake IJsselmeer can be either increased in the spring, and then used during dry periods, or decreased in dry periods. Water demands can be reduced by increasing the efficiency of water use in the regional system, by changing to salt and/or drought tolerant crops, and/or by decreasing agriculture or moving agriculture to areas with appropriate environmental conditions. Some of these actions can be taken without changing the current infrastructure; these can be considered as improvements of the current system. For other actions, the infrastructure would have to be changed considerably. To ensure safety from flooding in case of sea level rise and increased river discharges in the winter, flood management actions would need to be taken as well. Safety for the areas adjacent to the IJsselmeer can be achieved by either raising the water level in correspondence with the sea level, so the excess water can be drained under gravity into the Waddensea (of course, dikes need to be raised accordingly as well), or by building large pumps for discharging water into the

Waddensea. If the first action is chosen, the extra amount of water can be used in times of drought. If the second action is chosen, water inlets and shipping sluices need to be adapted for enabling water use during drought. Table 2 provides an overview of this set of actions.

4.3. Step 4: assess efficacy, sell-by date of actions, and reassess vulnerabilities and opportunities

Table 2 presents an assessment of the efficacy of each individual action and its sell-by date based upon expert knowledge, previous studies on possible actions, and preliminary modeling results for 2050 and 2100 indicating how much water (in cm IJsselmeer lake level) is needed to supply the amount of water demanded for an average, dry, and extremely dry year for the different scenarios (Klijn et al., 2011). For determining the sell-by date, we assume a linear change of climate and socio-economic developments. For the actions focusing on reducing the water demand, no model results were available. Together with stakeholders (water boards) the impact of these actions was translated into the amount of IJsselmeer water needed. Table 2 shows that the current plan is likely to be sufficient for achieving objectives for approximately 30 years. After this point, changes are likely to be needed. Improvements that can be made to the current system should enable the sell-by date to be extended by approximately 10 years.

The flood management actions and the actions for fresh water supply influence each other. A higher water level for increasing storage capacity will, at the same time, allow the system to discharge under gravity (depending on the sea level). If policy-makers were to decide to ensure safety against flooding by increasing the pump capacity and keeping the same target water level, fresh water supply actions with an increase of the water level would be screened out. There is also a relation between the actions in the IJsselmeer area and other regions in the lower Rhine Delta. For example, as part of the actions to ensure safety along the Waal and Nederrijn, more Rhine water could be distributed to the IJssel. In this case, enough capacity should be available in the IJsselmeer, implying that the water level can be raised at earliest in the

Table 2

Actions and assessment of their relative performance in terms of impacts on safety, fresh water capacity, side impacts on nature areas and shipping in the IJsselmeer and IJssel region, and sell-by date of actions based on preliminary expert knowledge and modeling results.^a

Action	Impact				Sell-by date (years)	Costs
	Safety	Fresh water	Nature	Shipping		
Flood management actions						
Increase target water level and the dikes correspondingly for enabling discharging under gravity to sea.	+++	++	--	--	>2100	+++
Keep the same target water level by increasing pump capacity largely.	+++	0	0	0	2100	++
Fresh water supply actions						
Increase water level to +1.1 m in spring, and adapt regional water system infrastructure. More water to the IJssel River in spring.	+++ ^b	++	--	--	>2100	++
Increase water level to +0.6 m in spring, and adapt regional water system infrastructure. More water to the IJssel River in spring.	++ ^b	+	--	-	2070–2090	+
Increase water level to +0.1 m, using current infrastructure	+ ^b	+	-/+	0	2050–2060	0
Decrease water level to -0.8 m in dry periods, and adapt infrastructure.	0	+++	+	-	2100	++
Decrease water level to -0.6 m in dry periods, and use current infrastructure.	0	++	+	--	2060–2070	+
Accept navigation obstructions during extreme droughts						
Adapt water distribution Rhine branches: more water to IJssel River during droughts	0	+	0	+	2040	0
Improving current plan with flexible water levels	0	+	0	0	2030–2040	0
Reduce water demand to the national water network, by improving the management of the regional network	0	+	0	0	2050–2070	+
Reduce water demand and damage by changing to salt and/or drought tolerant crops	0	+++	0	0	>2100	++
Reduce water demand by change land use to nature and/or urban areas	0	+++	++	0	>2100	+

^a -- large negative impact, - negative impact, 0 no or minor impact, + positive impact, ++ moderate positive impact, +++ large positive impact.

^b These impacts are considered as positive as this facilitates the preferred drainage of excess water from the IJsselmeer to the Waddensea under gravity.

beginning of spring. In some years, there will not be enough water to do this. Starting earlier with raising the water level would be possible only if the dikes were raised sufficiently. If more water is transported to the IJssel, there will be less water for the river branches to the western part of the country (Waal and Nederrijn), and thus less water for holding back the salt intrusion from the sea, making the water inlet at Gouda less reliable. In that case, the Midwest area might be supplied by IJsselmeer water. If, however, policymakers were to decide to close the Rhine estuary, this would not be necessary.

With the impacts of the actions in mind, the vulnerabilities and opportunities need to be reassessed. For example, if the IJsselmeer level is raised, achieving the EU Directives (Water Framework Directive, Habitat Directive, Birds Directive) may be endangered, due to the disappearance of shallow waters that provide an important habitat for species.

4.4. Step 5: develop pathways

Fig. 6 shows the Adaptation Pathways map for the 10 actions for fresh water supply from Table 2. For flood management, two actions are available. They are not presented in the Adaptation Pathways map, but they influence the preferences for certain pathways, as explained above.

To construct the pathways, the actions are grouped into actions influencing water demand and actions influencing water supply. Actions with long sell-by dates are shown on the top or bottom of the map, while actions with short sell-by dates are shown close to the current plan. The next step is to add the sell-by dates and all the possible transfers to other actions that would extend the sell-by date. Sometimes actions affect each other. If the sell-by date for an action will increase considerably, this is shown by an additional line in the same color. Next, illogical actions are eliminated (background color in contrast to bright colored logical actions). For example, implementing one of the large actions first is illogical, as this may not be necessary to achieve success, and it can be implemented later as well. It is also less logical, once policymakers have chosen to significantly adjust the water level, to switch to changing the crop type or land use. The sell-by date of an action depends on the scenario and the objectives. This is shown with the two x-axes, one for each scenario.

4.5. Step 6: select preferred pathways

From the Adaptation Pathways map, preferred pathways can be selected. Different decisionmakers and stakeholders can have different preferred pathways, depending on their values and beliefs. Fig. 7 presents an example of the preferred pathways for

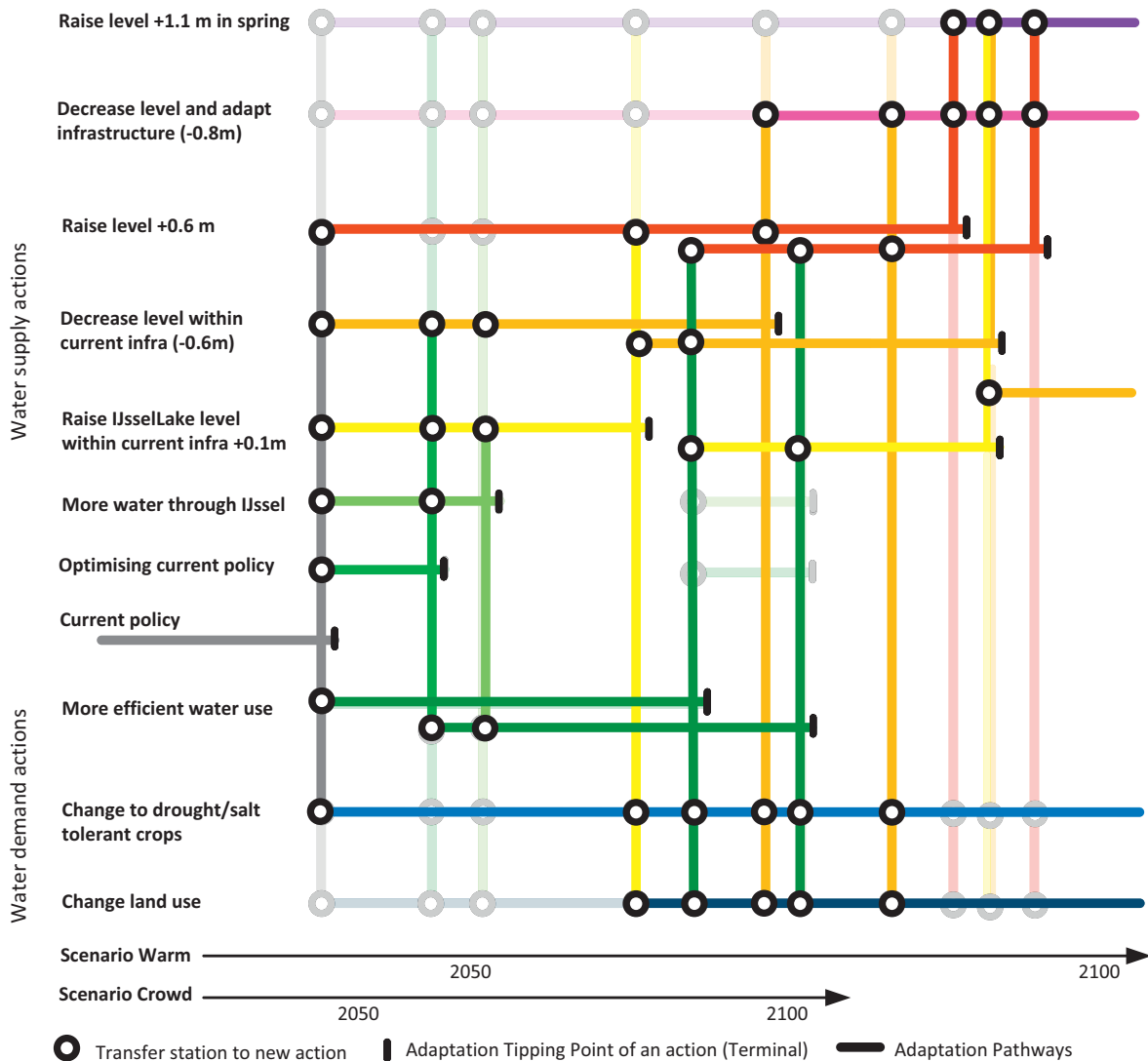


Fig. 6. Adaptation pathways map for fresh water supply from the IJsselmeer area.

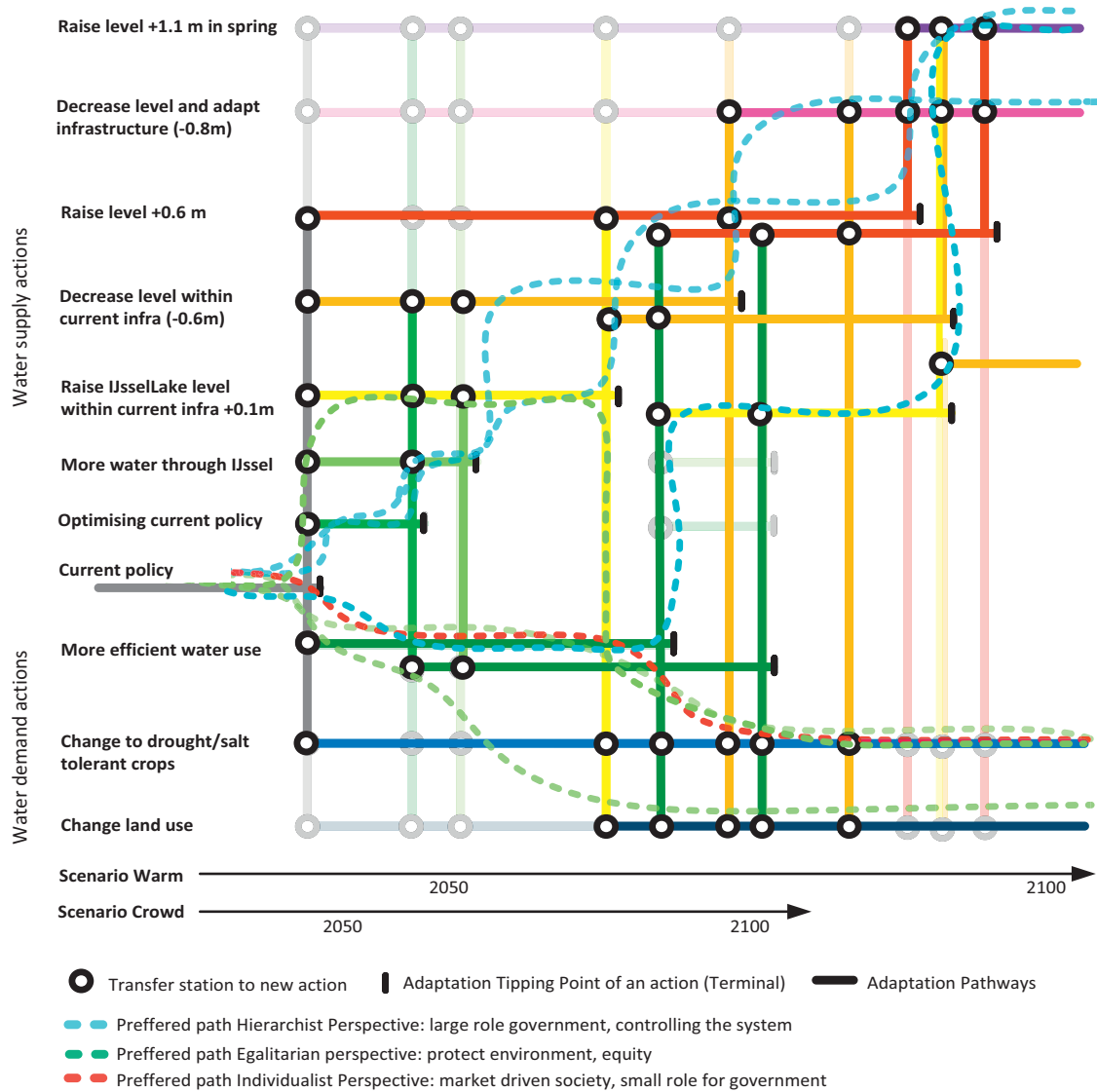


Fig. 7. Adaptation pathways map with preferred pathways for three different perspectives.

archetypes of three perspectives: Hierarchist, Egalitarian, and Individualist (see e.g. Hoekstra, 1998; Middelkoop et al., 2004 on these perspectives related to water). For example, Hierarchist believes in controlling water and nature, assigning major responsibilities to the government. This means a preference for actions related to managing water levels and water use. The Egalitarian focuses on the environment and equity, resulting in strategies for decreasing water demands by adapting functions to their environment (other crops or their relocation). The Individualist adheres to a liberal market and a high trust in technology and innovation. This means a preference for facilitating technological developments for more efficient with water use and drought tolerant crop types. Portions of the preferred pathways are similar. The point at which the paths start to diverge can be considered as a decision point. In our case, there are three decision points: (1) after 'current plan', (2) after 'raise the IJsselmeer level within current infrastructure', and (3) after 'more efficient water use'. The preferred pathways could be a start of a discussion on an adaptive plan. In addition, combinations of these pathways could be drawn as paths that have support from more than one perspective. For example, starting with 'more efficient water use in the regional areas' could be followed by a small raising of the IJsselmeer water level (+0.1 m), and, if needed, that water level can be raised more,

or the water demand could be reduced by changing crop types. The short-term action is one that all perspectives could agree upon, and can thus be considered a socially robust action (Offermans et al., 2011).

4.6. Step 7: determine contingency actions, signposts, and triggers

To get or stay on the track of a pathway, contingency actions can be specified. For example, the Government could stimulate the growth of salt and/or drought tolerant crops with subsidies, or by limiting water availability and holding farmers responsible for finding 'enough' water. Keeping the option open for an increase of the IJsselmeer level will require spatial planning rules (e.g. allow adaptive building only outside the dike rings). If structures need to be replaced, they can be built such that they are already able to cope with future actions. Corrective actions need to be taken to achieve objectives for nature. Constructing shallow zones and islands can mitigate the negative impacts of raising the water level. This can bring opportunities for dredging companies.

We distinguish three different groups of signposts and triggers: (1) trends and events in the natural environment (the water system); (2) human-driven impacts on the water system, such as the autonomous adaptation of farmers or a change in upstream

water use; and (3) societal perspectives about the future, such as expectations about climate change and population growth, knowledge about (or belief in) the effectiveness of certain policies, and societal values, such as the wish to protect nature and the amount of accepted flood/drought risk. The amount of agricultural area and the crops used could be an appropriate trigger for changes in water demand, since they can be well monitored and change slowly over time.

4.7. Step 8: specify a dynamic adaptive plan

Based on the problem, objectives, and pathways from the previous steps, a dynamic adaptive plan can be specified. Considering the scenarios, the amount of water storage needed in the future requires up to a 1.5 m water level in the IJsselmeer. Raising the water level is the preferred action from a safety point of view, because in that case water can be discharged to the Waddensea under gravity. However, in the short- and mid-term (<2080) this action is not needed. To keep this option open, spatial planning rules could be implemented. Initial actions can focus on improving the performance of the current plan by introducing a flexible water level (e.g. outside the growing season, the water level may drop) and making more efficient use of water in the regional areas (e.g. have a separate area for brackish and salty groundwater, in order to decrease the amount of water needed for flushing). To keep other options open, the Government could invest in research and development of drought and/or salt tolerant crops. The plan for future actions needs to be ready, in case a window of opportunity arises for adapting the water system to potential future conditions. An example of such an opportunity is when infrastructure (sluices, dams, etc.) requires maintenance. At the same time as maintenance is being carried out, new structures could be added that would be able to cope with an increase or decrease of the water level in the IJsselmeer. Huq and Reid (2004) assign the label ‘mainstreaming’ to actions that incorporate “potential climate change impacts into ongoing strategies and plans”. Another window for opportunity arises in the case of a dry year. In such a year, societal support for implementing such actions is likely to be higher.

4.8. Steps 9 and 10: implementation of dynamic adaptive plan and monitoring

The first actions of the plan are implemented, and the Government continues monitoring sea level rise and climate changes. Furthermore, the Government monitors changes in water demands through land use changes and determines additional signposts together with water boards (water managers of the regional system) and representatives of the agricultural sector.

5. Evaluation of the method

In this paper, we have presented an approach for supporting decisionmaking under uncertain global and regional changes, called Dynamic Adaptive Policy Pathways. This approach assists in designing dynamic adaptive plans, and is built upon the best features of two existing adaptation methods. From the concept of Adaptive Policymaking we used the ideas of (1) thinking beforehand of ways a plan might fail and designing actions to guard against such failures, (2) preparing for actions that might be triggered later, in order to keep a plan on track to meeting its objectives, and (3) implementing a monitoring system to identify when such actions should be triggered. From Adaptation Pathways, we used the idea of an Adaptation Pathways map, which visualizes sequences of possible actions through time, and includes uncertainties concerning societal values through perspectives.

The map is enriched with triggers from Adaptive Policymaking, which indicate when each new action should come into force.

We illustrated the integrated approach by applying it to a case inspired by a real strategy development project to prepare the Dutch water system for future climate change taking into account socio-economic developments. By applying our approach to a real world case, we have learned about the strengths and weaknesses of the approach, which we elaborate in this section.

A strength of the method is that it stimulates planners to include adaptation over time in their plans – to explicitly think about actions that may need to be taken now to keep options open, and decisions that can be postponed. Thus, the inevitable changes become part of a larger, recognized process and are not forced to be made repeatedly on an *ad hoc* basis. Planners, through monitoring and corrective actions, would try to keep the system headed toward the original goals.

The concept of Dynamic Adaptive Policy Pathways may be difficult to understand. But, the ten clearly defined steps described in Section 3 provide a set of clear tasks that, if followed, result in a dynamic adaptive plan. We have discussed the method with water and spatial planning policy advisors and policymakers in the Netherlands at both the national and regional/local levels. On the one hand, the approach is comprehensive and more complex than a traditional scenario-strategy impact analysis for one or two points in the future. On the other hand, planners have experienced that plans change over time, and an adaptive strategy is an attractive idea for planners facing deep uncertainty. Moreover, if political conditions are unsuitable, the approach helps to determine for how long a decision can be postponed. Thus, despite the complexity, both policy advisors and policymakers have shown an interest in the method (see e.g. EEA, forthcoming in 2013). The adaptation pathways presented in the ‘metro map’ and the triggers and signposts are considered particularly valuable, as these components of the method are the main new characteristics compared to classical policy planning approaches. For a discussion with high level decisionmakers a simplified pathways map, based on preferred pathways, could be used in combination with a more comprehensive map as background information. The case presented here has served as an inspiration for the Dutch Delta Programme, and is included in their implementation guide for ‘adaptive delta management’ (van Rhee, 2012). Currently, adaptation pathways are being developed for fresh water supply and flood risk management. New model results show that with the pathways presented here, an acceptable water shortage may occur once in 100 years, and that for a target of once in 10 years the sell-by dates are further away (e.g. current plan may be sufficient for achieving objectives for approximately 50 years if the target is sufficient water for once in 10 years).

The moment of an adaptation tipping point (the sell-by date) helps in identifying possible paths. However, most actions cannot be implemented immediately at their sell-by date. For those, we need to include a lead time. The thinking behind triggers helps in identifying required lead times. However, climate change may be difficult to detect, especially changes in extremes, due to large natural variability compared to the magnitude of change (see e.g. Diermanse et al., 2010; Hallegatte, 2009; Pielke, 2012). For example, water managers would like to know if climate change is happening because of the potential increase of floods and droughts. However, measuring (for example) peak discharges as a sign that climate change is happening is very difficult, because of high natural variability and the short time period of measurements (Diermanse et al., 2010). Still, land use, population changes, and sea level rise are gradual developments that are easier to detect.

With respect to decisionmaking, Adaptation Pathways provide insights into options, lock-ins, and path dependencies. Thus, an Adaptation Pathways map provides a valuable starting point for

decisionmaking on short-term actions, while keeping options open and avoiding lock-ins. All pathways satisfy a minimum performance level regarding the main targets. Still, some pathways are more attractive than others due to costs or negative/positive side effects. This can be used to select a set of preferred pathways. Potential future decisive moments can be identified based on the lead time of actions and the points where preferred pathways start to differ.

To determine the success of actions and pathways, quantitative targets are needed. However, in reality, policymakers sometimes choose to keep these targets vague, making it difficult to determine the efficacy of an action and pathway. Exploring different quantifications of the targets can show the effects of the different targets, which may support a discussion about appropriate targets. A worthwhile elaboration on the approach presented here would be the evaluation of pathways with, e.g. a cost–benefit analysis or a multi-criteria analysis.

The visualization of the pathways is seen as attractive by policymakers. This way of visualizing works best if the objectives can be summarized in a single main objective, such as ‘fresh water supply for different sectors’ or ‘safety against flooding’. In our case, we considered two main objectives that influenced each other. Because the flood management actions did not vary a lot, the relation between the two sets of actions could be easily described. In the Dutch Delta Programme the situation is more complex due to planning for different areas that have different pathways that influence each other.

The use of perspectives is an element that has previously received little attention in the planning literature. We used different perspectives (or visions) of the different stakeholders to identify alternative preferred pathways and socially robust actions (Offermans et al., 2008, 2011). Different stakeholders may support different plans, but they can also have different reasons to support the same plan. For example, allocating ‘room for a river’ may be preferred by some because it enhances nature and lowers water levels in the case of peak discharges, while others may prefer this action solely because it lowers the flood risk. Development of pathways using stakeholder participation (decisionmakers and stakeholders) has been explored in a game setting (Valkering et al., 2012). In this way, uncertainties arising from decisionmaking, and preferences among plans arising from different perspectives, can be further explored.

The analytical basis of the approach (e.g. for determining sell-by dates and developing pathways) can be supported with computational scenario-based approaches. Making the necessary runs in a reasonable amount of time requires a policy model that is fast and simple, but accurate enough to simulate the relevant transient scenarios and assess the relative effects from a wide variety of actions for the full set of performance indicators over time. Currently, there is no such model of the lower Rhine Delta. Therefore, we assessed the effectiveness and sell-by dates of the possible actions using expert judgment and model results from previous studies. We were able to assess the relative impacts qualitatively. McDaniels et al. (2012) used expert judgment to explore robust alternatives. But, for a better determination of the sell-by dates, a computational exploration is crucial. There is a need for fast simple models that are suitable for exploring actions over time in order to develop adaptation pathways. More complex models can then be used to obtain more detailed information about the performance of the most promising actions resulting from the initial exploration.

Further work is also needed on computational techniques that can help in identifying opportunities and vulnerabilities and developing promising pathways. In a real case, the combination of actions and consequently the number pathways can be huge. To support the identification of the most promising sequences of actions, we are working on an improved computer-assisted

approach for designing an adaptive policy to evaluate candidate pathways over an ensemble of possible futures and assess their robustness (Kwakkel and Haasnoot, 2012). Lempert et al. (2006), Lempert and Groves, 2010 present a computer assisted approach to develop robust strategies across a variety of deep uncertainties, grounded in Exploratory Modeling and Analysis (Agusdinata, 2008; Bankes, 1993; Bankes et al., 2013). We are developing a ‘workbench’ to support such computational scenario-based techniques. Early experiences with the workbench indicate that using a fast and simple model, exploring uncertainties in addition to climate change, and accounting for the joint impact of all the uncertainties, in support of the development of adaptation pathways is useful and feasible (Kwakkel and Haasnoot, 2012).

6. Concluding remarks

In light of the deep uncertainties decisionmakers are facing nowadays, a new planning approach is needed that results in plans that perform satisfactorily under a wide variety of futures and can be adapted over time to (unforeseen) future conditions. Various techniques are available (e.g. Robust Decision Making, Real Options Analysis, decision trees, roadmaps, and several policy planning approaches) that have been or are being applied for supporting planning under deep uncertainty (e.g. in the Thames Estuary in the UK, the Rhine-Meuse delta in the Netherlands, and New York City and the Port of Los Angeles in the USA). We have used two complementary approaches for planning under deep uncertainty – Adaptive Policymaking and Adaptation Pathways – to develop an integrated approach based on the strong features of each of them. This approach, called Dynamic Adaptive Policy Pathways, results in an adaptive plan that is able to deal with changing (unforeseen) conditions.

Key principles of the Dynamic Adaptive Policy Pathways approach are: the use of transient scenarios representing a variety of relevant uncertainties and their development over time; anticipating and corrective actions to handle vulnerabilities and opportunities; several Adaptation Pathways describing sequences of promising actions; and a monitoring system with related actions to keep the plan on the track of a preferred pathway. The approach supports the exploration of a wide variety of relevant uncertainties in a dynamic way, connects short-term targets and long-term goals, and identifies short-term actions while keeping options open for the future. There is evidence that such policies are efficacious (Kwakkel et al., 2012) and cost-beneficial (Yzer et al., submitted). In the end, all this has to fit into a political process, which has always been a real source of ‘deep uncertainty’. Political circumstances can give a window of opportunity (or not) to implement the designed adaptive plan. Also, the adaptive plan could be used to create the right political circumstances, for example by showing potential lock-ins, potential adverse impacts, and for how long a decision can be postponed. The Perspectives method could be used to frame the plan for different societal perspectives (as illustrated by Offermans et al., 2008).

In this paper, we have illustrated and tested the approach using a virtual world inspired by a real world decision problem currently faced by the Dutch National Government in the Delta Programme. We were able to apply the method, and this result was received with great interest by policymakers of the Dutch Delta Programme. The results suggest that it is worthwhile to further use and test the approach for a real quantitative case study, other policy domains, and other countries.

Acknowledgments

This research has been funded by the Deltares research project ‘*Perspectives in Integrated Resources Management in River deltas*’ and

the 'Knowledge for Climate' Research Programme, under the research theme '*Climate Proof Fresh Water Supply*'. We would like to thank our colleagues working on the Delta Programme (especially Pieter Bloemen, Ad Jeuken, Nathalie Asselman and Frans Klijn) for their feedback on the approach. We also thank the reviewers for their useful suggestions on an earlier version of the paper.

References

- Agusdinata, D.B., 2008. Exploratory Modeling and Analysis: A Promising Method to Deal with Deep Uncertainty. Faculty of Technology, Policy, and Management, Delft University of Technology, Delft.
- Albrechts, L., 2004. Strategic (spatial) planning reexamined. *Environment and Planning B: Planning and Design* 31, 743–758.
- America's Climate Choices, 2010. Informing an Effective Response to Climate Change. National Research Council, Washington. , http://www.nap.edu/catalog.php?record_id=12781.
- Bankes, S.C., 1993. Exploratory modeling for policy analysis. *Operations Research* 4, 435–449.
- Bankes, S.C., 2002. Tools and techniques for developing policies for complex and uncertain systems. *Proceedings of the National Academy of Sciences of the United States of America* 99, 7263–7266.
- Bankes, S.C., Walker, W.E., Kwakkel, J.H., 2013. Exploratory modeling and analysis. In: Gass, S., Fu, M.C. (Eds.), *Encyclopedia of Operations Research and Management Science* 3rd ed..
- Bruggeman, W., Hommes, S., Haasnoot, M., te Linde, A., Van der Brugge, R., 2011. Deltascenarios: Scenarios for Robustness Analysis of Strategies for Fresh Water Supply and Water Safety. (Deltascenario's: Scenario's voor robuustheidanalyse van maatregelen voor zoetwatervoorziening en waterveiligheid)). Deltares.
- Bryant, B.P., Lempert, R.J., 2010. Thinking inside the box: a participatory computer-assisted approach to scenario discovery. *Technological Forecasting and Social Change* 77, 34–49.
- Collingridge, D., 1980. *The Social Control of Technology*. Frances Pinter Publisher, London, UK.
- de Neufville, R., Odoni, A., 2003. *Airport Systems: Planning, Design, and Management*. McGraw-Hill, New York.
- Delta Programme, 2011. Working on the Delta. The 2011 Delta Programme. Investing in a Safe and Attractive Netherlands, Now and in the Future. , http://www.deltacommissaris.nl/english/Images/Deltaprogramma_ENG1_tcm310-286802.pdf.
- Delta Programme, 2012. Delta Programme 2013: The Road Towards the Delta Decisions. Dutch Ministry of Infrastructure and the Environment and the Ministry of Economic Affairs, Agriculture and Innovation http://www.deltacommissaris.nl/english/Images/Delta_Programme_2013_ENG_tcm310-334162.pdf (13.11.12).
- Deltacommissie, 2008. Working Together with Water: A Living Land Builds for its Future. Findings of the Dutch Delta Committee 2008. Ministerie van Verkeer en Waterstaat, the Hague, The Netherlands. , <http://www.deltacommissie.com/en/advies>.
- Dessai, S., Hulme, M., 2007. Assessing the robustness of adaptation decisions to climate change uncertainties: a case study on water resources management in the East of England. *Global Environmental Change* 17, 59–72.
- Dessai, S., Van der Sluijs, J.P., 2007. Uncertainty and Climate Change Adaptation – A Scoping Study. Copernicus Institute for Sustainable Development and Innovation, Utrecht.
- Dewar, J., Builder, C., Hix, W., Levin, M., 1993. *Assumption-Based Planning: A Planning Tool for Very Uncertain Times*. RAND Corporation, Santa Monica.
- Dewey, J., 1927. *The Public and its Problems*. Holt and Company, New York.
- Diermanse, F., Kwadijk, J.C.J., Beckers, J., Crebas, J., 2010. Statistical trend analysis of annual maximum discharges of the Rhine and Meuse rivers. In: BHS Third International Symposium, Managing Consequences of a Changing Global Environment, Newcastle, UK.
- EEA. *Adaptation in Europe*. European Environment Agency, Copenhagen, forthcoming.
- Frey, D.D., Dym, C.L., 2006. Validation of design methods: lessons from medicine. *Research in Engineering Design* 17, 45–57.
- Gersonius, B., Ashley, R., Pathirana, A., Zevenbergen, C., 2013. Climate change uncertainty: building flexibility into water and flood risk infrastructure. *Climatic Change* 116, 411–423.
- Groves, D.G., Lempert, R.J., 2007. A new analytic method for finding policy-relevant scenarios. *Global Environmental Change* 17, 76–85.
- Haasnoot, M., Middelkoop, H., Offermans, A., Van Beek, E., van Deursen, W.P.A., 2012. Exploring pathways for sustainable water management in river deltas in a changing environment. *Climatic Change* 115, 795–819.
- Haasnoot, M., Middelkoop, H., van Beek, E., van Deursen, W.P.A., 2011. A method to develop sustainable water management strategies for an uncertain future. *Sustainable Development* 19, 369–381.
- Hall, J.W., Harvey, H., 2009. Decision making under severe uncertainties for flood risk management: a case study of info-gap robustness analysis. In: *Hydroinformatics Conference*, Concepcion, Chile.
- Hall, J.W., Lempert, R.J., Keller, A., Hackbarth, A., Mijere, C., McInerney, D., 2012. Robust climate policies under uncertainty: a comparison of robust decision making and info-gap methods. *Risk Analysis* 32, 1657–1672.
- Hallegatte, S., 2009. Strategies to adapt to an uncertain climate change. *Global Environmental Change* 19, 240–247.
- Hallegatte, S., Shah, A., Lempert, R., Brown, C., Gill, S., 2012. Investment Decision Making Under Deep Uncertainty Application to Climate Change. The World Bank.
- Hamarat, C., Kwakkel, J.H., Pruyt, E., 2012. Adaptive Robust Design under Deep Uncertainty. *Technological Forecasting and Social Change*.
- Hansman, R.J., Magee, C., De Neufville, R., Robins, R., Roos, D., 2006. Research agenda for an integrated approach to infrastructure planning, design, and management. *International Journal of Critical Infrastructures* 2, 146–159.
- Hoekstra, A.Y., 1998. *Perspectives on Water: An Integrated Model-Based Exploration of the Future*. Faculty of Technology, Policy and Management, Delft University of Technology, Delft.
- Höjer, M., Mattsson, L.-G., 2000. Determinism and backcasting in future studies. *Futures* 32, 613–634.
- Holling, C.S., 1978. *Adaptive Environmental Assessment and Management*. John Wiley & Sons, New York.
- Huq, S., Reid, H., 2004. Mainstreaming adaptation in development. *IDS Bulletin* 35, 15–21.
- IISD, 2006. Designing Policies in a World of Uncertainty, Change and Surprise – Adaptive Policy-Making for Agriculture and Water Resources in the Face of Climate Change – Phase I Research Report. International Institute for Sustainable Development, Winnipeg.
- Jeuken, A., Reeder, T., 2011. Short-term decision making and long-term strategies: how to adapt to uncertain climate change. *Water Governance* 1, 29–35.
- Kabat, P., Fresco, L.O., Stive, M.J.F., Veerman, C.P., van Alphen, J.S.L.J., Parmet, B.W.A.H., Hazeleger, W., Katsman, C., 2009. Dutch coasts in transition. *Nature Geoscience* 2, 450–452.
- Klijn, F., ter Maat, J., Van Velzen, A., 2011. Zoetwater voorziening in Nederland. Landelijke analyse knelpunten in de 21e eeuw. Deltares <http://www.deltares.nl/actueel/nieuwsbericht/item/12706/knelpunten-watervraag-en-water-beschikbaarheid> (17.04.12).
- Korteling, B., Dessai, S., Kapelan, Z., 2012. Using information-gap decision theory for water resources planning under severe uncertainty. *Water Resource Management* 1–24.
- Kuijken, W., 2010. The Delta Programme in the Netherlands: The Delta Works of the Future. <http://www.deltacommissaris.nl/english/news/speeches/thedeltaprogrammeinthetherlandsthe deltaworksofthefuture.aspx> (29.05.12).
- Kwadijk, J.C.J., Haasnoot, M., Mulder, J.P.M., Hoogvliet, M.M.C., Jeuken, A.B.M., van der Krogt, R.A.A., van Oostrom, N.G.C., Schelfhout, H.A., van Velzen, E.H., van Waveren, H., de Wit, M.J.M., 2010. Using adaptation tipping points to prepare for climate change and sea level rise: a case study in the Netherlands. *Wiley Interdisciplinary Reviews: Climate Change* 1, 729–740.
- Kwakkel, J.H., Haasnoot, M., 2012. Computer assisted dynamic adaptive policy design for sustainable water management in river deltas in a changing environment. In: Seppelt, R., Voinov, A.A., Lange, S., Bankamp, D. (Eds.), *International Congress on Environmental Modelling and Software Managing Resources of a Limited Planet, Sixth Biennial Meeting*, Leipzig, Germany.
- Kwakkel, J.H., Van Der Pas, J.W.G.M., 2011. Evaluation of infrastructure planning approaches: an analogy with medicine. *Futures* 43, 934–946.
- Kwakkel, J.H., Walker, W.E., Marchau, V.A.W.J., 2010a. Adaptive airport strategic planning. *European Journal of Transport and Infrastructure Research* 10, 249–273.
- Kwakkel, J.H., Walker, W.E., Marchau, V.A.W.J., 2010b. Classifying and communicating uncertainties in model-based policy analysis. *International Journal of Technology, Policy and Management* 10, 299–315.
- Kwakkel, J.H., Walker, W.E., Marchau, V.A.W.J., 2012. Assessing the efficacy of adaptive airport strategic planning: results from computational experiments. *Environment and Planning B: Planning and Design* 39, 533–550.
- Lawrence, J., Manning, M., 2012. *Developing Adaptive Risk Management for our Changing Climate: A Report of Workshop Outcomes under an Envirolink Grant*. The New Zealand Climate Change Research Institute, Victoria University of Wellington.
- Lee, K., 1993. *Compass and Gyroscope: Integrating Science and Politics for the Environment*. Island Press, Washington.
- Lempert, R.J., Groves, D.G., 2010. Identifying and evaluating robust adaptive policy responses to climate change for water management agencies in the American West. *Technological Forecasting and Social Change* 77, 960–974.
- Lempert, R.J., Groves, D.G., Popper, S., Bankes, S., 2006. A general analytic method for generating robust strategies and narrative scenarios. *Management Science* 52, 514–528.
- Lempert, R.J., Popper, S., Bankes, S., 2002. Confronting surprise. *Social Science Computer Review* 20, 420–439.
- Lempert, R.J., Schlesinger, M.E., Bankes, S.C., Andronova, N.G., 2000. The impacts of climate variability on near-term policy choices and the value of information. *Climatic Change* 45, 129–161.
- Loucks, D.P., Van Beek, E., 2005. *Water Resources Systems Planning and Management: An Introduction to Methods, Models and Applications*. Unesco Publishing.
- Lovins, A., 1976. Energy strategy: the road not taken? *Foreign Affairs* 55, 63–96.
- Lowe, J.A., Howard, T., Pardaens, A., 2009. *UK Climate Projections Science Report: Marine and Coastal Projections*. Met Office Hadley Centre, Exeter.
- Marchau, V.A.W.J., Walker, W.E., van Duin, R., 2009. An adaptive approach to implementing innovative urban transport solutions. *Transport Policy* 15, 405–412.
- McDaniels, T., Mills, T., Gregory, R., Ohlson, D., 2012. Using expert judgments to explore robust alternatives for forest management under climate change. *Risk Analysis* no–no.

- McGahey, C., Sayers, P.B., 2008. Long term planning – robust strategic decision making in the face of gross uncertainty – tools and application to the Thames. In: *Flood Risk Management: Research and Practice*. Proceedings of FLOODrisk 2008, Taylor & Francis, London, UK, pp. 1543–1553.
- McInerney, D., Lempert, R., Keller, K., 2012. What are robust strategies in the face of uncertain climate threshold responses. *Climate Change* 112, 547–568.
- McLain, R.J., Lee, R.G., 1996. Adaptive management: promises and pitfalls. *Environmental Management* 20, 437–448.
- Metz, B., Davidson, O., Swart, R., Pan, J., 2001. *Climate Change 2001: Mitigation*. Contribution of Working Group III to the third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK.
- Middelkoop, H., Van Asselt, M.B.A., Van't Klooster, S.A., Van Deursen, W.P.A., Kwadijk, J.C.J., Buiteveld, H., 2004. Perspectives on flood management in the Rhine and Meuse rivers. *River Research and Applications* 20, 327–342.
- Offermans, A., 2010. Learning from the past: the interaction of the social system and the water system in the Netherlands. In: *Berlin Conference on the Human Dimensions of Global Environmental Change*, Berlin.
- Offermans, A., Haasnoot, M., Valkering, P., 2011. A method to explore social response for sustainable water management strategies under changing conditions. *Sustainable Development* 19, 312–324.
- Offermans, A., Haasnoot, M., Van Beek, E., Middelkoop, V.P.V., 2008. Advies van de Deltacommissie vergt breder perspectief. (Advice of the Delta committee calls for wider perspective). *H2O* 20, 36–40 (in Dutch).
- Pahl-Wostl, C., 2007. Transitions towards adaptive management of water facing climate and global change. *Water Resources Management* 21, 49–62.
- Pahl-Wostl, C., Sendzimir, J., Jeffrey, P., Aerts, J., Berkamp, G., Cross, K., 2007. Managing change towards adaptive water management through social learning. *Ecology and Society* 12 (30) [online].
- Pielke, R.J., 2012. Little Change in Drought Over 60 Years. <http://rogerpielkejr.blogspot.nl/2012/11/little-change-in-drought-over-60-years.html> (18.11.12).
- Projectteam Verkenning oplossingsrichtingen Volkerak-Zoommeer, 2003. Verkenning oplossingsrichtingen Volkerak-Zoommeer (in Dutch).
- Quist, J., Vergragt, P., 2006. Past and future of backcasting: the shift to stakeholder participation and a proposal for a methodological framework. *Futures* 38, 1027–1045.
- Ranger, N., Millner, A., Dietz, S., Fankhauser, S., Lopez, A., Ruta, G., 2010. *Adaptation in the UK: A Decision-making Process*. Grantham Research Institute on Climate Change and the Environment and Center for Climate Change Economics and Policy.
- Reeder, T., Ranger, N. How do you adapt in an uncertain world? Lessons from the Thames Estuary 2100 project, Washington, DC. http://www.worldresourcesreport.org/files/wrr/papers/wrr_reeder_and_ranger_uncertainty.pdf, 13 November 2012, online.
- Rijkswaterstaat, 2011. Water Management in the Netherlands. In: <http://www.rijkswaterstaat.nl/en/images/Water%20Management%20in%20the%20Netherlands.tcm224-303503.pdf> (17.04.12).
- Roosjen, R., Van der Brugge, R., Morselt, T., Jeuken, A., 2012. Adaptief Deltamanagement. Pilot voor deelprogramma Rijnmond/Drechtsteden. Deltares Blue-economy.nl: <http://kennisonline.deltares.nl> (in Dutch).
- Rosenhead, J., 1990. Rational analysis: keeping your options open. In: Rosenhead, J., Mingers, J. (Eds.), *Rational Analysis for a Problematic World: Problem Structuring Methods for Complexity, Uncertainty and Conflict*. John Wiley & Sons, Chichester, England.
- Rosenhead, J., Elton, M., Gupta, S.K., 1972. Robustness and optimality as criteria for strategic decisions. *Operational Research Quarterly* 23, 413–431 (1970–1977).
- Rosenzweig, C., Solecki, W.D., Blake, R., Bowman, M., Faris, C., Gornitz, V., Horton, R., Jacob, K., Le Blanc, A., Leichenko, R., Linkin, M., Major, D., O'Grady, M., Patrick, L., Sussman, E., Yohe, G., Zimmerman, R., 2011. Developing coastal adaptation to climate change in the New York City infrastructure-shed: process, approach, tools, and strategies. *Climatic Change* 106, 93–127.
- Sayers, P.B., Galloway, G.E., Hall, J., 2012. Robust decision-making under uncertainty—towards adaptive and resilient flood risk management infrastructure. In: Sayers, P.B. (Ed.), *Flood Risk Planning, Design and Management of Flood Defence Infrastructure*. ICE Publishing, pp. 281–302.
- Schön, D.A., 1983. *The Reflective Practitioner*. Basic Books, New York.
- Schwartz, E.S., Trigeorgis, L., 2004. *Real Options and Investment under Uncertainty: Classical Readings and Recent Contributions*. The MIT Press.
- Straatemeier, T., Bertolini, L., Brömmelstroet, M., 2010. An experiential approach to research in planning. *Environment and Planning B: Planning and Design* 37, 578–591.
- Swanson, D., Bhadwal, S., 2009. *Creating Adaptive Policies. A Guide for Policy-making in an Uncertain World*.
- Swanson, D.A., Barg, S., Tyler, S., Venema, H., Tomar, S., Bhadwal, S., Nair, S., Roy, D., Drexhage, J., 2010. Seven tools for creating adaptive policies. *Technological Forecasting and Social Change* 77, 924–939.
- Te Linde, A., Van der Brugge, R., Hommes, S., Haasnoot, M., Bruggeman, W. Balancing between science and policy while implementing a new method for scenarios for water management in The Netherlands, submitted.
- Valkering, P., van der Brugge, R., Offermans, A., Haasnoot, M., Vreugdenhil, H., 2012. A perspective-based simulation game to explore future pathways of a water-society system under climate change. *Simulation & Gaming*. <http://dx.doi.org/10.1177/1046878112441693>.
- Van Asselt, M.B.A., Rotmans, J., 1997. *Uncertainties in perspective*. In: Rotmans, J., de Vries, B. (Eds.), *Perspectives on Global Change: The TARGETS Approach*. Cambridge University Press, Cambridge, UK.
- Van den Hurk, B., Klein Tank, A., Lenderink, G., Van Ulden, A., Van Oldenborgh, G.J., Katsman, C., Van den Brink, H., Keller, F., Bessembinder, J., Burgers, G., Komen, G., Hazeleger, W., Drijfhout, S., 2007. New climate change scenarios for the Netherlands. *Water Science and Technology* 56, 27–33.
- van der Brugge, R., Rotmans, J., Loorbach, D., 2005. The transition in Dutch water management. *Regional Environmental Change* 5, 164–176.
- van Rhee, C.G., 2011. Structurering keuze capaciteitsuitbreiding Volkeraksluizen. Stratelligence (in Dutch).
- van Rhee, C.G., 2012. *Handreiking Adaptief Deltamanagement*. Stratelligence Decision Support, in assignment of the Staf of the Delta commissioner, Leiden, <https://deltaprogramma.pleio.nl/file/view/13006692/100812-handreiking-adm-definitief-concept-2pdf>.
- Walker, W.E., 1988. *Generating and screening alternatives*. In: Miser, H.J., Quade, E.S. (Eds.), *Handbook of Systems Analysis: Craft Issues and Procedural Choices*. Elsevier, New York, New York.
- Walker, W.E., 2000. Policy analysis: a systematic approach to supporting policy-making in the public sector. *Journal of Multi-Criteria Decision Analysis* 9, 11–27.
- Walker, W.E., Haasnoot, M., Kwakkel, J.H. Adapt or perish: a review of planning approaches for adaptation under deep uncertainty, accepted.
- Walker, W.E., Marchau, V.A.W.J., Swanson, D.A., 2010. Addressing deep uncertainty using adaptive policies: introduction to section 2. *Technological Forecasting and Social Change* 77, 917–923.
- Walker, W.E., Rahman, S.A., Cave, J., 2001. Adaptive policies, policy analysis, and policy-making. *European Journal of Operational Research* 128, 282–289.
- Wilby, R.L., Keenan, R., 2012. Adapting to flood risk under climate change. *Progress in Physical Geography* 1–31.
- Willows, R.L., Connell, R.K., 2003. *Climate Adaptation: Risk, Uncertainty and Decision-making*. UKCIP, Oxford.
- Yohe, G., 1990. Imbedding dynamic responses with imperfect information into static portraits of the regional impact of climate change. *International Workshop on the Natural Resource and Economic Implications of Global Climate Change*, Interlaken, Switzerland.
- Yohe, G., Leichenko, R., 2010. Chapter 2: adopting a risk-based approach. *Annals of the New York Academy of Sciences* 1196, 29–40.
- Yzer, J.R., Walker, W.E., Marchau, V.A.W.J., Kwakkel, J.H. Dynamic adaptive policies: a way to improve the cost-benefit performance of megaprojects? *Environment and Planning B: Planning and Design*, submitted.