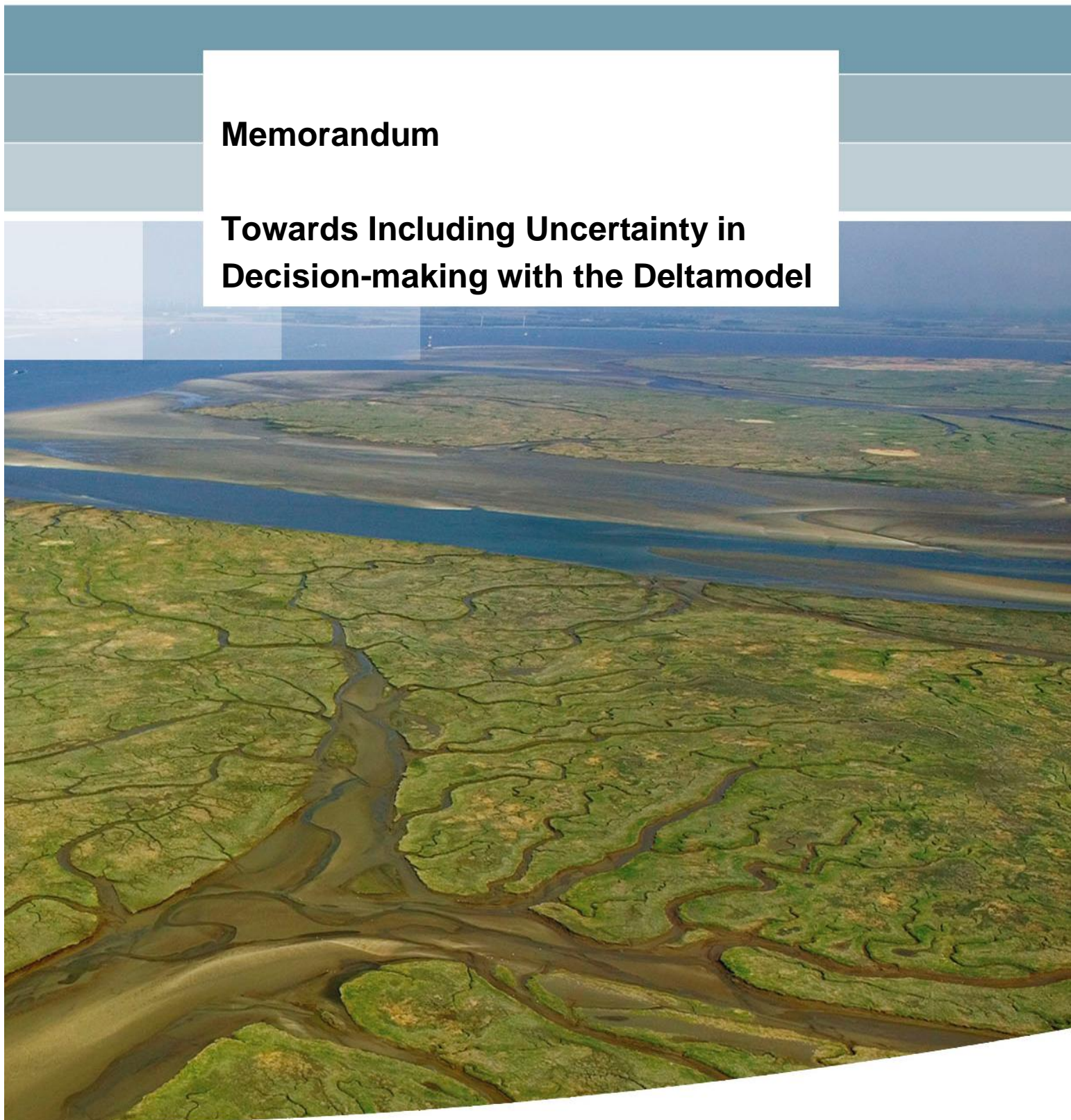


Memorandum

**Towards Including Uncertainty in
Decision-making with the Deltamodel**



Memorandum

Towards Including Uncertainty in Decision-making with the Deltamodel

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1 Introduction

Deltares and the RWS Waterdienst are currently working on the development of the 'Deltamodel'. The purpose of the Deltamodel is to establish a reliable and accepted basis for decision-making in the Delta Programme, with a particular emphasis on the Delta decisions. In a White Paper, we presented an overview of the various types of uncertainty and how the Deltamodel can be used to support decision-making under uncertainty (Walker and Haasnoot 2011). We also described the uncertainty matrix in relation to the Deltamodel (see Appendix A). This matrix can aid in classifying the uncertainties and describing how uncertainty can be treated in different parts of a specific study. The White Paper was presented at a meeting of the International Advisory Committee of the Deltamodel on 15 January 2011. An updated presentation was given to the staff of the Delta Commission and the Directorate-General for Water on 15 April 2011. Based on the recommended next steps and feedback from these two meetings, a follow-up project was initiated.

The main purpose of this follow-up project is *to construct an uncertainty matrix for the Deltamodel* and show which uncertainties are already being dealt with, how they are being dealt with, and identify important uncertainties that still need plans for dealing with them in decision-making with the Deltamodel to support the Delta Programme. In addition, the following activities were defined: 1) to set up an *uncertainty-impact matrix*, presenting the sensitivity of outcome parameters to changes in input parameters; 2) to provide some *guidelines* on how to deal with uncertainty in decision-making with the Deltamodel; and 3) to provide a *response to the IAC letter* on the issues related to uncertainty. This memo briefly describes the results of these follow-up activities.

Quantification of the uncertainty related to the use of a model is carried out by means of an uncertainty analysis (Morgan and Henrion 1990; Refsgaard et al. 2007). We distinguish seven steps in an uncertainty analysis (see Figure 1). In this project, we executed the first three steps shown in the figure – we identified uncertainties, classified them, and assessed their importance for decision-making with the Deltamodel. During this process we collected information to quantify the importance of the uncertainty for the outcomes of the Deltamodel (part of the fourth step of an uncertainty analysis). In addition to identification of uncertainties, we provide some guidelines on how policymakers and analysts can deal with these uncertainties in decision-making with the Deltamodel.

Chapter 2 describes our activities and the structure of the interviews we conducted during the project. In Chapter 3, we describe the uncertainties we identified, how they are currently being dealt with, and how the uncertainties not yet being dealt with can be included in decision-making with the Deltamodel. Chapter 4 quantitatively describes the impact of some of these uncertainties on the outcomes. We provide a set of guidelines on dealing with uncertainties in decision-making with the Deltamodel in Chapter 5, and a list of next steps in Chapter 6. In Appendix C we describe how we dealt with the recommendations of the IAC. Appendix D gives a list of things we noticed which may be relevant for the Deltamodel project.

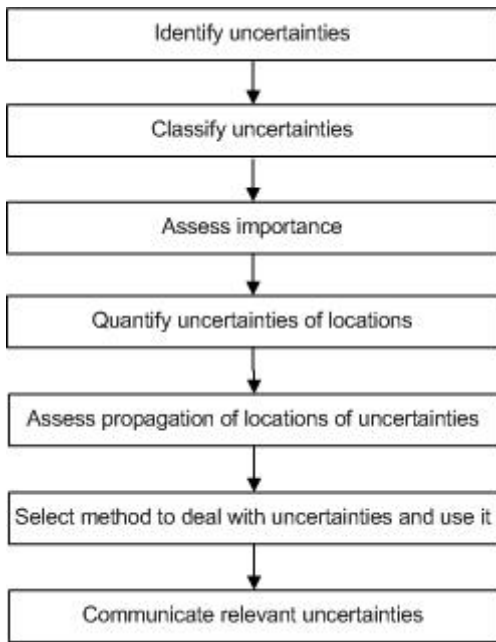


Figure 1.1 Steps in an uncertainty analysis (based on Van der Sluijs et al. (2005)).

2 Activities

To identify and classify uncertainties in decision-making with the Deltamodel we used the uncertainty classification from Walker et al. (in prep.-b), which is based on Walker et al. (2003) and Kwakkel et al. (2010). This matrix is described in Appendix A. We added an extra level of uncertainty to the matrix that we used in the White Paper. In this level, the uncertainties among the alternatives are described qualitatively with their likelihoods. Such an approach is typically used in the IPCC reports. To present the findings clearly, we limited our description of the uncertainties to the level-location portion of the matrix.

As a first step in filling in the uncertainty matrix for the Deltamodel, we conducted several interviews. After the interviews, we added information for the remaining parts of the uncertainty matrix using the following reports: Deltascenarios (Bruggeman et al. 2011), Memorandum for the Delta Committee on Uncertainty (Deltares 2008), Functional requirements Deltamodel (Kroon and Ruijgh 2011), Effectmodels Water Safety (De Waal 2010). The final step in filling in the matrix was to identify uncertainties not yet being covered, and to formulate suggestions on how they can be dealt with. In addition to identifying the uncertainties and indicating how they can be dealt with, it is important to know how these uncertainties are likely to affect the outcomes. By this we mean which outcome variables are likely to be affected by an uncertainty, and, more importantly, the relative importance of the uncertainty for decision-making on the 'Delta decisions'. This can be an extensive task. Therefore, we set-up an 'uncertainty-impact knowledge base' in which we stored information we came across on the sensitivity of the outcomes of the Deltamodel to the various uncertainties. Note that there is no Deltamodel yet, so it is not possible to perform a true sensitivity analysis. We collected information from the interviews and a selection of reports to make a first estimate, and used results of previous model simulations to get an idea of the relative importance of these uncertainties.

Interviewees

We interviewed the following persons:

- Jos van Alphen (Staff Delta Commissioner)
- Pieter Bloemen (Staff Delta Commissioner)
- Tjalle de Haan (Waterdienst), working on water safety
- Frans Klijn (Deltares), working on the Deelprogramma Zoetwatervoorziening
- Timo Kroon (Waterdienst), Deltamodel
- Willem Mak (Directorate-General for Water)
- Erik Ruigh (Deltares), project manager for the Deltamodel
- Maarten van der Vlist (Waterdienst), working on adaptive delta management
- Hans de Waal (Deltares), working on the Deelprogramma Veiligheid

Structure of the interviews

In each interview, we focused on one or more of the locations in the policy analysis framework (context, system model, and outcomes) in which uncertainties may occur that may be relevant for decision-making on the Delta decisions. (The weights on the outcomes is a location in the framework that is relevant for decision-making with the Deltamodel, but is not part of the Deltamodel and, thus, was not included in the interviews. It was, however, mentioned during the interviews and is therefore included in the matrix.)

For each of the locations, we formulated several broad questions within two main topics:

1. What are the uncertainties associated with the Deltamodel and its use, which uncertainties are already being dealt with, and how are they being dealt with? The purpose of this part of the interview was to help us to fill in the uncertainty matrix (see Appendix A to this memo) for the locations (context, model, outcomes – see below) and levels (1 to 5) of uncertainty.
2. What is the impact of these uncertainties on the Deltamodel outcomes, and what is the relative importance of these uncertainties for decision-making? The purpose of this part of the interview was to add information to the ‘uncertainty impact knowledge base’.

Context:

- How will the Deltascenarios affect the Deltamodel (which submodels/modules; which parameters?) What effect will the Deltascenarios have on the outcomes of the Deltamodel? Which outcome indicators are most affected?
- Do you think all relevant uncertainties are included in the Deltascenarios? If not, which are missing, and what might be their effects on the model and its outcomes?
- Can you think of plausible situations in which the current policy/water system would fail? (For example: What if, in a summer such as 2011, the drought continued through August?)
- Appendix B gives a thought experiment. If you consider the four futures, what would be the effect on the model outcomes and the decision-making?

System model;

- Which parameters have a large effect on the model outcomes? What is the uncertainty associated with these?
- Are there alternative models (alternatives to the screening and analysis tool, or SOBEK and WAQUA for rivers)? What would be the effect on the outcomes of the Deltamodel if these different structures would be used? How different might the results be? How might the differences affect decision-making?

Model Outcomes:

- The IAC pointed out that the Deltamodel should not only be water-oriented. They stress that an integrated approach is needed. Are the relevant model outcomes for water policy decision-making included in the Deltamodel (or Delta-instrument)?
- Based on Functional requirements (Kroon and Ruijgh 2011), discuss: point estimates, confidence intervals, ensemble results, probabilities, accuracy (spatial, temporal detail, validation).

Decision-making:

- How are the results of sub-programmes related (e.g., connection between decisions about the IJsselmeer and Rijnmond)?
- Regarding the outcome indicators, can you indicate which range of parameter change would be relevant for decision-making? (For example, for the water level in the IJsselmeer, a change of 10 cm is relevant for decision-making on water supply; for a difference of x milj. euro, damage on agriculture is relevant).

3 Uncertainty Matrix Filled In for the Deltamodel

Based on the interviews and literature, we filled in the uncertainty classification matrix. To identify the location, level, and nature of each uncertainty, we used the decision trees shown in Figure 2, which are based on Warmink (2011), but adapted to the uncertainty classification matrix of Walker et al. (Walker et al. in prep.-b). An overview of the uncertainties we identified is given in Table 1 (which appears at the end of this chapter). Table 2 (also at the end of the chapter) describes how these types of uncertainties are already being dealt with in the Delta Programme (green text) or how they can be dealt with (blue text). (Note that the uncertainties that can be classified under ‘nature’ are shown in the row labeled ‘weights’ in the tables, in order to avoid using a 3-dimensional table to present the results clearly.)

This chapter first describes the identified uncertainties and how to deal with them for each location (context uncertainties in Sec. 3.1, model uncertainties in Sec. 3.2, and outcome uncertainties in Sec. 3.3). We then address the question of how to deal with each of these types of uncertainties in decision-making (in Sec. 3.4).

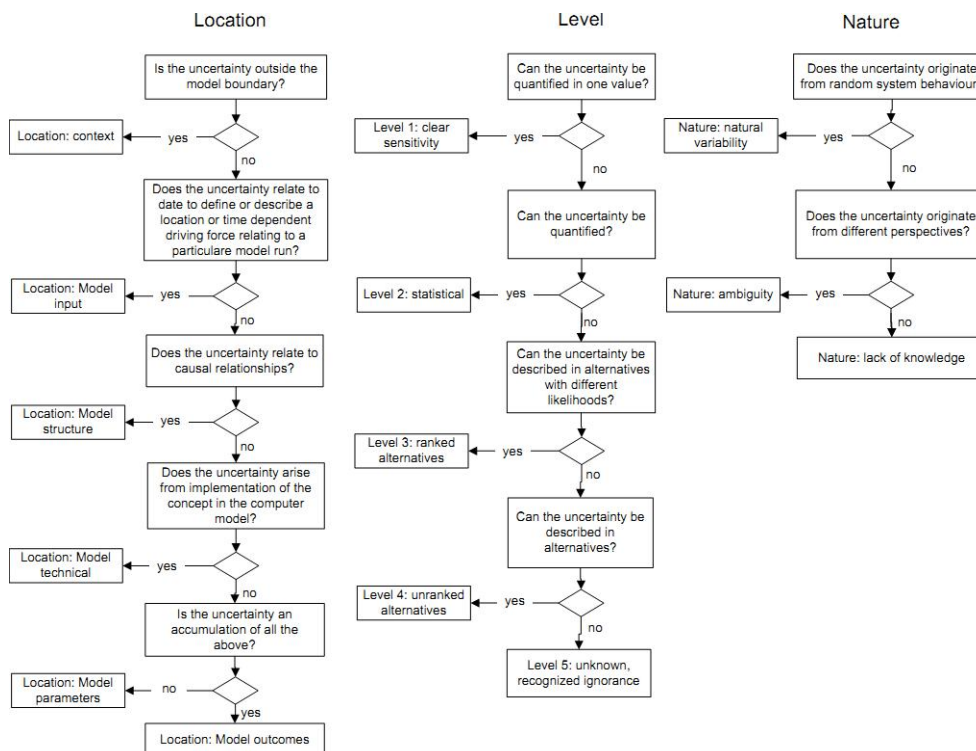


Figure 3.1 Decision trees to identify the location, level, and nature of uncertainty. These trees are based on the uncertainty classification scheme of Walker et al. (in prep.-b) (see also Appendix A), and on the decision trees of Warmink (2011).

3.1 Context Uncertainty

In the Delta Programme, uncertainties in the context are being addressed by using the Deltascenarios. All interviewees believed that most of the relevant context uncertainties are included in the Deltascenarios. Nevertheless, they reported the following missing context uncertainties:

- Some of the outcomes from the Global Climate Models (GCMs) presented by the IPCC are not covered in the KNMI'06 scenarios (they cover 80% of the IPCC's global GCM outcomes¹). There may be relevant situations outside this box (within the other 20%, or even outside this range).
- Wind climate and tidal shape are assumed to stay the same (they are not mentioned in the Deltascenarios. The potential future wind climate is very uncertain – as can be concluded from contradicting articles – and wind effects (speed, direction and duration) are relevant for the outcomes on safety. In fact, wind is much more important than sea level, since without a wind effect we can cope with sea level rise. In addition, we do not know if the tidal shape remains the same when the sea level rises. This was also brought up in the working group that provided the Veerman scenarios (Katsman et al. 2011).
- Adaptation in the external context of the water manager (e.g., emergent behavior) is an uncertainty in the context that is not considered in the scenarios. For example, there is uncertainty about what the farmers will do. Will they install new irrigation pumps? Also, will the crop mix change? (e.g., will farmers switch to arable crops?; switch to bulbs?) The northern regions are trying to make an assessment of this.
- Policy feedbacks are not included in the scenarios². For example, there is an indirect influence of socio-economic developments on the safety standards. If some socio-economic variables change (e.g., the economic values inside dike rings), policymakers might want higher safety standards.
- The specific changes in land use in the scenarios (i.e., where the changes take place and which crop change) are not detailed enough. As a result, assumptions need to be made by modelers to implement the scenarios in the model.
- Perspective-based uncertainty (different expectations about the future by different persons or organizations) is not included in the Deltascenarios (or in the Deltamodel).

One of the interviewees noted that there seems to be a tendency by the sub-programmes to ignore all but one of the scenarios. For example, in a study for one of the sub-programmes, most of the described impacts are related to the W+ scenario (the most extreme scenario). This could lead decision-makers to focus on this one scenario and to ignore the other scenarios. This one scenario will very likely not turn out to be the future. Such an approach may result in overinvestment. This is also mentioned in the advice of the Raad van Verkeer en Waterstaat (Raad voor Verkeer en Waterstaat 2009). By exploring the full range of uncertainties, sustainable strategies can be identified. By sustainable strategies we mean strategies that are (1) effective (objectives for people, profit, and planet are achieved to the extent possible), and (2) robust

¹The regional outcomes show much more spreading than the KNMI scenarios.

²The Deltascenarios are described without policies on purpose to allow for a straightforward impact analysis of identified strategies. However, feedbacks are important for decision-making. Such uncertainty could be included by analyzing transient scenarios (time series describing the external context) and adaptation pathways, wherein the pathways allow for dynamic interaction between the water system and society (i.o. the policies).

(strategies that are effective now and in the future, no matter which of the scenarios occurs), or (3) flexible enough to adapt to future conditions. Sustainable strategies are 'future-proof' strategies (Haasnoot et al. 2009).

All interviewees agreed on the importance of taking climate variability into account, and that future climate variability is uncertain. In fact there was general agreement that climate variability (especially an increase in extreme values) may be more important than climate change (which will be gradual). In the climate scenarios, variability is included by changing the peak and average. But, the frequency of the peak is based on current variability and not on any estimate of how variability might change (this is a 'known unknown').

Climate variability is partly incorporated in the scenarios by presenting values for a selection of events (e.g., a 1/100 discharge). The sub-programme 'Fresh water supply' used illustrative drought years to estimate impacts of the Deltascenarios. For safety, statistics on the climate are used (e.g. the chance of specific events). Climate variability is also important for decision-making, which we describe later.

Uncertainties in the design discharges are also context related uncertainties. The uncertainty in the design discharge is high as mentioned by interviewees (see also chapter 4). This uncertainty is related to climate variability, but there are also other elements of uncertainty. For example, one interviewee mentioned that there may be correlations between peak flows in the Rhine and Meuse, which in that case results a much larger amount of water in the downstream part of Rhine Meuse delta. This interviewee also raised that it is not clear whether a storm at sea and high discharges are correlated (but their joint occurrence should be considered when designing flood protection policies). There is some statistical evidence for this, but physical analysis on this subject would be more useful than statistical analysis (Waterdienst and KNMI are looking into this). A similar situation could occur at the IJsseldelta (e.g., Kampen), where the IJsselmeer and IJssel River interact. These are low probability high impact events (see below).

Upstream developments, such as a potential increase in water use in the Meuse basin or changes in spatial planning are also not included in the Delta scenarios. This was not mentioned by the interviewees. Changes in upstream water management were mentioned as Black Swan (see below).

Black Swans and Low Probability-High Impact Situations

Situations with a very low probability are generally not taken into account in scenarios. However, if such situations have a high impact it may be worthwhile to have a look at them. These situations could occur in any one of the scenarios. A similar idea is described in the concept of Black Swans³ (Taleb 2007). The Theory of Black Swan events is a metaphor that encapsulates the concept that "*The event is a surprise (to the observer) and has a major impact. After the fact,*

³ According to Taleb (2007), a Black Swan is "an event with the following three attributes. First, it is an outlier, as it lies outside the realm of regular expectations, because nothing in the past can convincingly point to its possibility. Second, it carries an extreme impact. Third, in spite of its outlier status, human nature makes us concoct explanations for its occurrence after the fact, making it explainable and predictable" (The New York Times. 22 April 2007). The first two attributes refer to low probability high impact situations.

*the event is rationalized by hindsight*⁴. Although, a Black Swan by definition is slightly different (see footnote), we further refer to Black Swans for clarity. Our idea is not to look at them all, as there can be many of such situations, but to use some of them for testing the vulnerability of a policy being considered. Maybe some can be easily prepared for. If so, these preparations can be added to the policy to make it more robust.

For coping with Black Swans, it is useful to consider what options are left in case the boundary of a policy is met, beyond which it would fail. For example, what if the dike fails, what options are left? Does the evacuation plan work in case Black Swan/flood event occurs? What actions can be taken to protect the policy from failing? (I.e., how to be prepared?). Several interviewees mentioned that ways of keeping a policy from failing are rarely discussed.

Together with the interviewees, we developed the following list of situations with a low probability but with a potential high impact:

- The 'perfect storm' and failure of a structure: e.g., a storm at sea *and* high discharge *and* failure of Maeslantkering. (This could be an extreme storm or a storm with a long duration.)
- An economic crisis that may result in a lack of money to implement a measure (which you may have first postponed, but now really have to implement).
- A change in the political climate resulting in not implementing a measure (which you may have first postponed, but now really have to implement).
- The failure of structures (e.g. a dike breach due to drought, subsidence of houses and structures, a Betuwe dike section resulting in flooding of a large area). Note: It is not fully clear what the economic consequences are once a structure fails—there are no euro estimates.
- A W+ scenario with less sea level rise than is currently mentioned in the scenario. This is possible because precipitation and sea level rise are not coupled. If the water level strategy for the IJsselmeer is to raise the level with the sea level rise to enable discharging under gravity, the final sea level could be too low for supplying enough fresh water in case of a drought.
- A situation in which the current policy could fail to provide enough drinking water.
- (It is frequently mentioned that providing enough drinking water will not be a problem. However, because a problem with drinking water could have a high impact, it is useful to think about it.)
- A pollution spill in the harbour area of Rotterdam and the inability to flush away the pollution due to a closed structure or lack of water.
- An extreme discharge, such as 18.000 or 20.000 m³/s . (If the same type of event that led to flooding in other parts of Europe (for example flood events on the Elbe or the Danube⁴) happens in the Rhine and Meuse basin, what discharge would we get?)
- Flood waters from Germany flooding a big part of the lower rivers in NL.

Most Black Swans mentioned are related to floods. For drought, one interviewee mentioned that he found it difficult to identify a Black Swans, as it is related to problems that concern single

⁴ RIZA (Waterdienst), WL (Deltares), KNMI, and RIZA assessed what the Rhine and Meuse discharges would be in case the same amount of precipitation of the Elbe basin in August 2002 were to fall in the Rhine and Meuse basin. Such an event would result in a discharge of 11.600 m³/s (Rhine) and 2.600 m³/s (Meuse), which is lower than the 1/1250 design discharges (van de Langemheen et al. 2002).

sectors and can be solved globally (e.g. food supply). This is different from the situation in 1976, when the Netherlands still felt the need for self-sufficiency in food production (so, the water system was viewed as a failure in 1976, but would not be viewed that way now). But, drought might lead to a dike failure and/or subsidence (TNO is working on these effects).

Spatial planning and upstream water management (e.g., if Germany were to increase their safety levels by raising the levees) could result in Black Swans. Both are, however, slow processes, which can be well monitored. It is not likely that Germany will do this, however, since they do not need as high safety standards as in the Netherlands, since their evacuation possibilities are much better.

3.2 Model Uncertainty

Safety modeling generally uses a probabilistic approach to deal with uncertainties. Uncertainties in this part of the Deltamodel involve model input data (such as wind and water level statistics), parameters (best guesses for dike strength), and model context (through the scenarios). There are two model structures available for this part of the Deltamodel: the Hydra models and PCRing. The former calculates dike failure probabilities for dike sections, while the latter calculates the probability for a dike ring. The Hydra models will be used in the Deltamodel. There are also two model structures models (SOBEK and WAQUA) for calculating the failure probabilities for different water levels. The differences between these two models are less relevant for policies addressing the long term (2050, 2100) than the near term. So, in most Delta Programme cases, you might as well use SOBEK for the policy analysis – it's faster. In the memo on the comparison between SOBEK and WAQUA (Chbab 2011), the author compared results in the middle of the river (as both models have results in this area, while the border near the dike is important for determining the dike height).

The fresh water supply models use a deterministic approach. Uncertainties in the model structure for fresh water supply relate to the amount of water needed for flushing. At the moment, this is a static parameter that does not change in response to changes in salt concentration or water users. There are two model structures for water distribution (the Distribution Model and SOBEK). In the Deltamodel SOBEK will be used. Although the SOBEK model is better in modeling salt water intrusion in the Rhine-Meuse estuary, one interviewee mentioned that the modeling of salinity should be improved (especially, the estimates of salinity of the surface water in the polders, and the effects of this salinity). Also, interviewees mentioned that in some areas there is not good data on how water use is split among its three uses (irrigation, level management, and flushing) for the various polders/regions in the country.

Regarding the whole Deltamodel, the interviewees mentioned, large input data uncertainties are found in the values for hydraulic resistance of the river bed, drainage resistance in polders, inlet capacity, operation of sluices, and water demand, most of which are based on expert estimates rather than empirical measurements. The inlet capacities and operations of sluices are both parts of managerial rules that can be gathered from the operational water managers. Water demands are not measured by the water boards and, therefore, cannot be validated. The hydraulic

resistance and drainage resistance are difficult to measure, especially for the whole of the Netherlands.

The implementation of strategies in the Deltamodel is not always straightforward as there is not always a 'button' in the model for a measure and sometimes strategies are defined vaguely, so they have to be operationalized in order to be modeled. In that case implementation depends almost entirely on assumptions made by the modelers. For example, land use maps need a translation for a use in the Deltamodel. Their specification can have a large effect on the safety outcomes. The impact of the assumptions made by the modelers on the outcomes is very high (maybe ten times higher than the uncertainties due to the assumptions made about the structure of the Deltamodel and its inputs). Strategies should therefore be story lines, so they can be better implemented in the model. All of the assumptions need to be completely and carefully documented.

There are some uncertainties that are not included in the Deltamodel, but may be relevant: the shape of the storm surges may change if the sea level goes up (and/or if the winds change). The same accounts for the statistics of levels and discharges used as input for the Hydra models.

To deal with uncertainties related to model input and model structure, the Deltamodel will use data and regional models from the waterboards. The data and models will be scaled for the national model. This consistency between the regional models and the national model should increase trust in the Deltamodel. Several persons will use the Deltamodel (NHI), which will improve the Deltamodel further.

The Deltamodel will be validated for the current situation. One interviewee noted that it is impossible to know whether the model will still be valid once the system changes.

One way of dealing with uncertainty in the causal relationships in the model is to actually implement a measure (small scale), monitor what happens, and improve the model and/or implement the measure in the model based on what you have learned. For complex measures that cannot be tested in the real world, scale models could be useful. If another more detailed model is considered well suited for this model purpose, this model could be used to screen whether the measure could work. This also applies to measures to address groundwater and salinity problems.

3.3 Model Outcome Uncertainty

In general, uncertainty in the values of the outcome indicators is an accumulation of the uncertainties coming from the uncertainties in the context and in the model.

Some outcome indicators are missing. For example, an interviewee mentioned that the outcome from level control in the boezems around the polders in 'peaty Holland' is not shown in the list of outcomes, although it is a first priority in water management. This outcome will be generated by the Deltamodel, but is not listed in the document with functional requirements (Kroon and Ruijgh 2011). Level control is important and relevant for fresh water supply. A lot of water is needed for

level control (more than for agriculture), and if it is not supplied it may have severe impacts for infrastructure, such as houses and dikes (due to unequal speeds of subsidence) and for salt damage to crops. Furthermore, an interviewee mentioned that the way the quality of nature is specified as an outcome is ambiguous.

Although we did not focus on it in our interviews, we should take into account perspective-based uncertainty, which involves different expectations about the future situation, different beliefs about how the system works, and different weights stakeholders give to the outcomes (even if the outcomes themselves are not uncertain). This type of uncertainty was raised by several interviewees⁵. The different expectations about the future can be taken into account by using different scenarios. Different beliefs about how the system works can be taken into account by using different model structures to estimate the effects of policies. As for different weights, the Deltamodel should produce unweighted outcome indicators, which can be placed into scorecards. Different beliefs could be taken into account by describing how different perspectives would evaluate different policies, based on the outcomes shown in the scorecards (Haasnoot et al. under review; Middelkoop et al. 2004; Offermans et al. 2009; Offermans et al. 2008; Rotmans and De Vries 1997; Van Asselt 2000; Verweij and Viner 2001).

It is not yet clear what the most important outcomes for decision-making are. This is being considered by the sub-programmes. Through the organization of the Delta Programme there is a risk that each sub-programme focuses on its own problems and not or less on the Delta decisions, which are typically decisions that relate to a national scale, nor on the interconnections among the different sub-programmes. A focus on integrated, national decision-making seems to get little attention so far.

The staff of Deltacommissaris is currently working on a 'vergelijkings-method', to compare policy options (like a scorecard). A scorecard would be prepared for each set of assumptions (e.g., for each scenario and/or for each different model structure) showing the results for various (static) policy options. It has not yet been decided how many outcomes will be presented, which ones, or how uncertainty in the outcomes presented will be indicated (if at all).

Our interviewees pointed out that the Delta Programme is currently focused exclusively on safety and fresh water supply. As such, it is more or less ignoring effects on nature and agriculture, although both are indirectly included as users of fresh water supply. The Deltamodel aims to model safety and fresh water supply. But, the Delta-instruments will include effect models. Coupling of these models could introduce uncertainty.

⁵ A colleague noted that an interesting nature uncertainty (which originates from different perspectives) is the application of the HYDRA models to estimate the probability of a flooding of a polder. For the acceptance of the model results, whether you adopt a Bayesian or frequentist perspective is relevant. That is, acceptance depends on whether you are willing to treat expert opinion in a probabilistic way or not.

3.4 Decision-making under Uncertainty

Adaptive Delta Management and strategies

Some decisions you need to take and implement now, because you want to be sure to avoid undesirable impacts that are fairly certain or plausible, and sometimes you want to keep options open to be able to take measures at a later stage. The implementation of other things might be able to be postponed for example, if the impacts are not (very) high, and/or you are able to see them coming, and thus be able to monitor the situation and act in time. (E.g., Diermanse and Kwadijk (2010) investigated whether it would be possible to monitor a trend in river discharges.) But, even in the latter case, it would be good to plan in advance for possible implementation in the future. (Some of this thinking appears as Appendix D in *The 2012 Delta Programme*, entitled “Detailing Adaptive Delta Management”.)

The five Delta decisions have been carefully chosen as indicated by one of the interviewees. All the other decisions strongly depend on the Delta decisions. Once these decisions are taken, the others will follow. The approach to decision-making is to work with the sub-programmes to develop several (consistent) strategies, to screen these to identify promising strategies, and to run the promising strategies through the models. Our interviewees support the idea that a Fast Simple Model might be helpful in this process.

Given the increased uncertainty associated with flood safety levels based on probabilities (the top layer (‘prevention’) of the current 3-layer flood safety policy), increased attention should be given to the second layer (mitigation, based on spatial planning), and to the third layer (emergency planning, including evacuation). The third layer is getting little attention in current Dutch policy.

Climate variability

Climate variability plays an important role in decision-making. The ‘thinking experiment’ (Appendix B) made this clear during our interviews. Not only are strategies often aimed at coping with extremes, water managers and society tend to respond to (nearby) events. An event can serve as a trigger to implement measures. But also, the absence of an event may result in the loss of support for a policy. Decisions may have implications for future decisions. Events may put us on a different path than we first intended. For example, once we decide to raise dikes and allow more spatial developments in the floodplain, it is difficult to go back to implement more space for the river.

Several interviewees agreed that climate variability (especially, an increase in extreme values) may be more important than climate change (which will be gradual) in the next 50 years. The main problem in this period of climate change is that the flood safety norms are based on probabilities, which assume stationarity (the idea that hydrologic systems fluctuate in an unchanging envelope of variability – i.e., the mean and the degree of variability of hydrologic time series do not change over time). So, statistics based on the past may not be the best basis for a flood safety policy. As pointed out in a report from the U.S. National Research Council

(prepublication), “continuing to use the assumption of stationarity in designing water management systems is no longer practical or defensible.”

Other strategies, such as designing dikes based on 1.5 times the second highest design discharge ever measured, rather than on 1/1250 or 1/10000 year predictions, may be more effective under changing conditions. Such a strategy has no memory and is, therefore, very useful in a system that is undergoing change – i.e., a system for which historical data might not be useful for predicting the future. The probabilistic approach fits well in case of long-time stable systems, and probabilities that are based on time series data within the period of stability (see also above statement of the U.S. National Research Council).

There are plausible situations in which the current policy for the water system would fail. For example, in January of this year, if the rain had lasted one week longer, there might have been a big flood. (“We are not yet prepared for a discharge of 15,000 m³/s.”) Also, this spring, if the dry season had continued for a few more weeks, it would have been a disaster as was pointed out by one of the interviewees. The national committee on water distribution scaled the situation to stage 3 (called ‘actual water shortages’) which is before the highest stage 4 (‘potential crisis’). The effects of drought (salination and pollution) are not only problems for agriculture – they can change the nature of the country if they occur more times.

The ‘thinking experiment’ in Appendix B is interesting from a decision-making perspective for another reason. The last two examples in that experiment (even the one without climate change) may be perceived as being even worse than the first two. (In each case, it is hard to tell the difference between the scenario with climate change and the scenario without climate change.) In the first two examples, you are alerted to get prepared (because of extreme events early on), but not in the last two. This indicates that it is necessary to carefully consider (1) decisions you can postpone and monitor for changes in the meantime, and (2) decisions you need to take soon, to implement measures, and be prepared for events that can come even now – even without climate change.

The importance of changes in the outcome values for decision-making is considered in the next chapter.

Support

Regarding decision-making, societal support for strategies is very important. People’s belief in climate change may be diminishing, resulting in less support for strategies. (“People are tired of climate discussions.”) For example, in the Parliament, people raised questions about the necessity of the ‘Room for the Rivers’ project along the IJssel. It may take a big flood in order to get action. (The best for gaining support for a flood safety policy would be a ‘near miss’ as a ‘warning shot’ was mentioned by one of the interviewees.) Further, people’s values influence the support for strategies. For example, in the past the society became more aware about the importance of the environment as a habitat for species, but also as a place to live in (Offermans 2010b).

Integration and consistency of results

To ensure consistency and a good match among the sub-programmes, all will use the same Deltamodel and the same scenarios.

Among the interviewees, there are different views on whether the interconnections among different sub-programmes of the Delta Programme are sufficiently taken into account. The sub-programmes are beginning to discuss results with each other, resulting in an integration of their results. This is a big improvement from the past, when the ideas and concepts for strategies for the regional programs did not fit together. The Delta Commissioner is helping to force this integration, and the Deltamodel will now use consistent hydraulic parameters on a national scale.

The different regions should not only be linked through boundary conditions, but also consistency in policy options should be considered (e.g. a policy option of one sub-programme could be incompatible with one from another). Consequently, an analysis at national scale is also needed for robust decision-making in the face of uncertainty.

Table 3.1 Location and Level of Uncertainties Related to the Deltamodel

	Level 1	Level 2	Level 3	Level 4	Level 5
Context	Current operational management rules not always known.	Past climate variability (incl. sea level, lake levels, and river discharges) is known probabilistically. Future climate variability and co-occurrence of events is not known.	Farmers will likely adapt (e.g. in response to drought, by using more sprinkling installations)	- Future climate (incl. sea level) and socio-economic situation is uncertain. - Translation of scenario variables into model inputs is not straightforward. - Land use is a context uncertainty (but can also be controlled).	Surprises and feedback may change the context.
System model	- Some input data and parameters based on expert judgment, not measurements (e.g. drainage resistance, shape of storm surge, wind, dike strength) - Causal relationship between flushing and salt concentration is not included (flushing is 1 static value). - Managerial rules for water distribution in east and north regions not accurate - Validated for current situation; uncertain if model is valid after the system changes			- There are different model structures for water levels, dike levels, and water distribution - Implementation of scenarios and strategies in model involves making assumptions	
System outcomes	(accumulation of the above) - Level control is missing - Agriculture and nature are not part of the Deltamodel - It is not yet clear what are the most important (changes in) outcomes for decision-making	Climate variability, the order and co-occurrence of extreme events is important for decision-making	(accumulation of the above)	(accumulation of the above)	Events are important for decision-making
Weights on outcomes				Different stakeholders assign different weights to outcome indicators**	

** These uncertainties can be classified under 'nature'. To keep the matrix simple we left it at the weight on the outcomes.

Table 3.2 How to Deal with the Uncertainties in Decision-making on the Delta Decisions (Green values indicate how the Delta Programme already deals with this type of uncertainty; blue values indicate how this type of uncertainty can be dealt with.)

	Level 1	Level 2	Level 3	Level 4	Level 5
Context	Obtain additional information through monitoring of asking the water boards.	- The Hydra models use probabilities for wind, storms, discharges, lake levels, sea level - Obtain additional information through monitoring of asking the water boards.	- The Northern region assesses what farmers will likely do.	- Explore effects of Deltascenarios - Document assumptions - Consider adaptation pathways, explore options, and define triggers to develop a dynamic adaptive plan - Include autonomous adaptation of farmers in scenarios and policy options - Include change in land use as a policy option - Explore perspective-based scenarios	- Consider different Black Swans and low probability high impact situations. - Ask 'what could make the policy fail?' - What can be done to reduce or mitigate impacts now or in the future? - Can we monitor to know when to adapt?
System model	- Use regional data and regional models - Several analysts will use the Deltamodel - The Hydra model uses a best guess for the dike strength - Make additional measurements			- Document assumptions - Explore alternative models; use the models that are accurate enough and describe outcome ranges and confidence in outcomes	
System outcomes	-Deltamodel outcomes are point estimates - Add confidence level and/or agreement level based on expert judgment	Develop probability density curves, or probabilities of occurrence.	- Produce a range of outcomes with likelihoods - Add confidence level and/or agreement level based on expert judgment	Produce a range of outcomes for the full set of scenarios, models, and other assumptions for various (dynamic or static) policy options	Have your plans ready and make use of the sense of urgency after an event.
Weights on outcomes				- Present scorecards including indicators from stakeholders** - Explore different evaluation values**	

** These uncertainties can be classified under 'nature'. To keep the matrix simple we left it at the weight on the outcomes.

4 Start of an Uncertainty-Impact Database

Quantitative information was not given by any of the interviewees. Consequently, we could only use a few reports to obtain quantitative information. The reports we used were listed in the original assignment. (Due to time limits, we were unable to consult much more literature. We list this as a next step.) This chapter describes the (admittedly little) information we were able to gather on the quantitative impacts of uncertainties on model outcomes.

Chbab (2011) compared model outcomes of the SOBEK model (1D) to the WAQUA-RMM model (2D). More specifically, he estimated the effect on the water levels ('toetspeilen') due to a transition from the SOBEK model (1D) to the WAQUA-RMM model (2D). He compared the results of 108 SOBEK and WAQUA computations for 14 locations. The computations vary in inputs (9 discharges, 6 sea levels, and 2 stages of the sluices). Hydra-B is used for probabilistic analysis. The results are summarized in Figure 3. The differences in water levels (toetspeilen) between WAQUA and SOBEK differ by 5 cm, except for the location Hoek van Holland and Keizersveer, where the differences are 17 and 8 cm. This is caused by the influence of wind, which is higher at these locations, and is not included in SOBEK calculations. Choosing a different norm, results in a water level change. For Hoek van Holland 1:1000 4.5 m to 1:10,000 to 5.3 m; for Rotterdam 3.2 to 3.5 m for return period of 1:1000 and 1:10,000. The difference between Waqua and SOBEK is 0.18 m at Hoek van Holland and 0.08 m at Keizersveer, and 0.01 to 0.05 m at other locations. However, compared to the effects of different discharges or sea level rise, this effect is also very low for Hoek van Holland. At Hoek van Holland, the effect of sea level rise is much higher than effect of discharge. A rise of 1 m results in approximately 1 m rise in the water level. An increase of the discharge from 600 to 18000 increases the water level ca. 20 cm. At Keizersveer, the discharge has a higher impact on the water level than the sea level. An increase of the discharge from 600 to 18000 increases the water level by ca. 2 m.

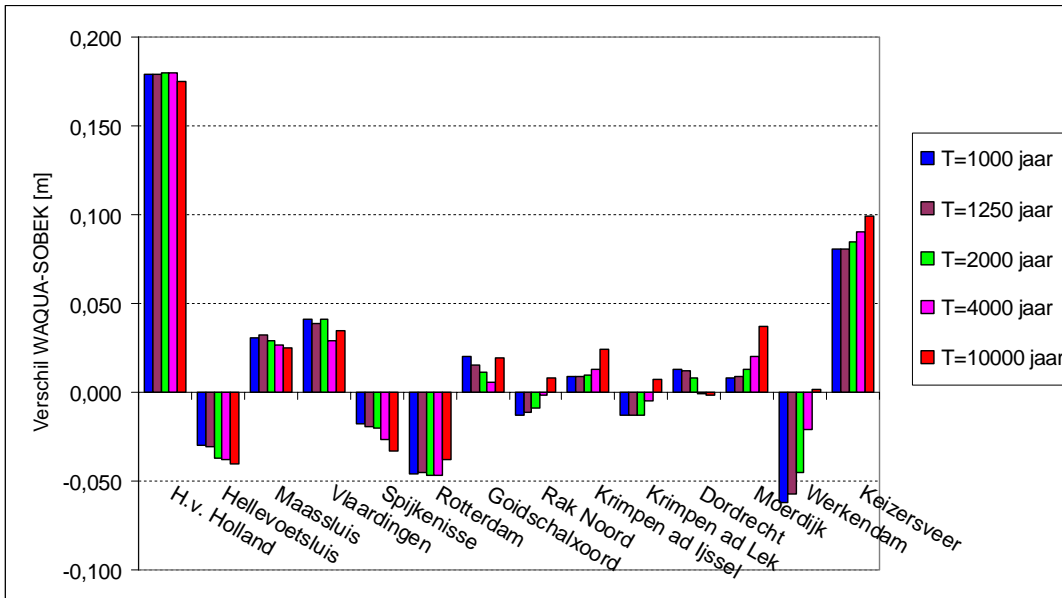


Figure 4.1 Differences between SOBEK and WAQUA for T = 1000, 1250, 2000, 4000, and 10000 years.

For the sub-programme ‘Fresh water supply’, a problem analysis was carried out (Klijn et al. 2011). The study concluded the following, which indicates the effect of context-related uncertainties on the outcomes:

- The effects of climate variability appear to be larger or in the same magnitude as the effects of climate change.
- KNMI has determined the G and W climate scenarios in such a way that in the W scenarios the climate changes twice as much as in the G scenario. The extra agricultural damage in the case of the W+ scenario is almost two times larger than the damage calculated for the G+ scenario (conform Van Beek et al. 2008).
- Drinking water is a very small demand compared to agricultural demand, so developments in drinking water are less relevant. However, on a smaller scale, drinking water developments are relevant for the model outcomes (and drinking water withdrawals will affect nature conservation areas). For example, extractions of groundwater in the eastern part of the Netherlands are significant and can have an impact on nature.
- Agriculture water use is important (and will have a large effect on outcomes).
- Land use is not an important factor affecting the outcomes.

One of the interviewees mentioned that the quality requirements of the Deltamodel (Kroon and Ruijgh 2011) can be used as an indicator of what change in outcomes could be relevant for decision-making. The document describes the accuracy of the Deltamodel by giving a maximum value that the outcomes can differ from measurements for both the screening and analysis tool. Most of these indicators are outcome indicators for the water state, and not the end-outcome indicators such as those presented in the report with evaluation criteria. Examples of these quality criteria are:

- the discharge distributions of the screening and analysis models should differ by less than 1% from the total discharge.
- the water levels for the probabilistic models should differ by less than 0.2 -0.3m for the screening model, and less than 0.1m for the analysis model.
- the mean highest groundwater (GHG) level should
 - for the screening model, be within 50 cm in 75% of the areas with controlled surface water level areas, and within 75 cm in 75% of the areas discharging under gravity. The median should be less than 15 cm.
 - for the analysis model, be within 20 cm in 80% of the areas with controlled surface water level areas, and within 35 cm in 80% of the areas discharging under gravity. The median should be less than 10 cm.

The indicators for groundwater are defined within the framework of the National Hydrological Instrument together with regional water managers and the STOWA. Kroon and Ruigh (2011) assume that the requirements of the Deltamodel are the same as the ones for the NHI, or at least not more severe.

Deltares (2008) quantified the effects of uncertainty in the 1:1250 design discharge with 5000 m³/s, which corresponds to a 1.5m water level difference. According to them, this uncertainty arises mainly from limitations in the historical data (short time series) and the statistical analysis. They noted that the chance of flooding is much lower, due to the overdimensioning of the dikes (freeboard). In this report, a quantitative analysis was carried out for each source of uncertainty. The uncertainties for low discharges for the Meuse are dominated by the uncertainties in upstream extractions. Differences in low discharges for the Rhine and Meuse caused by results of climate models are larger than the natural variability. Differences due to different emission scenarios are less important. The uncertainty in sea level rise was quantified with a bandwidth (80% interval and standard deviation) for 2050 and 2100 (based on the KNMI'06 report). For 2050, the central value was 25 cm, the 80% interval 15-35 cm, and the standard deviation 8 cm. For 2100, these values were respectively, 60, 35-85, and 20 cm.

5 Ten Guidelines for Dealing with Uncertainties in Decision-making with the Deltamodel

Based on interviews and our experience, we provide a list of guidelines, which we have grouped in (1) guidelines related to uncertainty analysis, and (2) guidelines related to dealing with uncertainty in strategy development:

Uncertainty analysis

1. Identify and classify uncertainties
2. Determine the importance of these uncertainties for decision-making
3. Quantify the uncertainties (if possible)
4. Specify how to deal with important uncertainties
5. Communicate uncertainties, assumptions, and limitations clearly (e.g. range of outcomes, confidence, and agreement interval)

Dealing with uncertainty in strategy development

6. Think outside the box: think about Black Swans (low probability, high impact events), include variability (not only trends/developments), and include different perspectives (ambiguity)
7. Two different models are needed. A fast simple model can help to estimate the sensitivity and to screen policy options ; a detailed model can then be used to estimate the effects more accurately
8. For a robust decision-making in the face of uncertainty a policy analysis provides a structured way to support the consistent development, screening, and evaluation of strategies, using tools such as scenarios, computer models, and scorecards
9. Consider dynamic adaptation: explore uncertainties, monitor, and adapt; be robust and/or flexible
10. Make the policy stronger by asking “what could make the policy fail”?

Ad. 1. Identify and classify uncertainties

Consider all sources of uncertainties, using a systematic typology such as Appendix A: i.e., consider uncertainties for each location (context, model, outcomes), level, and nature. The uncertainty classification matrix of Appendix A and the questions used in the interviews can help to identify uncertainties. Using the decision trees of figure 1, uncertainties can be classified into the matrix.

Ad. 2. Determine the importance of these uncertainties for decision-making

Determine what the effect of the uncertainties is on the outcomes of the model, and whether these changes are important for decision-making. If the effects on the outcomes are large, and if this could potentially result in a different decision, then these are uncertainties that policymakers should pay attention to. It is possible that a quantification of these uncertainties is needed.

Ad. 3. Quantify the uncertainties

Determine the effect of uncertain parameters on crucial outcome indicators through a sensitivity analysis (e.g. Morgan and Henrion 1990; Saltelli et al. 2000). Note that not all uncertainties can be quantified.

Ad. 4. Specify how to deal with important uncertainties

Once the uncertainties are classified and assessed on their importance, an appropriate method can be selected to deal with the important uncertainties. In chapter 3 and table 2, we give an overview of such methods for each type of uncertainty. A summary of these methods is listed below:

- Obtain additional information by measuring and asking (waterboards).
- Present information concerning the model and parameter uncertainty on the outcomes by showing a range of outcomes. By 'outcomes', we mean the relevant indicators in the scorecard on which the Delta decisions will be based.
- Classify the confidence and agreement levels on the outcomes using expert judgment. The IPCC 3rd guideline gives a calibrated language for this (Risbey and Kandlikar 2007; IPCC 2005).
- Assess the effects of a range of plausible relevant futures using scenarios. There are many publications on scenario analysis in environmental decision-making (e.g. Alcamo 2001, 2009; Carter et al. 2007; Van 't Klooster 2008; Van Asselt et al. 2010a; Van Asselt et al. 2010b; Van der Heijden 1996; van Drunen et al. ; Van Notten et al. 2005; Van 't Klooster and Van Asselt 2006).
- Assess the vulnerability and opportunities of policy options using Black Swans and Low Probability High Impact situations.
- Explore the effectiveness of policy options for different scenarios. This is part of policy analysis (see points 8 and 10).

Ad. 5. Communicate uncertainties, assumptions, and limitations clearly

"The job of the analyst is to help the policymakers to make good decisions, possibly based on bad information." Although sometimes unwanted, communication of what is known and what is unknown or not well-known, can be valuable information for decision-makers. A clear statement on the range of assumptions made, and how they affect the outcomes, is important for understanding (differences in) model results and the effectiveness of policy options. This may also indicate the vulnerabilities of the decisions (see point 10).

The way in which a statement is framed will have an effect on how it is interpreted (Kahneman and Tversky 1979). The IPCC guidance document gives an example: "*A 10% chance of dying is interpreted more negatively than a 90% chance of surviving.*" Therefore, they suggest to "*use neutral language, to avoid value laden statements, to consider redundant statements to ensure balance (e.g. chances of dying and of surviving), and to express different but comparable risks in a consistent way*". The IPCC guidance provides calibrated language to minimize possible misinterpretation and ambiguity and to avoid that the uncertainty perceived by the reader is different from that intended (IPCC 2005).

The study results and their related uncertainties should be clearly communicated as well. The IPCC advises to develop clear statements for key findings that are quantitative, and to give

explicit time frames as far as possible (IPCC 2005). They adopted a hierarchy of expressions from less to more confidence in the results:

- A. Direction of change is ambiguous or the issue assessed is not amenable to prediction: Describe the governing factors, key indicators, and relationships. If a trend could be either positive or negative, explain the pre-conditions or evidence for each.*
- B. An expected trend or direction can be identified (increase, decrease, no significant change): Explain the basis for this and the extent to which opposite changes would not be expected. Include changes that have a reasonable likelihood even where they are not certain. If you describe a collective level of confidence in words, use the language options in Table 2 or 3.*
- C. An order of magnitude can be given for the degree of change (i.e. sign and magnitude to within a factor of 10): Explain the basis for estimates given and indicate assumptions made. The order of magnitude should not change for reasonable ranges in such assumptions. If you describe a collective level of confidence in words, use the language options in Table 2 or 3.*
- D. A range can be given for the change in a variable as upper and lower bounds, or as the 5th and 95th percentiles, based on objective analysis or expert judgment: Explain the basis for the range given, noting factors that determine the outer bounds. If you cannot be confident in the range, use a less precise approach. If you describe a collective level of confidence or likelihood of an outcome in words, use the language options in Tables 3 or 4.*
- E. A likelihood or probability of occurrence can be determined for an event or for representative outcomes, e.g. based on multiple observations, model ensemble runs, or expert judgment: State any assumptions made and estimate the role of structural uncertainties. Describe likelihoods using the calibrated language given in Table 4 or present them quantitatively.*
- F. A probability distribution can be determined for changes in a continuous variable either objectively or through use of a formal quantitative survey of expert views: Present the PDF graphically and/or provide the 5th and 95th percentiles of the distribution. Explain the methodology used to produce the PDF, any assumptions made, and estimate the role of structural uncertainties.*

For further reading on communicating uncertainty, see for example Kandlikar et al. (2005), and Schenk and Lensink (2007).

Ad. 6. Think outside the box: think about Black Swans (low probability, high impact events), include variability (not only trends/developments), and include different perspectives (ambiguity).

The Deltascenarios describe a plausible range of futures. Outside this range, or even inside this range, there are other uncertainties that may affect decision-making. For example, events, such as flood and drought events, or periods with no events, influence public opinion, and thus can change the support for water management strategies (Offermans 2010a; Van der Brugge et al. 2005). Recent history has shown that events may serve as triggers for implementation or change of policies (e.g. Katrina in the US, tsunami-earthquake- reactor meltdown in Japan, influencing Germany's nuclear energy policy and automobile supply chains). Climate variability is, therefore, an import factor in decision-making. Not only, are most policies focused on extremes, they also trigger the implementation and the success of a policy. For the next 50 years, climate variability may be more important than climate change (Haasnoot et al. 2009). Extreme events can happen in the near future or in the long term, and they can occur in scenarios with and without climate change. The probability of such events differs, but they can happen in any scenario and every

year. Thinking about situations with a low probability and a high impact will make us better prepared. Preparing involves (a) implementation of additional or more intensified measures to prevent the policy from failing, and/or (b) developing a plan with actions in case the policy fails (e.g. evacuation plans). Chapter 3 provides a list of possible Black Swans.

Besides variability, people's values and objectives differ and may change. Different stakeholders can have different targets and give different weights to outcomes. They can have different perspectives about the future and about the working of the system. This perspective-based uncertainty (ambiguity) about the future can be included through interviewing stakeholders and developing perspective-based scenarios. The latter is also recommended by the WRR (Van Asselt et al. 2010a). Including ambiguity on the outcomes involves presenting a long list of outcome indicators for all stakeholders (see also point 8). A policy is more robust if it succeeds, even if the targets change. By exploring different targets and analyzing the effect of a target change on the performance of a policy, a more robust policy can be developed.

Ad. 7. Two different models are needed. A fast simple model can help to estimate the sensitivity and to screen policy options and a detailed model can then be used to estimate the effects more accurately of promising policy options.

For different types of analysis, different types of models are needed. Both a fast simple model and a detailed model are needed to for decision-making in the Delta Programme. For the screening of possible strategies, a large number of runs are needed, since there are many possible futures, many possible strategies, and many possible combinations of strategies. An appropriate tool for this purpose needs to be fast enough to be able make these runs in a short amount of time, and the spatial and temporal detail should be large enough to enable the analysis of the most important impacts for the Delta decisions. One of the lessons of the Aquatic Outlook study (Rijkswaterstaat 1996), in which a precursor of the Deltamodel is used to estimate the impacts of strategies, was that, for a policy analysis, not only groups of measures should be calculated with the model, but also single measures, to ensure a straightforward analysis of the performance of the strategies (without being blurred by other measures) (RIZA 1997).

Once a strategy appears promising, its performance can be analyzed in more detail. For fine-tuning, in order to prepare to really implement the strategy at a local scale, more detailed models can be used. The detailed models should be able to represent the current situation with much more detail (spatial, temporal, and process), and can have much longer run times.

Besides screening of policy options, a fast simple model can also be used for a thorough sensitivity analysis. If there is only a complex model available, a 'smart' set of model runs could be used to screen policy options. For example, for a policy analysis on drought strategies, van Beek, et al. (2008) started with the large-scale format of strategies, to see whether this could help. In case this would not be effective enough, then there was no need to investigate this strategy further. Furthermore, they assessed what would be the 'maximum' amount of water needed in the IJsselmeer by assessing the impacts for the maximum scenarios in the most extreme dry year.

The RAND Corporation has published several reports on metamodels and multi-resolution modeling (Davis and Bigelow 1998, 2003).

Ad. 8. For a robust decision-making in the face of uncertainty a policy analysis provides a structured way to support the consistent development, screening, and evaluation of strategies, using tools such as scenarios, computer models, and scorecards.

To facilitate the decision-making process, a policy analysis framework can be used (De Bruijn et al. 2008; Haasnoot et al. 2009; Loucks and Van Beek 2005; Walker 2000). The policy analysis framework describes the different steps in a policy analysis study and identifies where and how in the process the model can be used. Examples of steps are: identification of the problem, specification of objectives, screening of strategies, analysis of strategies, evaluation of strategies, and choice of a strategy to implement. Evaluation of strategies is often done with a scorecard, presenting results of each strategy for each scenario and outcome indicator (see figure 4 below). Although a short list of outcome indicators is often preferred by policymakers, stakeholders should be able to see their criteria (see point 6). Therefore, a list of criteria could be built at different levels of aggregation.

Figure 5.1 presents the way that different model runs can support a policy analysis (Walker et al. in prep.-b).

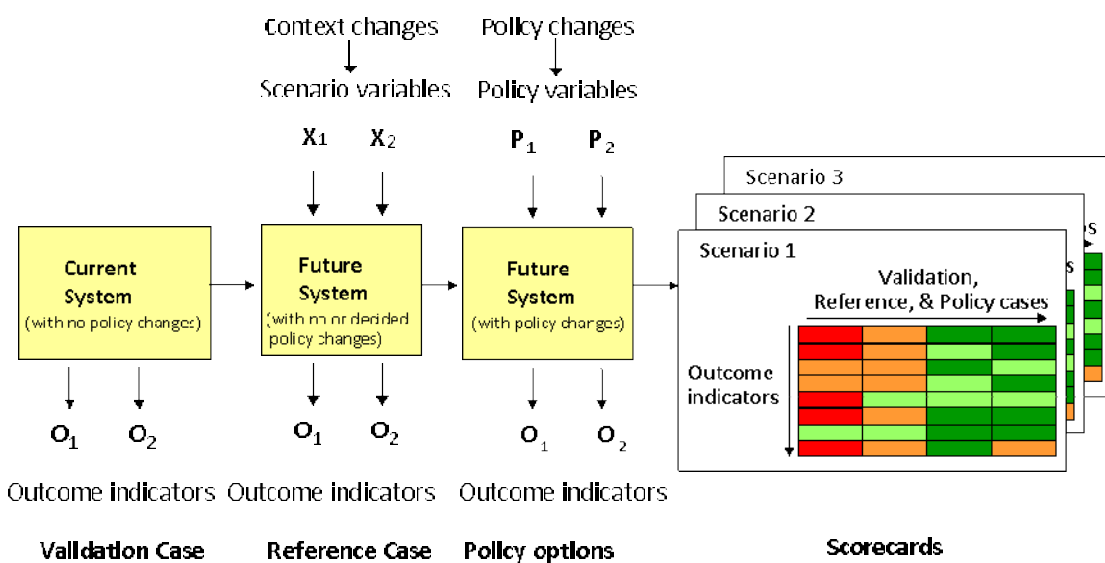


Figure 5.1 Different model runs (yellow blocks) can be used in a policy analysis (Walker et al. in prep.-b).

Ad. 9. Dynamic management

For dealing with deep uncertainty, a different approach than the traditional ‘predict and act’ approach is needed (Walker and Haasnoot 2011). The Raad voor Verkeer en Waterstaat (2009) recently recommended such an adaptive approach. In its advice to the Ministry, it wrote: “a fundamentally different approach to the uncertainties associated with climate change must be adopted in policy-making and in government. A change of outlook is needed: the pursuit of certainty should be replaced by the acceptance of and allowance for uncertainty. Instead of

basing policy on what is or appears to be certain, uncertainties should be explicitly covered by the policy analysis and proactively accommodated in the policies that are formulated. We need what academics describe as 'planned adaptation' or 'adaptive policy-making'." The 2012 Delta Programme Book describes a process called 'adaptive delta management'. Such approaches are currently under development. But there are examples from some research studies (Haasnoot et al. under review; Kwadijk et al. 2010; Walker et al. 2001).

Such an approach could build on the following key elements (based on Haasnoot et al. under review; Kwadijk et al. 2010; Walker et al. 2001; Walker et al. in prep.-a):

- **Explore policy options under uncertainty:** Estimate the performance of strategies for different scenarios.
- **Determine tipping points and what could make a policy fail:** Using transient scenarios, and/or a vulnerability assessment, the 'sell-by date' or the adaptation tipping point of a policy option can be assessed (Haasnoot et al. under review; Kwadijk et al. 2010). This can be used to develop adaptation pathways, describing a sequence of policy actions. With a set of adaptation pathways (an adaptation map), it is possible to identify opportunities, no-regret strategies, threats (dead-ends), and when and how to change a strategy, all of which can be used by policymakers to develop water management roadmaps into the future (Haasnoot et al. under review). Think about Black Swans (low probability, high impact situations) that could make a policy fail, in order to be prepared in case the preferred policy fails.
- **Define a Dynamic Policy Plan:** During the policymaking process, a definition of policy success is formulated and the vulnerabilities of the policy (in terms of potential adverse consequences or policy failure) are identified (Walker et al. 2001). The Dynamic Policy Plan describes a desired pathway with defensive, corrective, and capitalizing actions to stay on track, and a map with different adaptation pathways presenting other policy options when the desired path fails.
- **Monitoring:** The conditions for success are translated into signposts to monitor progress toward or away from the objectives, and to trigger the adaptive responses (Walker et al. 2001; Dewar et al. 1993). Triggers can be based on information on the past or current situation (such as monitoring results), but also information about the future, such as scenarios on future climate, or new estimates of the Dutch population (e.g., 20 million instead of the currently planned for 16 million).

Ad. 10. Make the policy stronger by asking: What could make the policy fail?

By considering 'What could make the policy fail?' or 'What if the assumptions behind the policy are wrong?' policymakers can identify the vulnerability of a policy and define actions to reduce this vulnerability (Walker et al. 2001; Dewar et al. 1993). These actions can either be additional measures, or can be predefined actions that can be implemented once the policy fails or, preferably, once it is clear that the policy is likely to fail in the coming years. For the latter, signposts can be used to monitor the environment to decide whether adaptation is necessary.

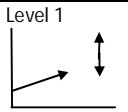
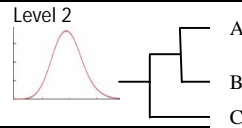


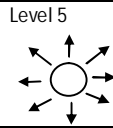
6 Next steps

To include uncertainty in the Deltamodel and decision-making with the Deltamodel we propose that the following next steps be performed:

1. Communicate the guidelines
2. Elaborate the uncertainty-impact database: in other words, get an idea of the sensitivity and importance of the uncertainties on the outcomes.
3. Indicate what change in an outcome indicator is important for decision-making. This determines the needed accuracy of the Deltamodel and also the importance of some uncertainties.
4. The importance of these changes on decision-making should be assessed. The 'thinking experiment' could help. For example, Would you make a different decision if the result of the model is e.g. 10 cm instead of 20 cm?; if the agricultural damage is 110 milj. Euro instead of 100 milj. Euro?
5. A fast simple model/screening tool is needed. Not only for the screening of policy options, but also to get an idea of the sensitivity.
6. Indicate the uncertainties in the model outcomes. For example, assigning confidence levels to the outcomes and/or showing the ranges of outcomes.
7. Follow the structured approach of policy analysis, using models and dealing with uncertainty.

Appendix A. Uncertainty Classification Matrix for the Deltamodel

This table presents the uncertainty classification matrix based on Kwakkel et al. (2010) and Walker et al. (2003 and in preparation), with examples for the Deltamodel.

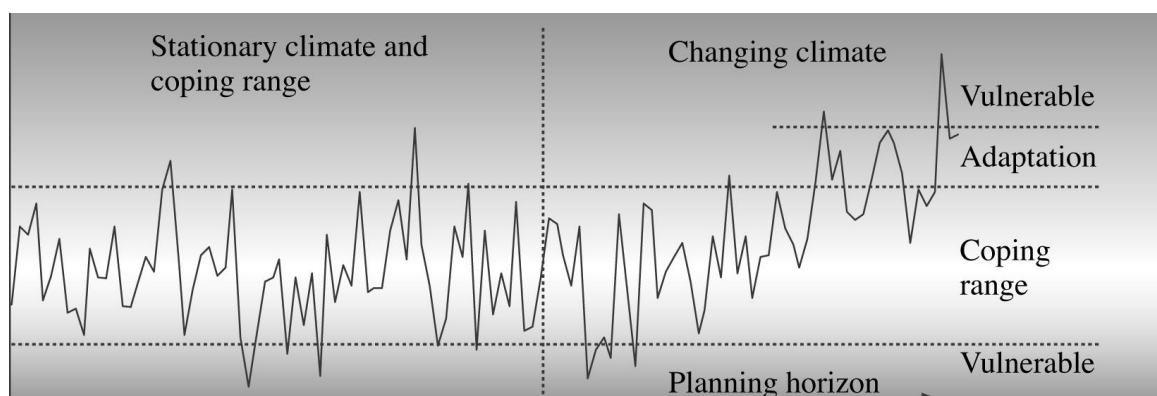
Location	Level					Nature		
	Level 1 	Level 2 	Level 3 	Level 4 	Level 5 	Ambiguity (perspectives)	Epistemology (imperfection of knowledge)	Ontology (natural variability)
Context	Single forecast for the future: e.g., single estimates of future water demand for drinking, industry, and agriculture	Scenarios with probabilities: e.g., three climate change scenarios with probabilities	Scenarios for plausible futures ranked with a likelihood classification	Scenarios for plausible futures without probabilities: - Climate change, Sea level rise - Socio-economic developments	Scenarios with surprises and dynamics: - Credit crunch resulting in less money for water - Dike collapse - Include interaction of the water system with society (e.g. autonomous adaptation of water users: self-supply in response to dry conditions)	Different perspectives (expectations) about the future, the system, the problem, etc.	- Lacking information on potential climate change - Too few monitoring locations (for e.g. land subsidence river discharge)	Time series of discharges of the river Rhine
System model	- One Deltamodel - Assuming current q-h relation ($q=\alpha h$) - Assumed strength of dikes	- One model structure with different (probabilistic) parameterizations - $q=\alpha h$, with $\alpha \sim N(\mu, \sigma^2)$	Several model structures, one of which is most likely. Agreement classification on the model structures	- Several model structures: WAQUA, SOBEK-1d for the river system - $q=f(h), g(h), k(h)?$	- Explore alternative models - $q=??$	Different processes in the model based on different 'beliefs' on how the system works	Several model structures describing the same process	
System outcomes	A point estimate and confidence interval for each outcome (e.g., groundwater level); a single scorecard with results for various (static) policy options	Several sets of point estimates and confidence intervals for the outcomes, with a probability attached to each set (e.g., water levels based on different sets of assumptions); a scorecard for each set of assumptions (e.g., for each scenario) with results for various (static) policy options	Several sets of point estimates, ranked according to their perceived likelihood and degree of agreement from experts.	Ensembles of water levels and other outcomes; a scorecard for each set of assumptions (e.g., for each scenario and/or for each different model structure) with results for various (static) policy options	Water levels and other outcomes for the full range of scenarios, models, and other assumptions for various (dynamic or static) policy options	Different interpretations of what the outcomes mean		- Probability distribution of results - frequency of exceedance - frequency of low flows
Weights on outcomes	A single set of weights	Several sets of weights, with a probability on each set	Several sets of weights ranked according to their likelihood.	Several sets of weights, with no probabilities on the sets	Explore policy implications under a range of assumptions about weights	Different weights for different stakeholders	Different stakeholder configurations in the future	

Appendix B. Low probability, high impact situations

Current water management in the Netherlands is well prepared for situations which occur regularly. Extreme situations can result into problems. Low probability, high impact situations are situations with a low frequency of occurrence (e.g. 1:10.000), but with a high impact. (For example, the combined occurrence of a storm at sea and a high river discharge or extreme long period of drought.)

Therefore, despite the low probability, policymakers decide to prepare for such events. The climate variability (e.g. the extent to which variations in precipitation occur) is thus important to included in strategy development. These situations can occur in each scenario, but with a different frequency of occurrence. From simulations with transient scenarios (time-series like in Figure 1) it appear that for the short term (< 50 year) climate variability is more important than climate change (Haasnoot et al 2009). On the long term it is at least as important as climate change.

Events with a large impact influence our thinking about water management and also our policies. A well-known example from the past, are the Delta Works. Despite, that policymakers knew from previous studies the coastal defense of the southwestern part in the Netherlands was insufficient to cope with south western storms at sea, the implementation of the Delta Works came into force after the flood disaster of 1953. At first all barriers were designed to stay closed. Later when society recognized the potential impact on nature the Oosterscheldekering was kept open with the possibility to close in case of a storm. Other examples, are the values of the design discharges and the plans for 'Room for the river' (co-triggered by high river waters in 1993 and 1995). These events remember us what can happen in extraordinary situations. This can support the influence of the political and societal agenda. On the other side, it is also possible that the absence of an event can diminish support for strategies. Not only events in the water system but also other events, such as a credit crisis, Al Gore's movie 'the unconvient thruth' or discussion about errors in the IPCC reports, influence our thinking about the water system and thereby also our decision-making (Offermans et al. 2009; Haasnoot et al. 2009).



FigureError! No text of specified style in document..1: Relation climate change, climate variability, and vulnerability, coping range en adaptation (Jones & Mearns 2004).

Thinking experiment

Our water management has always been adapted to changing conditions. Although often successful in the end, such adaptations did attend with high costs and/or societal impacts (e.g. after a flood). Despite our intention to act proactive and anticipate on the future, our actions are often determined by a reaction to extreme events (see examples from the pasts). Also, from game sessions where participants manage the water system of a fictive delta for the next century, it appeared that strategies are often implemented in response to events (van Deursen et al. 2010, 2010, Haasnoot et al, 2010, Valkering et al. 2011).

To illustrate the above we give a thinking experiment. Figure 2 present four possible realizations of the maximum discharge of the river Rhine at Lobith. The upper two and the lower two have similar variability but differ in climate scenario. The ranges are based on precipitation time-series of the Rainfall generator (Buishand and Brandsma, 1996) and simulations with a rainfall-runoff model (Te Linde et al., 2010) which are then made transient (Beersma, 2009; Haasnoot et al. 2009).

The first two time-series present a similar situation like in 1993 and 1995 with two peak discharges close after each other. At that time people were evacuated from the Betuwe area because the discharge was around 12.000 m³/s. The discharges presented here are 14.500 and 15.000 m³/s in the realization without climate change and 15.000 and 16.000 m³/s in the realization with the Wplus scenario. It is thinkable that such a situation will result in discussion about our water management strategy. That is the moment to implement rigorous measures (of needed) and to prepare for a future where climate may change and may result in a larger occurrence of such events. If we would determine the design discharge again based on the new information of river discharges it would be higher. Would this occur then we are possibly well prepared for peak discharges around the 18.000 m³/s which occur later in this realization according to the Wplus scenario (second graph).

It is also thinkable that in the next 50 year no peak discharges will occur (two lower graphs in figure 2). This may result in a different adaptation path than the first two examples. Possibly the attention for and belief in climate change may diminish. The urgency for adaptation may disappear. However, when peak discharges occur (in this realization in year 57, 58 en 74) the impacts may be high. The time-series of figure 2 also show that for the nearby period the differences between the realizations with and without climate change are very small, but on the long term the differences become visible (for the Wplus scenario). Also, the lower time-serie shows that it is possible that climate change is happening, but that we do not see this in the occurring discharges.



Figure 2: Transient scenarios for two different climate realisations (indicated with realisations 5 and 8) for a situation without climate change and a situations with climate change according to the Wplus scenarios. In 1995 people were evacuated in the Betuwe area when the Rhine discharge was about 12000 m³/s.

References appendix B

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Appendix C. Response to IAC letter

The International Advisory Committee wrote an advice for the Deltamodel in response to our White Paper and our presentation regarding 'Uncertainty Analysis and Decision-making under Uncertainty with the Deltamodel'. In this appendix we shortly respond to their suggestions.

'Don't make the Delta Instruments only water-orientated:

The Deltamodel is now mainly water-orientated. However, we feel that you need an integrated approach that takes all developments, including on land, into account. The Delta Programme Commissioner should be as concerned about managing the land as about managing the water. You really need to make policy that allows you to deal with the Delta (or the Netherlands) as a system.

.....

This does not relate to uncertainty but it does relate to decision-making with the Deltamodel. Some interviewees also mentioned this. They mentioned that some impacts are missing in the Deltamodel, and that they worry about the integration of the results.

Provide an uncertainty range and test the uncertainty in the effects models

Uncertainty is a fundamental element of this Delta Programme and its components and this should be explicitly addressed in the Deltamodel and Delta Instruments. The ultimate goal must be quantitative assessment, but initially qualitative assessments are better than ignoring this issue. Addressing uncertainty in the Delta Instruments may be more difficult than in the Deltamodel. **Hence, in this regard, this point of advice that can only be implemented at a later stage (after 2014), although qualitative judgements should be considered even over the short term.** Hence, you need to work together to test uncertainty propagation for the Delta Instruments. Initially, this is probably best achieved in a workshop setting, as was also advised above (2b).

We agree that this is an important activity. It is included in the guidelines, and is included in the recommended methods for dealing with uncertainties.

As an example you should have a look at the Guidance Notes for Lead Authors of the IPCC on Addressing Uncertainties

We refer to the IPCC 3rd TAR guidelines, and use them in the ten guidelines. Also, we added an uncertainty level based on likelihood.

Analyse the full range of future conditions: concentrate on expected reasonable ranges, but do not exclude the more extreme possibilities

The extreme range possibilities correspond with uncertainties of Level 5 (Black Swans/ high impact, low probability events). We also included this advice in the guidelines.

Appendix D. Things we noticed

- It is not yet clear what the most important outcomes are for decision-making.
- Interviewees find it difficult to say what are relevant changes in outcomes for decision-making. This makes it difficult to make an appropriate model.
- Uncertainties in model outcomes was not really mentioned. Maybe we do not know (ignorance or recognized ignorance?)
- Trust in the model seems to be very important -- sometimes not based on facts, sometimes on old information, sometimes on different assumptions.
- Trust in policymakers is important. We feel too safe (e.g. no operational evacuation plans).
- Given the uncertainties about the future climate (variability), is it wise to base the flood safety policy on probabilities and statistics? Doesn't this give a false sense of security?

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