WATER GOVERNANCE IN TIMES OF UNCERTAINTY

INSIGHTS FOR THE FURTHER DEVELOPMENT OF ADAPTIVE DELTA MANAGEMENT

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■ Water governance is characterized by various uncertainties. Consider for instance climate change. Climate change research is plagued by imperfect and incomplete understanding about the functioning of natural (environmental) phenomena and processes, about how changes in these phenomena and processes translate into increases in the variability of important climate variables (e.g., precipitation, storm intensities, and global temperatures), and the economic and social consequences of such climatic changes.

For a long time, these uncertainties opened the very existence of global climate change to challenge. In recent years, the uncertainty as to whether climate change is taking place, and that this is caused mainly by human behavior, has been largely removed (e.g., Cook et al. 2013). There remains, however, considerable uncertainty about (Hallegatte 2009; IPCC 2014):

- The magnitude of climate change (with estimates of increased average temperatures differing greatly across a range of future scenarios);
- The speed of climate change (which determines how quickly policy actions need to be taken);
- The implications for specific areas and regions (the effects of climate change are potentially larger for countries like Bangladesh and the Netherlands than for countries like Mongolia; but even within sub-national regions, such as California, the effects of climate change are hard to determine);
- The policies that should be implemented to mitigate and/or hedge against the adverse consequences of climate change (because of a lack of knowledge about the costs and benefits of different alternatives for protecting ourselves from the adverse consequences of climate change).

In the Netherlands, in response, we have seen various ways to handle these uncertainties in developing water policies. An analysis of Dutch policy documents on flood safety shows an evolution in dealing with uncertainty, especially in the way in which scenarios are used in strategy development. The advice of the Commission Water Management 21st Century on future water policy (Stumpe and Tielrooij, 2000) uses three climate scenarios:[1] the 'minimum scenario', the 'middle scenario', and the 'maximum scenario'. Uncertainty is dealt with by indicating that plans and measures should be based on the middle scenario. The maximum scenario is used only to test the robustness of the proposed interventions (p. 25). In the first Dutch National Water Plan 2009-2015 (2009), a distinction is made between measures that have to be implemented in the short term and measures for the long term; dimensions of measures in the first category are based on the moderate scenario, the second category on the more extreme scenario. The proposals in the Delta Program 2015 report are based on four 'plausible' scenarios that combine climate change (rapid or moderate) with socio-economic developments (growth or shrinkage).

Haasnoot and Middelkoop (2012) analyzed six decades of scenario use in the Netherlands. They concluded that "the possibilities for robust decisionmaking increased through a paradigm shift from predicting to exploring futures, but the scenario method is not yet fully exploited

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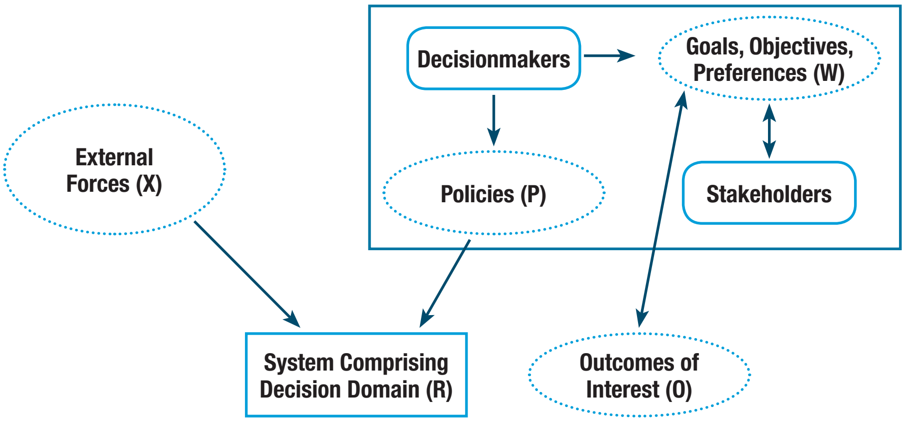

Figure 1:
A framework for decision support (Walker, 2000).

for decisionmaking under uncertainty; and the scenarios enabled learning about possible impacts of developments and effectiveness of policy options" (p.108).

Recent years have seen the birth and proliferation of new ways to support Decision Making under Deep Uncertainty (DMDU). Deep uncertainty refers to a situation in which no reliable statistics are available, so predictions are often wrong and relying on them can prove costly and dangerous. One attempt to incorporate uncertainty into decisionmaking in water management was developed in the context of the Netherlands' Delta Programme: Adaptive Delta Management (ADM).

Developed in 2010- 2013, ADM was used in developing the policy frameworks ('Delta Decisions') and regional strategies that formed the basis for the €20 billion proposal published in 2014. ADM has already used some elements of DMDU approaches. It seeks to maximize flexibility by keeping options open and avoiding lock-in in flood risk management, freshwater availability, and spatial adaptation (Bloemen et al., 2019). It also includes a systematic recalibration, every six years, of the overarching policy frameworks and the regional strategies. As part of the recalibration, possibilities for further developing ADM are inventoried and discussed. Where applicable, adjustments can be proposed and research questions can be formulated and added to the research agendas, as addressed in the National Water and Climate Knowledge and Innovation Programme[2] and in focused research projects, such as the Sea Level Rise Knowledge Program.[3]

In this article we summarize some possibilities for future ADM actions based on DMDU approaches. In Section 2, a framework for designing policies under deep uncertainty is presented. The case of ADM is described in Section 3.Suggestions for the support that DMDU approaches could give to further developing ADM are given in Section 4. Conclusions are given in Section 5.

A Framework for Designing Policies under Deep Uncertainty

DMDU approaches use the same general framework for decision support as does policy analysis (Walker 2000). The framework views decisionmaking as choosing among alternatives in order to change system outcomes in a desired way (see Fig 1.). It involves the specification of policies (P) to influence the behaviour of the system to achieve the goals. At the heart of this view is the system that decisionmakers influence directly by their policies, distinguishing the system's physical and human elements and their mutual interactions. The results of these policies (the system outputs) are called outcomes of interest (O). They are considered relevant criteria for the evaluation of policies. The valuation of outcomes refers to the (relative) weights given to the outcomes by crucial stakeholders, including decisionmakers (W). Other external forces (X) act upon the system along with the policies. Both may affect the relationship among elements of the system (R) and hence the structure of the system itself, as well as the outcomes of interest to decisionmakers and other stakeholders. External forces refer to forces outside the system that are not controllable by the decisionmakers, but may influence the system significantly (e.g., technological developments, societal developments, economic developments, political developments, and developments in the physical system).

In a broad sense, uncertainty (whether deep or not) may be defined simply as *limited knowledge* about future, past, or current events (Walker et al. 2013). With respect to decisionmaking, uncertainty refers to the gap between available knowledge and the knowledge decisionmakers would need in order to make the best policy choice. This uncertainty clearly involves subjectivity, since it relates to satisfaction with existing knowledge, which is coloured by the underlying values and perspectives of the decisionmakers (and the various actors involved in the decisionmaking process). But this in itself becomes a trap when implicit assumptions are left unexamined or unquestioned. Uncertainty can be associated with all aspects of a problem of interest (e.g., the system comprising the decision domain, the world outside the system, the outcomes from the system, and the importance stakeholders place on the various outcomes from the system). "Deep uncertainty" has been described as the situation in which we do not know or the parties to a decision cannot agree upon (i) the external context of the system, (ii) how the system works and its boundaries, and/or (iii) the outcomes of interest from the system and/or their relative importance (Lempert et al. 2003). Deep uncertainty does not mean that one cannot do anything; what one can do is to prepare for all sorts of developments that could happen and would affect the outcomes of interest.

Recent years have seen the development of many DMDU approaches for preparing for an uncertain future. The generic steps of a DMDU approach are the following (Marchau et al., 2019) (see Fig.2):

- **Frame the Analysis**: In this step the policy analysis framework (see Figure 1) is filled in. In particular, the triggering issue (problem or opportunity) is formulated in terms of the gap between the objectives/goals of the decisionmakers (and other stakeholders) and the system outcomes. A system model (or models) is developed to examine policy alternatives and identify a preferred policy in the next steps. Alternative policies whose outcomes are to be assessed using the system model(s) are identified.

- **Exploratory Analysis**: In this step the uncertainties about external forces (X), system structure (R), outcome indicators (O), and valuation of outcomes (W) are specified. Given these uncertainties, the vulnerabilities (and opportunities) of the alternative policies are explored. In particular, this step involves exploring how a given policy (P) would perform, in terms of the outcomes (O), under a wide variety of states of the world (X), model structures (R), and alternative value systems (W). The exploration is often carried out using a large number of computational experiments ('cases') under a wide variety of assumptions. This step includes 'Scenario Discovery' to identify factors (vulnerabilities or opportunities) that would determine the failure or success of the policies under investigation.

- **Choose Initial Actions and Contingent Actions**: In this step, the potential for addressing uncertainty through further changes in policy design and sequencing is explored. Based on the results of the earlier steps, a set of initial actions is chosen that should do well given the vulnerabilities (and opportunities), and future contingent actions are prepared to respond to uncertain events and developments. In addition to the (initial) policy, a 'signpost monitoring system' is defined, which specifies what should be watched in order to know if the underlying assumptions are still valid, if implementation is proceeding well, and if needed policy adjustments are taken in a timely and effective manner.

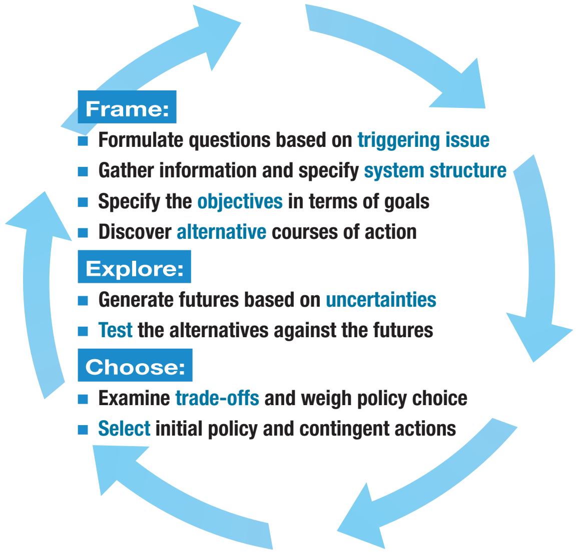

Figure 2: Steps of DMDU approaches.

Adaptive Delta Management

From discussions in the year the Delta Programme was set up (2009), the choice evolved to tailor 'our own' approach for dealing with deep uncertainty–an approach that matches the specific characteristics and context of the Dutch Delta Programme. Elements from available methods would be 'cherry-picked' to build an approach that would fit well with the mission and tasks of the Programme, would be easily explainable to policymakers from regional and local public authorities that were to develop the regional strategies, and would offer both structure (for consistency) and flexibility (for tailoring to theme-specific and region-specific characteristics).

The approach, labelled Adaptive Delta Management (ADM), was developed in interaction with both researchers and practitioners in the Dutch Delta Programme. The Delta Programme started in 2010, and presently unites the central government, provinces, municipalities, and water boards on the improvement of flood risk management, reduction of vulnerability to water scarcity, and spatial adaptation (Delta Programme Commissioner 2017; van Alphen 2016). It has its legislative foundation in the Delta Act, and has a Delta Fund with a 'rolling' budget of €1 billion per year. This yearly budget is reserved until 2029—and the lifetime of the Delta Fund is prolonged by another year every year.

The concept of Adaptive Delta Management is based on the following four principles (Delta Programme Commissioner, 2013):

- Connect short-term decisions in the wide field of spatial planning (housing, nature, infrastructure, recreation, etc.) with long-term objectives in the (narrower) field of flood risk management, freshwater availability, and spatial planning. A typical example is the construction of a river bypass close to the city of Nijmegen. The bypass is not required under *present* climatic conditions, but is expected to be necessary to accommodate expected increases in peak river discharges *in the coming decades*. It is constructed now to be sure that future urban developments will not sprawl over the allocated area. This measure not only improves local flood safety, but also contributes to protection against downstream flooding.

- Develop adaptation pathways that visualize what measures address what physical conditions, and estimate when these conditions could occur under what scenario.

- In choosing strategies, look for and 'rate' flexibility. The high uncertainty on the possible increase in sea level rise makes sand suppletion an attractive, inherently flexible, alternative for raising and strengthening sea dikes.

- Link Delta Programme measures with other investment agendas (e.g. aging infrastructure, urban development, nature, shipping, and recreation). A typical example would be the Prins Hendrik dike in Texel. The flood safety-oriented works foreseen for the dike were adjusted to accommodate ambitions in nature conservation. The additional costs were covered by the regional, nature-oriented Wadden Fund.

The following activities were undertaken in applying the ADM approach in practice in the Dutch Delta Programme:

- Overarching policy frameworks ('Delta Decisions') were developed– three overarching thematic policy frameworks (on new flood safety standards, on sustainable freshwater provision, and on climate-resilient design and construction of urban and rural areas across the Netherlands), two regionally structuring choices for flood risk management and freshwater supply in two critical regions (the IJsselmeer region and the Rhine-Meuse delta), and a separate decision on sand (focusing on sand suppletion for flood safety along the coast). These policy frameworks were developed iteratively with six regional strategies, consisting of goals, measures, and a tentative timeline. The Delta Decisions are the interventions at system level. The regional strategies 'translate' the national ambitions defined in the Delta Decisions into actions that match regional and local agendas. They were developed by the teams in the regional subprogrammes of the Delta Programme. In these teams the national government, provinces, municipalities, and waterboards worked together in developing the regional strategies, also involving the scientific community, NGO's, and the private sector.

- Four 'Delta Scenarios' were developed to guide the process of formulating the Delta Decisions and constructing the regional strategies (Bruggeman et al. 2011; Bruggeman and Dammers 2013; KNMI 2014). These scenarios combine the two main sources of uncertainty that determine the future water challenges: climate change and socio-economic conditions. The scenarios provide qualitative and quantitative data on the climate, water systems, water consumption, and the use of land. The qualitative information consists of narratives and maps that describe the backgrounds and demonstrate the interconnectivity of the issues. The quantitative data are reflected in the form of indicators. The indicators cover future time series for various factors, including rise in temperature, sea level rise, precipitation (total per year, total per season), potential evaporation (yearly and summer), and river discharges.

- The existing flood safety standards were based on the size of the population and the value of investments in the early 1960s. The new standards, which came into effect on January 1, 2017, take into consideration the "high end" of the four Delta Scenarios. For 2050, when the new protection level has to be realized, they assume considerable climate change (average temperature +2 degrees, sea level rise +35 cm, and winter precipitation +14%, taking 2008 as a reference point for the socio-economic developments, and the period 1961-1995 as reference point for the hydrological consequences of climate change), an increase in population (to 20 million people), and an increase in the value of investments (ongoing economic growth of 2.5% a year) (KNMI 2014).

- The Delta Plan on flood risk management and the Delta Plan on freshwater, both financed from the Delta Fund, comprise the measures from the regional strategies. The Delta Decisions, regional strategies, and two Delta Plans formed the central elements of the proposal sent to Parliament in September 2014. The proposal contains a total of 14 adaptation pathways, developed with a planning horizon of 2100. The proposal was accepted and the necessary budget of over €1 billion/year until 2029 was allocated (Delta Programme Commissioner 2014).

Suggestions for DMDU Support in Further Developing Adaptive Delta Management

Until now, ADM has handled uncertainty by applying elements of two approaches within DMDU theory: Dynamic Adaptive Planning (DAP) (Walker et al., 2019) and Dynamic Adaptive Policy Pathways (DAPP) (Haasnoot et al., 2019) (Bloemen et al., 2017). DAP focuses on the implementation of an initial plan prior to the resolution of all major uncertainties, with the plan being adapted over time based on new knowledge. DAP specifies the development of a monitoring program and responses when specific trigger values are reached. DAPP considers the timing of actions explicitly in its approach. It produces an overview of alternative routes into the future. The alternative routes are based on Adaptation Tipping Points (ATPs).

The practice of ADM might benefit from some of the other approaches within DMDU theory. Some ways in which future ADM might handle uncertainty are (see also Table 1):

1. **To prepare for a wider range of futures.** The Delta Programme combines climate change (rapid or moderate) with socio-economic developments (growth or shrinkage) in four 'Delta Scenarios', framed as 'plausible futures' (KNMI 2014; Wolters et al. 2018). The proposed policies were designed to be able to address the most extreme of this set of scenarios (to be 'robust') and to be relatively easy to adjust in case of less demanding or more extreme physical conditions (to be 'flexible'). Since the publication of the Delta Programme report of 2014, several unexpected climate-related developments have been observed, such as prolonged drought, heat, and torrential downpours. Concurrently, research has shown that in the future, the sea level may rise faster than the pace underpinning the Delta Scenarios. It follows that a wider range of futures should be considered. This can be done by applying Exploratory Modeling (EM), an element of Robust Decision Making (Lempert, 2019). EM is a tool to explore a wide variety of scenarios, alternative model structures, and alternative value systems based on computational experiments (Bankes 1993). A computational experiment is a single run with a given model structure and a given parameterization of that structure. It reveals how the real world would behave if the various hypotheses presented by the structure and the parameterization were correct. By exploring a large number of these hypotheses, one can get insights into how the system would behave under a large variety of assumptions (Bankes et al. 2013). This would significantly broaden the range of futures that are considered. Introducing this approach in the Delta Programme would, amongst others, require explicit attention to two notions: the (political) risk of being accused of alarmist standpoints, and the notion that people tend to be motivated more to take on a challenge that looks 'doable' than an overwhelming challenge that requires anticipating physical conditions that have never occurred before.

2. **To strengthen the structure of the adaptation process.** The implementation of adaptive policies requires different rules and mechanisms to enable adaptation as knowledge proceeds and events unfold. In this context, the concept of Planned Adaptation (Sowell 2019) is useful. It distinguishes substantive (primary) rules governing the behavior of a system from secondary rules used to identify, evaluate, and change rules when the rule system no longer effectively sustains system integrity. An initial set of variables is established for comparing instances of planned adaptation in terms of how secondary capabilities and capacities are used to adapt primary rules. Variables identified in this model characterize the factors that affect the development, implementation, and application of secondary rules. Variables fall into two categories: (a) those that characterize sources of new information, and (b) those that characterize the rough organizational structure(s) supporting evaluative capabilities and capacities. Sources of new information are characterized in terms of *triggers* that signal that adaptation (Adaptation Tipping Points) may be warranted, and the character of *events* producing the new information. Evaluative variables characterize the *timing* of evaluation relative to triggers and events, the *loci* of evaluative capabilities and capacities in the organizational complex, and how *coupled* rulemaking principals are to evaluative agents. As insights into both the speed of climate change and its consequences continue to evolve, it might be useful to analyze how the application of the conceptual model of Planned Adaptation could contribute, as part of the recalibration process, to the further development of Adaptive Delta Management.

3. **To strengthen the interaction between decisions made in regular water management and decisions made in relation to large-scale structures.** The Engineering Options Analysis approach (de Neufville and Smet, 2019) can be used to explicate the added value of adjustments that increase flexibility in the design of waterworks (dams, sluices, storm surge barriers, levees, etc.) that justify the costs of these adjustments. For example, as they show in the case of a pumping station at IJmuiden, introducing additional flexibility in the design of the pumping facilities adds significant value; more flexibility in the flood defense height structure does not. Since the consequences of building large-scale water management structures exceed those of most regional and local water management interventions, they can be used to structure choices in climate adaptation. Their impact is large and widespread. Structures originally built, or adjusted later, to increase flood safety can influence the effectiveness of measures in the freshwater domain. They modify the structure and dynamics of both the national water system, and the regional water systems that depend on the national water system. Building flexibility into these structures, in the design phase or later, as part of maintenance focused on increasing the functional or physical lifetime of the structures, influences the planning, locations, and dimensions of small-scale measures that are part of regular water management.

4 **To improve the possibilities for timely changing course by reformulating goals.** Monitoring and evaluation in the Delta Programme is centered around four questions:

- *are we on scheme* (did we realize the measures that were planned)?
- *are we on track* (do the outcomes of these measures correspond with expectations)?
- do we work in an *integrated way* (do we tune our interventions with plans and ambitions in other policy fields)?
- do we work in a *participatory way* (do we involve NGOs, the private sector, and local stakeholders in our planning)?

The 'on track' question appears to be the hardest– how to measure if the goals are actually being realized on time. It might be worth the effort to explore the possibility of looking from a completely different angle at the issue of operationalizing 'outcome'. Usually desired system outcomes are defined in terms of specific characteristics that are to be realized: a physical 'state of the world' that needs to be realized at a certain moment in the future (for example, a flood safety standard). Realizing these outcomes requires implementation of physical measures (e.g., x kilometers of dike have to be heightened, y retention areas have to be developed, z storm surge barriers have to be adjusted, etc.). Achieving outcomes is translated into a series of step-by-step measures, each contributing to fulfilling short-term and middle-long term objectives that have been agreed upon, and the last step resulting in realizing the desired outcome in the predefined final moment. Are there other ways for defining the desired outcome and discretizing the precursory process? Here the Info-Gap approach (Ben-Haim, 2019) might be useful. A central question in the Info-Gap approach is "what degrees of safety and operability are essential for acceptable performance? . . . More demanding performance requirements can fail in more ways and thus are more vulnerable to uncertainty. This implies a *trade-off* between performance and robustness to uncertainty: greater robustness is obtained only by accepting more modest performance" (p. 101). This calls for explicating the minimal system performance that has to be secured, and the strategy that is adequate for the broadest range of future conditions. As part of a thought experiment in the six-yearly recalibration of the overarching policy frameworks and regional strategies of the Dutch Delta Programme, the minimal system performance could, for instance, be redefined in terms of maintaining the present adaptive capacity of the water-and-governance-system, thus minimizing the path dependency of adaptation measures (prevent lock-ins) that might ultimately result in system failure.[4]

5 **To enable and stimulate more effectively the implementation of innovative solutions.** ADM is confronted with the 'innovation dilemma': an innovative alternative might be viewed as better than the others, but also more risky–because not yet tested in practice. Traditional alternatives have, as such, an important competitive advantage. The downside of continuing to follow the traditional path is that it increases the risk of further enlarging path dependency. The use of Adaptation Pathways (APs) does not automatically enable the (future) implementation of innovative interventions. APs are based on identifying when present strategies no longer deliver the required outcome (called an Adaptation Tipping Point), forcing a switch to an alternative strategy. Increasing the probability that an innovative alternative is chosen requires 'levelling the playing field': the differences in knowledge about the efficacy of the options should be reduced. It follows that research on the ins and outs of the innovative alternative needs a 'head start' to conduct research on more traditional alternatives, and should be initiated long before the decision node is reached. This notion could be included in the programming of the research in the National Water and Climate Knowledge and Innovation Programme (NKWK) that has been initiated to feed expertise into the decisionmaking processes of the Delta Programme.

DMDU approaches have mostly been developed in theory, mainly by policy analysts. Like other real world attempts to deal with deep uncertainty, ADM has many challenges that cannot be solved by further investing in theoretical elaboration of existing DMDU approaches. Weighing the pros and cons of policies, for example, has a strong normative character. Organizing broad commitment to a final set of proposed policies often is a *conditio sine qua non*. Achieving this usually involves elaborate participation processes, which typically include political and institutional considerations. Also, the institutional requirements to apply a DMDU approach cannot always be met in practice (e.g. limitations of the yearly budget process).

Having made this disclaimer about what can and cannot be used from DMDU in ADM, there are some possibilities that have not yet been tried. Table 1 presents a first tentative inventory of such possibilities.

Conclusions

The implementation of adaptive policies requires the specification of procedures and legislation to: (a) enable policies to respond to events and information as they arise, (b) undertake data collection (monitoring and modeling), and (c) repeatedly review goals. In the Netherlands, Adaptive Delta Management (ADM) has been shown to be successful in this context, by maximizing

Observations from applying ADM in the Delta Programme (2014-2019)	Illustrations for the Dutch water system	Possible support from DMDU approaches, and suggested actions → Recommendations for future ADM development
1. The overarching policy frameworks and regional strategies published in 2014 did not take into account the recent, new, and unexpected climate-related events	In the Netherlands, unexpected climate related developments that are now being considered in recalibrating the Delta Decisions and regional strategies are: cluster precipitation, long periods of extreme drought, and a possible acceleration of sea level rise.	*Robust Decision Making:* Use exploratory models to map a wide range of assumptions onto their consequences without privileging one set of assumptions over another. → *Prepare for a wider range of futures.*
2. Adaptation Tipping Points (ATPs) are rare in (Dutch) real-world water management; timely adjustments of strategies require additional procedures.	(a) The strategy that has been developed for defending against flooding from the sea is sand suppletion. This strategy is inherently flexible as volumes supplied can be changed at any time, depending on sea level rise; the only tipping point could be a lack of sand. (b) The natural variability of river flows is too large for the timely detection of the signal that river dikes should be raised or strengthened; so the design of the flood protection system is based on fixed values of discharge rates of the rivers.	*Planned Adaptation:* Shift from adaptive planning to planned adaptation: strengthen the six-yearly recalibration process; explicate issues that are expected to require decisions in the next recalibration; plan research accordingly; and formulate secondary rules for adjusting primary rules set in the previous recalibration. → *Strengthen the structure of the adaptation process.*
3. Implementation, maintenance, and adjustments of existing large-scale waterworks dominate timing and dimensions of adaptation processes at all scales and strongly influence the efficacy of all water management interventions.	Actually realizing the long-term option to replace the present Maeslant storm surge barrier with a dam and a sea sluice would drastically change freshwater availability in the west of the Netherlands.	*Engineering Options Analysis:* Make an inventory of decisions related to large-scale waterworks, and of decisions related to regular water management; map their mutual influence; and discuss possible adjustments on both sides. → *Strengthen the interaction between decisions made in regular day-to-day water management and decisions made in relation to large-scale structures*
4. In the domain of climate proofing freshwater availability, it is extremely difficult to match intermediate goals (e.g. 2030, 2040) with long-term goals (e.g. 2050)	For freshwater availability and spatial adaptation, goals are often defined in terms of abstract notions (e.g. 'climate proof in 2050'). Such goal definitions are difficult to translate into measurable intermediate goals; other types of goal definitions should be tested.	*Info-Gap:* (Re)define long-term goals in terms of critical performance indicators; shift the focus from defining worst-case conditions to defining critical outcomes; and analyse how that would change the possibilities to make timely adjustments to the overarching policy framework and regional strategies. → *Improve the possibilities for timely changing course by reformulating goals.*
5. There is a strong tendency towards traditional measures (e.g. raising or strengthening dikes), with the risk of a lock in, missing innovative opportunities.	Changing the discharge distribution among the Rhine branches with new constructions that are operable during autumn and winter could contribute significantly to flood safety, but would introduce new, possibly large uncertainties, because there is no experience in this type of water management.	*Planned Adaptation:* Explicate innovative interventions; specify under what conditions they might be considered to be an alternative answer to challenging conditions; and plan research accordingly. → *Enable and stimulate more effectively the implementation of innovative solutions.*

Table 1: Potential DMDU support for the future development of ADM

flexibility, keeping options open, and avoiding lock-in in flood risk management, freshwater availability, and spatial adaptation.

The preceding sections of this paper have shown how deep uncertainty was dealt with in practice, in setting up and running a large-scale climate adaptation program. Is enough being done and planned to prevent a next flood from happening? Do new insights require further stepping up the efforts? Or is the Netherlands already overinvesting—preparing for climate conditions that will never materialize? Only time can tell for sure. But by matching the needs from practical experiences with applying ADM with concepts, methods, and approaches that have recently been developed in research on ways to deal with deep uncertainty, the following lessons are considered worth sharing:

- Prepare for a wider range of futures using Robust Decision Making;
- Strengthen the structure of the adaptation process using Planned Adaptation;
- Strengthen the interaction between decisions made in regular water management and decisions made in relation to large-scale structures using Engineering Options Analysis;
- Improve the possibilities for timely changing course by reformulating goals using concepts of Info-Gap Theory;
- Enable and stimulate more effectively the implementation of innovative interventions by organizing a 'head start' for research on innovative interventions long before Adaptive Tipping Points are reached.

This paper has highlighted how some future ADM issues (practice) might be handled through using DMDU approaches (theory). The results of applying this 'improved' version of ADM in practice will be used to formulate additional challenges for theory. In a broader sense we will continue to be alert for opportunities to test and improve DMDU approaches developed in theory in real-world settings like ADM in the Netherlands. In addition to the present use in ADM of elements of the DAP and DAPP approaches, the future development of ADM could benefit from elements of other DMDU approaches, as indicated in Section 4. We are convinced that this interaction needs to be intensified: developing strategies that respond to the uncertainties intrinsic to climate adaptation is a challenge that will almost certainly increase in the near future.

1 Assuming an increase in temperature at the end of this century of respectively 1, 2, and 4 degrees Celsius.
2 Nationaal Kennis- en innovatie Programma Water en Klimaat (NKWK).
3 Kennisprogramma Zeespiegelstijging (KP ZSS).
4 The advice of the Commission Water Management 21st century (2000) states: "The Commission does not consider dike heightening a sustainable approach".

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