Third International Engineering Systems Symposium
CESUN 2012, Delft University of Technology, 18-20 June 2012

Designing Adaptive Policy Pathways for Sustainable Water Management under Uncertainty: Lessons Learned from Two Cases

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Abstract. *Water management in river deltas is increasingly being challenged by pressures from population growth, sea level rise, increasing variability in river runoffs, and potential climate change. Adaptation to such changes is not only determined by what is known or anticipated at present, but also by what will be experienced and learned as the future unfolds, as well as by policy responses to social and water events. As a result, a pathway emerges. Instead of responding to surprises and making ad hoc decisions, exploring adaptation pathways into the future will provide indispensable support to water management decision-making. We have developed a structured approach for designing a dynamic adaptive policy based on the concepts of adaptive policy making and adaptation pathways. Such a policy can change over time in response to how the future unfolds, what is learned about the system, and changes in societal preferences. Ingredients of this approach are: (a) transient scenarios (time series of various uncertain developments such as climate change, economic developments, societal changes), (b) a methodology for exploring many options and sequences of these options across different futures, and (c) a stepwise policy analysis. We have applied the method to two cases, a hypothetical case based on a river branch in the lower Rhine Delta, and a real-world case for the Rhine Delta in the Netherlands. In this paper, we describe the approach and lessons learned based on these two cases.*

Keywords. *adaptive policy making, adaptation pathways, water management, uncertainty.*

1 Introduction

Sustainable water management in a changing environment full of uncertainty is a profound challenge. Traditionally, water system planners use forecasts assuming the future context for water system management can be predicted. Although some recent planning studies explore uncertainties in more depth by using a few plausible futures (scenarios) for one or two projection years, they ignore the dynamic aspect of adaptation, which includes transient scenarios and the interaction between the water system and society. To deal with these uncertainties, dynamic adaptive policies can be used. Such policies can change over time in response to how the future unfolds, what we learn about the system, changes in the environment, and changes in societal preferences.

We combined the strong features of two approaches for dealing with uncertainties - adaptation pathways (AP) (Haasnoot *et al.*, accepted) and dynamic adaptive policy making (APM) (Kwakkel *et al.*, 2010, Walker *et al.*, 2001) - to produce a new approach, called Adaptive Policy Pathway (APP) (Walker *et al.*, in prep).

This paper presents the lessons learned from applying the APP approach to two cases: a hypothetical case and a real-world case. We first describe the APP approach (Section 2). Sections 3 and 4 present the application of APP to the two cases. The lessons learned about APP and its value for decision-making from these two cases is presented in Section 5.

2 The Adaptive Policy Pathways Approach

The combined approach of APM and AP, called adaptive policy pathways (APP), includes the strong elements of both. In short, this integrated approach includes: *transient scenarios* representing a variety of relevant uncertainties and their development over time; different types of *policy actions* to handle vulnerabilities and opportunities; *adaptation pathways* describing sequences of promising policy actions; and a *monitoring system* with related *contingency actions* to keep the policy on track of a preferred pathway. The steps in APP approach are presented in Fig. 1.

Step 1 is to *describe the study area,* including a specification of the water system characteristics and related societal issues (e.g. agriculture, flood risk, nature), and the identification of objectives, constraints in the current situation, and potential constraints in the future. The main output from this step is a definition of success, which is a specification of the desired outcomes in terms of indicators and targets. The definition of success is used in subsequent steps to identify problems, and to evaluate the performance of policy actions and policy pathways. The description of the study area should include a specification of the uncertainties that are relevant for decision-making. These uncertainties are not restricted to uncertainties about the future, but can also cover uncertainties related to data or the models that are being used (Kwakkel et al., 2010b).

Step 2 is the *problem analysis*. In this step, the uncertainties specified in Step 1 are used to generate an ensemble of plausible futures in the form of *transient scenarios*. Next, using the condition for success, the possible *vulnerabilities* are identified (vulnerabilities are developments that can cause the policy to fail to achieve success). This determines if and when policy actions are needed. During the problem analysis, attention is also given to the identification of *opportunities* (opportunities are developments that can help in achieving the objectives.

In Step 3, *policy actions* for addressing the identified vulnerabilities and seizing the identified opportunities are defined. To assemble a rich set of possible actions, we distinguish four types of policy actions*: shaping actions, mitigating actions, hedging* *actions, and capitalizing actions* (Kwakkel *et al.*, 2010). In subsequent steps these actions are used as the basic building blocks for the assembly of adaptation pathways.

Step 4 is the *assessment of the efficacy* of each of the identified policy actions. Here, a computational model can be of assistance, by performing an impact analysis across the ensemble of transient scenarios. The efficacy of each of the policy actions is assessed in light of the definition of success. The point in time at which the policy action first fails to meet the success state is called the *sell-by date*. The sell-by date, therefore, indicates how long a particular action in isolation is sufficient to meet the definition of success. Furthermore, the previously identified vulnerabilities and opportunities need to be reassessed. For each action, one needs to assess whether the action was able to reduce or remove a specified vulnerability; whether the action was able to utilize the opportunities; and whether action created new opportunities and/or vulnerabilities.

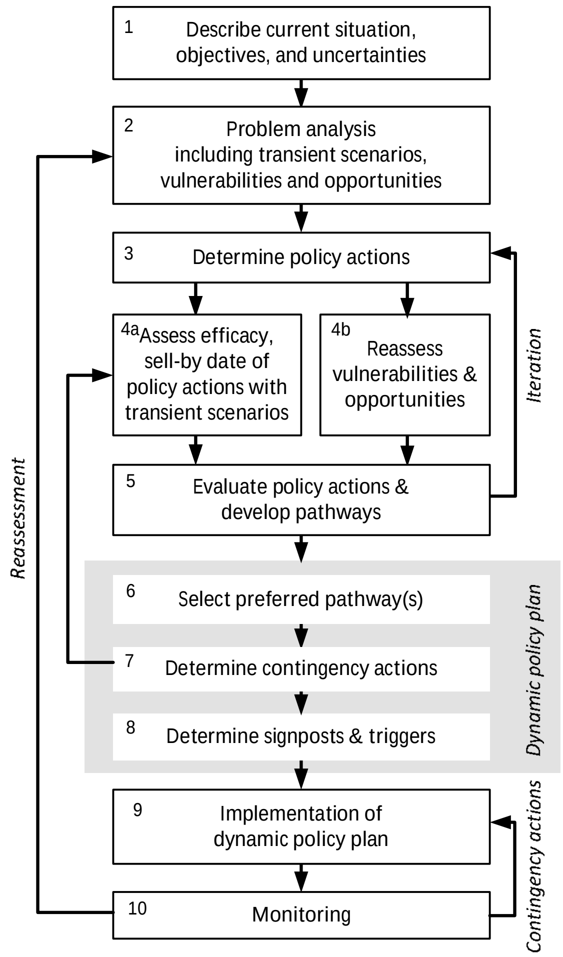

Fig. 1. The Adaptive Policy Pathway approach.

Step 5 is the *development of adaptation pathways*. An adaptation pathway consists of a sequence of policy actions, in which a new policy action is activated once its predecessor is no longer able to meet the definition of success. Pathways can be assembled by exploring all possible routes with all available policy options. However, some actions may exclude others, and some sequences of actions may be illogical. In addition, basic criteria, such as the urgency of actions, the severity of the impacts, the uncertainty involved, and the desire to keep options open, can be used to develop a set of promising pathways. Steps 3- 5 can become an iterative process in which policy actions are added.

The actual *dynamic policy plan*, which consists of a manageable number of preferred pathways, contingency actions, and triggers, is assembled in Steps 6, 7, and 8. Preferred pathways (Step 6) are pathways that fit well within a specified strategy, and can be selected from the set of pathways (which is called an *adaptation pathways map*). A preferred pathway can be improved through contingency planning. We distinguish three types of contingency actions: corrective, defensive, and capitalizing actions (Step 7). Contingency actions are associated with a monitoring system with trigger values (Step 8). The monitoring system specifies what to monitor and when a specific contingency action should be activated. From the final adaptation pathways map, the final dynamic policy plan can be specified (Step 9). This plan specifies which actions are to be taken immediately, which developments need to be monitored, when contingency actions should be implemented, and when a shift to a totally different policy (a policy reassessment - returning to Step 2) should take place.

3 Case 1: Waas

The hypothetical case study, called the Waas, is inspired by a river reach in the Rhine Delta of the Netherlands (the river Waal). The river and floodplain are highly schematized, but have realistic characteristics. The river is bounded by embankments, and the floodplain is separated into five dike rings (Figure 3). A large city is situated on higher grounds in the south-east part. Smaller villages exist in the remaining area, including greenhouses, industry, conservation areas, and pastures. In the past, two large flood events resulted in considerable damage to houses and agriculture. Drought events have limited navigation through the river. These events demonstrate that the system may not have been adequately managed. In the future, climate change and socio-economic developments may increase the pressure on the available space and potential future damages, so additional strategies are needed.

The objectives are to limit the flood damage and to ensure navigation, both of which can be quantified. To achieve these objectives, possible policy actions are identified. Low flow policy options include different ship types and scales of dredging. Flood management options include different dike raising strategies, damage mitigation options (floating houses, building houses on mounds), cooperation with upstream areas, and ‘room for the river’.

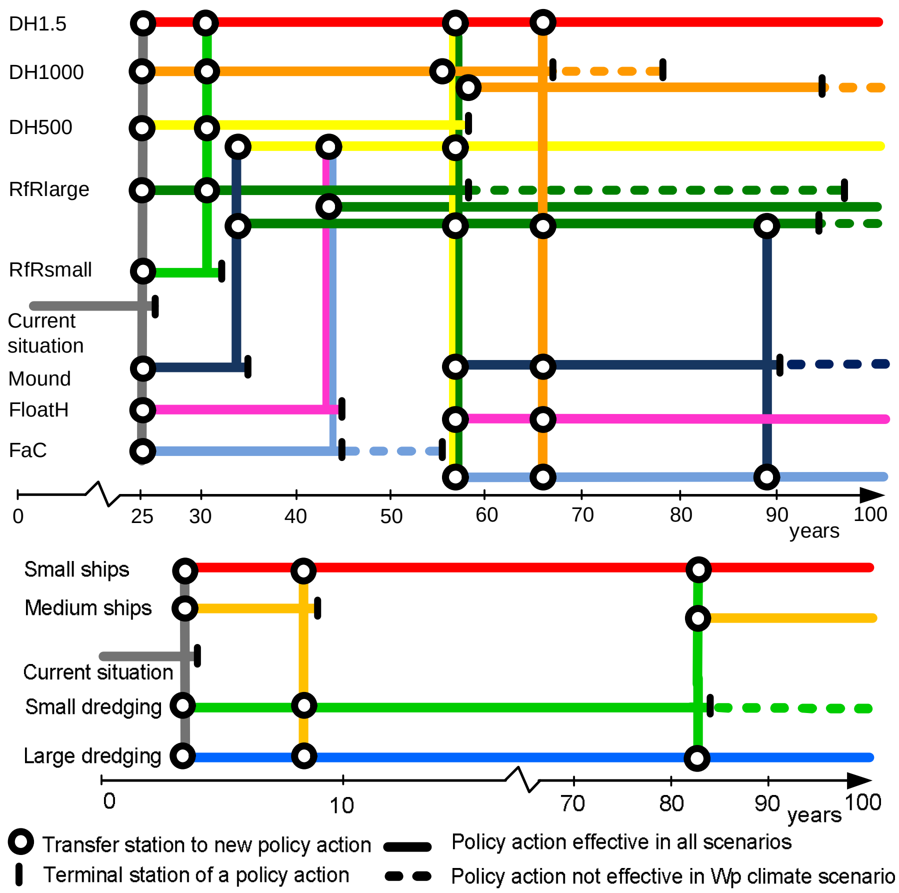

Fig 2. Adaptation pathways maps for flood management and low flow management for the Waas case. DH1.5: dike height rise to 1.5 times the second highest discharge ever measured. DH500, DH1000: dike height rise to respectively 1:500 and 1:1000 disharge. RfRsmall, RfRlarge: small and large scale room for the river. Mound: all cities raise 4 m. FloatH: floating houses. FaC: fort cities, extra embankments.

In order to explore the impacts of alternative futures and policy actions, we built an Integrated Assessment Meta Model (IAMM) (Haasnoot *et al.*, accepted). The model simulates the effects of (changes in) climate conditions and land use on river hydrology (e.g. water levels) and river functions (housing, agriculture, nature, and shipping). To perform dynamic simulation, we used transient scenarios describing an ensemble of climate conditions over time in terms of river discharges. We simulated three different climate scenarios. For each scenario, we obtained 10 realizations. In a follow-up we also explored uncertainties due to land use changes, cause-effect relations and implementation of policy actions (Kwakkel and Haasnoot, 2012).

The policy options were evaluated using flood damage and non-navigable time as performance indicators. The weights assigned to these indicators will generally differ per stakeholder. We captured these differences by using different target values for three different stereotypical Perspectives on water (Middelkoop *et al.*, 2004). We analyzed the effects of individual actions for all transient scenarios (all 10 realizations of the 3 scenarios) and for the 10 realizations of each scenario separately. This resulted in a sell-by year for each policy action and for each realization, which was used to construct the adaptation pathways maps, presented in Fig. 2. The median value of the sell-by year for each action denotes the point in time (terminal station) decision-makers need to consider shifting to another policy action (transfer station). The dashed line indicates that the sell-by date is met in the ensembles of the most extreme climate scenario.

The adaptation pathways maps show that flood mitigation actions are always needed to achieve the objectives, either 1) by raising the dikes extensively (in such a way that they are able to cope with 1.5 times the second highest discharge measured), 2) by combining the dike-raising options with the 'room for the river' measure, or 3) by combining one of the flood mitigation strategies with a damage mitigation measure. The dike-raising options score better in the most extreme climate scenarios than giving 'room for the river', as these strategies include adaptation through raising the dikes to the new design discharge after an event has occurred. This characteristic could be added to the other policy options to improve them. The low flow policy options of small ships and large-scale dredging will meet the targets in all transient scenarios. Choosing small-scale dredging includes taking a risk, as it does not meet the targets in the most extreme climate change realizations.

4 Case 2: Lower Rhine Delta-IJsselmeer

Like other countries in river deltas, the Netherlands, situated in the lower Rhine Delta, requires well-designed water management not only for current challenges, but also to cope with potential future pressures from climate change, sea level rise, and population growth. The Dutch Government is aware of this need, and is presently investigating if actions are needed now or in the future. In our second case, we focus on the real situation in the IJsselmeer area.

Step 1. The IJsselmeer area consists of the Markermeer and IJsselmeer lakes. The Afsluitdijk dam protects its adjacent areas from flooding, and captures fresh water supplied by the IJssel river. During dry periods, water from these lakes is used to supply large parts of the Netherlands. In the future, climate change and socio-economic developments may result in an *increase in water demands* due to more salt intrusion and/or changes in the agricultural sector; *lower fresh water availability* in the summer due to less rain and lower river discharges, and more salt intrusion in the rivers; and an *increase in flood risk* due to sea level rise, higher river discharges, and population and economic growth.

Step 2 and 3. The IJsselmeer area will become even more important as 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. Changes in water levels for lake Markermeer are not explored, as this would require adaptation of current cities, and it is not necessary if the IJsselmeer is used as storage basin. 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 by decreasing agriculture areas or moving them to areas with appropriate environmental conditions. To ensure safety from flooding, either the water level can be raised in correspondence with the sea level, such that excess water can be drained under gravity into the Waddensea (dikes need to be raised accordingly as well), or large pumps can be built for discharging water into the Waddensea. If the first option is chosen, the extra amount of water can be used in times of drought; if the second option is chosen, water inlets and shipping sluices need to be adapted for enabling water use during drought.

Steps 4 and 5. To construct the pathways, the policy actions were grouped into actions influencing water demand and actions influencing water availability. Actions with a long sell-by date are drawn on the top or bottom of the adaptation pathways map (see Fig. 3), while actions with a short sell-by date are drawn close to the current policy. The next step was to identify the sell-by dates and all the possible transfers to other policies, if this would extend the sell-by date. Next, we eliminated illogical options (background color instead of bright colors for logical options in Fig. 3). For example, implementing one of the large actions first would is illogical, as this 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.

Step 6. From the set of pathways, preferred pathways were selected. Different stakeholders can have different preferred pathways depending on their values and beliefs. The variety of perspectives is illustrated for stereotypical Perspectives. Within a Perspective, different pathways are possible. Parts of the pathways are similar. The point, at which the paths start to diverge can be considered as a decision point. In our case, we can see two major decision points - after 'current policy' and 'raise the IJsselmeer level within current infrastructure' reach their sell-by date.

Step 7. To get or stay on the track of a pathway, actions can be used. 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. only allow adaptive building outside the dike rings). If structures need to be replaced, they can be built such that they are already able to cope with future policy actions. Corrective actions need to be taken to achieve objectives for nature. Constructing shallow zones and islands can mitigate negative impacts of water level raising. This can bring opportunities for dredging companies.

Step 8. Signposts and triggers can be used to implement contingency actions or call for a reassessment of the dynamic policy plan. Potential signposts are trends and events in the natural environment (sea level, precipitation), human-driven impacts on the water system (autonomous adaptation of farmers), and societal perspectives. The amount of agricultural area and the crops used, could be an appropriate trigger for changes in water demand, as they can be well monitored and change slowly over time.

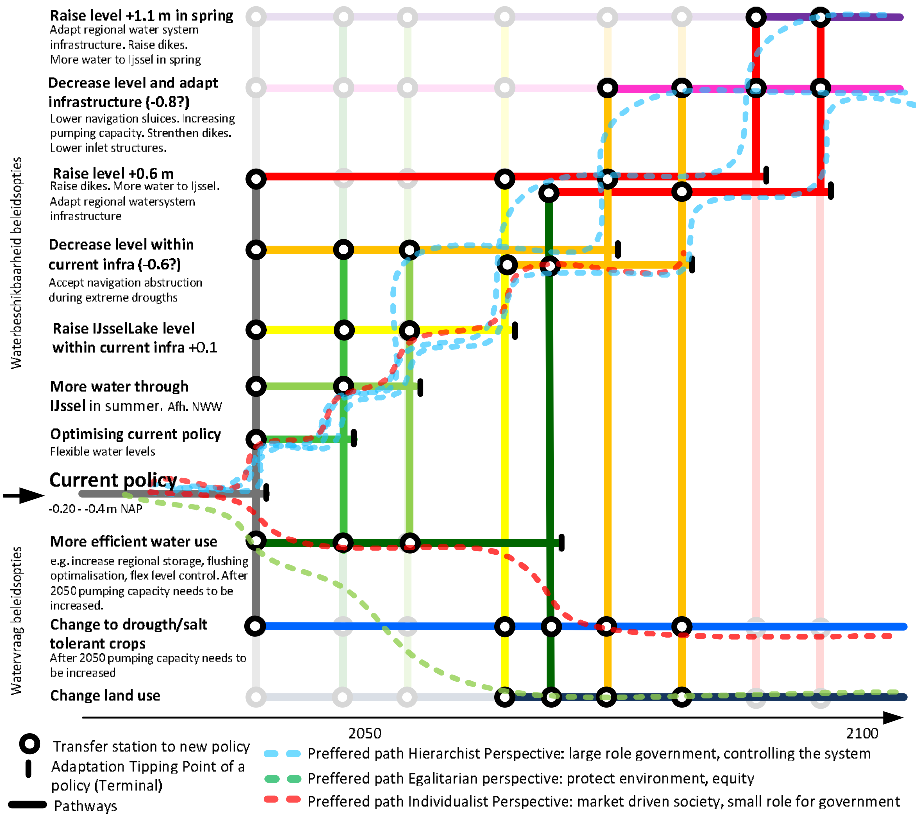

Fig. 3. Adaptation pathways for the lower Rhine Delta-IJsselmeer case.

5 Lessons learned from the two cases

In our evaluation of the two cases, we focus on the lessons regarding the stepwise policy analysis, the role of a computer model, the hypothetical versus real-world case, and the value of the results for decision-making.

The presented *stepwise policy analysis* (ten clearly defined steps) provides guidance on how to develop adaptive policy pathways. The concept of adaptive policy pathways is difficult to understand and explain. But the steps provide a set of clear tasks that, if followed, result in a dynamic policy plan.

The *sell-by date* helps in assembling possible paths. However, for some actions the variety of the sell-by date is large, making it difficult to decide when to start the implementation. Most actions cannot be implemented immediately. For these, we need to include a lead time, indicating the time needed to implement the action. The triggers for these actions need to be set accordingly.

The way to develop *preferred pathways* has previously received little attention. The Perspectives on water or different visions can be to identify these pathways, such as was done in the IJsselmeer case.

Social robustness has also received little attention. Actions that are socially robust perform well under a variety of different Perspectives (Offermans *et al.*, 2011, Offermans *et al.*, 2008). Different Perspectives can have different reasons to support the same policy. For example, 'room for the 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. In the Waas case, the Perspectives were used to explore social uncertainty in terms of different objectives.

A *computer model* is the most appropriate tool for assessing the efficacy of policy actions under a wide variety of relevant *transient* scenarios. The computer model and transient scenarios are needed to determine the sell-by date and develop pathways. 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 impact of policy actions and contingency 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 efficacy and sell-by dates of policy actions using expert judgment and previous studies. We were able to assess the relative impacts, but for determining the sell-by dates a computational model and transient scenarios are crucial. There is a need for a new generation of water policy models that are suitable for exploring policy actions over time in order to develop adaptation pathways. A more complex model can subsequently be used to obtain more detailed information about the performance of the most promising options resulting from the policy exploration using the fast and simple model. A fast and simple model can also be used develop pathways with participatory modeling (e.g. policymakers in a game setting). In this way, uncertainties arising from decision-making can be explored.

The IAMM that was used for the Waas case is connected to an exploratory modeling workbench (Kwakkel and Haasnoot, 2012). This workbench is a tool to automatically explore uncertainties, allowing for significantly more calculations and the inclusion of more (different types) of uncertainties (e.g. uncertainties in the cause-effect relations). Our experience with the Waas case illustrates that, given a fast and simple model such as the IAMM, exploring uncertainties other than climate change and accounting for the joint impact of all the uncertainties is doable. Further work is needed on computational techniques that can help in identifying opportunities and vulnerabilities and developing promising pathways.

The *hypothetical case* (Waas) allowed us to simplify the analysis, and helped us to elaborate our ideas into a structured approach and to show and discuss this approach. Subsequently, the approach was improved and refined using a real-world *case* (Rhine Delta). The benefit of having a good hypothetical case is that it can continually be used to test new ideas. To convince policymakers about the value of the approach, a more realistic case is needed as well, in order to show how it can work in reality. In a real case, the complexity increases. For example, the number of policy options increases significantly, flood management and low flow management actions may interact, and different areas may have specific actions resulting in different pathways, which may at some point influence the pathways of other areas. This complexity was encountered in the Rhine Delta case (which we simplified by presenting only one area). Real world situations create the need for additional computational techniques to help analysts in identifying promising paths.

With respect to *decision-making*, adaptation pathways provide insights into options, lock-in possibilities, and path dependencies. Thus, an adaptation pathways map provides a valuable starting point for decision-making on short term policy actions, while keeping options open and avoiding lock-ins. The stepwise policy analysis provides guidance for designing a policy. To determine the success of policy actions, quantitative targets are needed. However, in reality, policymakers sometimes choose to keep these targets vague, making it difficult to determine the efficacy of a policy action and pathway. Exploring different quantifications of the targets can show the impact of these targets, which may support a discussion on the targets. Currently, the method lacks assessment of the costs of the various pathways. We are currently investigating how this can be done.

References

Haasnoot, M., Middelkoop, H., Offermans, A., van Beek, E. & van Deursen, W.P.A. (accepted). Exploring pathways for sustainable water management in river deltas in a changing environment. *Climatic Change*.

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., Walker, W.E. & Marchau, V.A.W.J. (2010). Adaptive Airport Strategic Planning. *European Journal of Transport and Infrastructure Research,* 10, 249-273.

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., 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., P., V. & Middelkoop, H. (2008). Advies van de Deltacommissie vergt breder perspectief. (in Dutch) Advice of the Delta committee calls for wider perspective. *H2O,* 20, 36-40.

Walker, W.E., Haasnoot, M. & Kwakkel, J.H. (in prep). Combining adaptation pathways and adaptive policymaking to create adaptive policies for the Rhine Delta.

Walker, W.E., Rahman, S.A. & Cave, J. (2001). Adaptive policies, policy analysis, and policy-making. *European Journal of Operational Research,* 128**,** 282-289.