# Decision making under uncertainty – towards an approach for finding robust and flexible fresh water supply strategies

**Work package leader: Prof.dr.ir. W.A.H. (Wil) Thissen**

## Content



# 1 Description work package

## 1.1 Problem definition, aim and central research questions

Decision making and planning for fresh water supply are challenging because of different reasons: First, a variety of individual measures or tactics need to be considered at both the supply and the demand side, and appropriate combinations of these need to be made in the process of policy design. Second, different scales need to be considered, such as the local, regional, national and river basin scales, each having their associated governmental bodies. Third, a range of sometimes conflicting interests need to be considered. Fourth, various uncertainties come into play. In addition to the relatively well known natural climate variability, long-term decision making in view of adaptation to climate change brings a new class of important uncertainties. These include the speed of climate change, its impacts on precipitation and evaporation patterns, its impacts on salt intrusion and salinisation, and a variety of possible developments in other fields including transport, land use and agricultural conditions, food markets, spatial developments, economic developments, future technology, and future societal values. While acknowledging and including the other (notably the multi-actor, multi-objective) complexities mentioned, this work package will in particular focus on the development and testing of approaches to deal with long-term uncertainties in planning for fresh water supply. Clearly, designing policy measures and water supply systems for a ‘worst-case‘ scenario involves the risk of over-investing. But simply ignoring uncertainties and developing policy for a ‘most likely’ (or a chosen normative future) also involves risks as reality will most likely be different. Conversely, possible future developments may not only imply certain risks, but also provide interesting new opportunities. During the last decade, it has become accepted that different types of uncertainties should be dealt with differently, depending on the values of the decision makers and contextual conditions (Dessai and Van der Sluijs, 2007 – see projects 5.1 and 5.3). The central aim of the proposed research in this work package is to develop and test tools, and to design guidelines for dealing with the typical uncertainties policy makers have to face when considering longterm policy planning for fresh water supply and demand, at the regional level.

The central research question therefore is:

- What are suitable approaches for finding robust and flexible fresh water supply strategies at the regional level, in light of the various long-term uncertainties encountered?

Sub-questions include:

- What are the characteristic regional fresh water supply situations to be dealt with in the Netherlands?
- What are the relevant uncertainties in each of these, what is their character, and how important are they?
- What analytical approach suits the different uncertainties?
- What mix of policy approaches is recommended for these characteristic situations?
- How can these policy approaches be operationalised for the cases studied in work package 6?

## 1.2 Interdisciplinarity and coherence between the projects

The approach taken in this work package is rooted in the conviction that (a) a number of key uncertainties cannot easily be reduced and have to be accepted, and (b) different approaches will be needed for different types of uncertainties in different situations. We postulate that two main strategies will be relevant. In the first, water supply systems are designed to be sufficiently robust. Robust systems will be able to function – or quickly recover and restore functioning after disturbed – under a variety of conditions and/or disturbances, without external intervention in the system. Various approaches and mechanisms may contribute to system robustness, such as built-in feedbacks and recovery mechanisms, diversification, redundancy (see project 5.1 ). This strategy seems best fitted for uncertainties where natural variability is a key characteristic, such as weather conditions.

In the second strategy, labeled ‘robust decision making’ or ‘adaptive policy making’, a policy strategy is chosen that explicitly considers and includes options for deliberate policy adaptation as the future evolves. This strategy seems to best suit situations characterized by so-called 'deep uncertainties': a variety of developments are thought to be possible and can significantly impact policy outcomes, but information about their probabilities and/or consequences is scarce or even absent (scenario-uncertainties, or so-called wild cards). In addition, stakeholders may disagree about the best system representation and about the valuation of alternative outcomes.

For fresh water supply in the perspective of climate change, both variability and deep uncertainties are relevant. Hence, the proposed research in this work package will explore both approaches, in three complementary projects:

- Project 5.1: Adaptation under uncertainty: resilience as a strategy for climate proofing fresh-water dependent networks of protected areas (with special emphasis for the "groene ruggengraat")
- Project 5.2: Robustness analysis methods to support flood and drought risk management
- Project 5.3 : Towards robust policy making for fresh water supply.

Both projects 5.1 and 5.2 will focus on robustness principles for socio-ecological systems, in particular protected natural areas, resp. flood protection and water supply systems. Both will primarily be oriented to dealing with variability uncertainties and preventing or reducing undesirable outcomes.

Project 5.3 will be complementary to projects 5.1 and 5.2 in three respects: it will focus on overall policy strategies as deliberate interventions in socio-ecological systems including adaptive policy actions over time; it will be mainly oriented to deep uncertainties, and it will also explicitly explore opportunities that future uncertainties may hold.
Project 5.3, in addition, will take the lead in combining insights, i.e., for a given situation, which (mix of) approach(es) will be best fitted?
Each of these projects is interdisciplinary in itself, combining water-related knowledge with ecosystem knowledge (project 5.1); and with socio-economic knowledge (projects 5.2 and 5.3).
In identifying possible solutions, this work package will build, among other things, on the findings in work packages 1 (for socio-economic conditions and scenarios), 2 through 4 (for possible solutions), and 6 (providing more detailed and full information on the case studies to be elaborated). Conversely, the case-based more in-depth uncertainty analyses performed in WP5 will directly feed into WP6.

## 1.3 Stakeholders

Finding appropriate ways of dealing with the variety of uncertainties is in the interest of all stakeholders and policy makers involved in fresh water supply.
As the WP5 research team will actively contribute to the cases that are further elaborated in work package 6, interactive sessions with the key stakeholders in these cases will be organized to discuss the identification and relevance of uncertainties, identify policy options, and in general discuss and evaluate the uncertainty analysis and policy approaches from stakeholder and policymaker perspectives. In addition, as the workpackage intends to contribute approaches to dealing with uncertainties in water supply a more general sense, other key stakeholders such as DGW will be invited to contribute their

views and react to research findings and recommendations.

Finally, to ensure inclusion of expert subject knowledge, and to foster dissemination of the concepts and approaches to be developed, part-time involvement of senior staff of Deltares, KWR and Alterra is foreseen.

# 2 Project 5.1 Adaptation under uncertainty: resilience as a strategy for climate proofing fresh-water dependent networks of protected areas ("groene ruggengraat")

**Project leader: Dr. Jeroen P. van der Sluijs**

## 2.1 Problem definition, aim and central research questions

The "Green Backbone" (Groene Ruggengraat) that is currently being realized in the West of the Netherlands will connect a range of wetlands to form a robust ecological network of protected areas. These wetlands derive much of their ecological value, biodiversity and attractiveness from the abundance of fresh water of sufficient quality. Climate change may bring disturbing stresses such as periods of extreme droughts, periods of extreme rainfall, salt water intrusion, floods and invasive species. Through these stresses, climate changes poses major challenges to the long term viability of the Green Backbone and may force it into regime shifts towards undesired system states. These stresses come on top of non-climate related stresses such as soil subsidence, drying out, fragmentation, pollution, and a multitude of competing land use claims and functions that need be integrated.

Climate proofing ecological networks has to deal with many uncertainties, including statistical uncertainty (possible outcomes and their probabilities are known), scenario uncertainty (a plausible range of possible outcomes can be established but the relative probabilities of each possible outcome are largely unknown) and ignorance (outcomes unknown: unanticipatable surprises).

Approaches for dealing with uncertainty in climate change adaptation include: risk approach, anticipating design, resilience, adaptive management, and robust decision-making. These decision frameworks can be grouped into the predictive top-down approach and the resilience bottom-up approach. Top down explores the accumulation of uncertainty going from emission scenarios, to global climate response, to regional climate scenarios to produce a range of possible local impacts in order to quantify what needs to be anticipated. The bottom up resilience based approach starts at the impacted system, and explores how resilient or robust this system is to changes and variations in climate variables and how adaptation can make the system less prone to uncertain and largely unpredictable variations and trends in the climate. Resilience also means that the impacted system is adapted in such a way that its essential functions can recover more quickly after a shock and that restore times after damage and response time following early warning signals are made as fast as possible. This project further develops a system-oriented strategy: strengthening the resilience of the impacted system to climatic changes.

The project aims to operationalise the concept of resilience. Folke (2006) identifies a sequence of resilience concepts, from narrow to broad: (1) engineering resilience, (2) ecosystem resilience and social resilience, and (3) social-ecological resilience. The first two focus on recovery rate and withstanding shock respectively. The last focuses on the interplay between disturbance and reorganization. In the literature on resilience, the concept is currently defined as "the capacity of a system to absorb disturbance and reorganise while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks". Three characteristics of (socialecological) resilience are identified:

1. The amount of change the system can undergo and still retain the same controls on function and structure
2. The degree to which the system is capable of self-(re)organization to accommodate external changes
3. The ability to build and increase the capacity for learning and adaptation

This relatively broad definition seems suitable for the Green Backbone that faces not only disturbing events (shocks; e.g. floods), but also disturbing trends (e.g. increased salt intrusion). On longer timescales, withstanding and recovering from singular disturbing events is insufficient. A resilient system should also encompass the dynamics to accommodate trends and co-evolve; to bounce back in better shape.

This project will develop and explore policy options and strategies that could enhance a system's resilience. Several studies propose resilience indicators for specific subsystems, aiming to provide a basis for quantitative evaluation of possible policy strategies (e.g. Adger, 2000, Carpenter et al., 2001, De Bruijn 2004). Other studies have taken a qualitative approach (Wardekker et al, in press). This project aims to combine and integrate quantitative and qualitative approaches to resilience.

The main question is: what could a resilience based system approach to climate change adaptation entail for a fresh water dependent Nature area?

What are relevant possible disturbances of the Ecological network under various climate change scenario's?

- What are the essential values and functions of the Green Backbone system?
- How vulnerable is each of these functions to climate changes?
- In what way does the current policy framework for the Green Backbone take climate change into account and how is dealt with uncertainties surrounding climate change?
- What are the different alternate states of the system?
- What is the desirable (future) state of the system?
- In which state is the system at present?
- Which regime shifts could possibly occur as a result of the combined effect of climate change and other anthropogenic disturbances?
- How resilient is the system at present?
- What specific measures can be taken to enhance the resilience of the system?

## 2.2 Approach and methodology

The operational definition of a resilient system used in this study is: "a system that can tolerate disturbances (events and trends) through characteristics or measures that limit their impacts, by reducing or counteracting the damage and disruption, and allow the system to respond, recover, and adapt quickly to such disturbances". In this definition, tolerating disturbances is taken in contrast to resisting these. We will assess trends/impacts, define characteristics that make a system resilient, and use these to explore options and to specify and categorise how they can contribute to the system's resilience.

This study uses six 'resilience principles' from ecological and system dynamics literature (Watt and Craig) for generating resilience indicators and policy options in relation to adaptation of ecological networks of wetlands:

- Homeostasis: multiple feedback loops counteract disturbances and stabilise the system.
- Omnivory: vulnerability is reduced by diversification of resources and means.
- High flux: a fast rate of movement of resources through the system ensures fast mobilization of these resources to cope with perturbations.
- Flatness: the hierarchical levels relative to the base should not be top-heavy. Overly hierarchical systems with no local formal competence to act are too inflexible and too slow to cope with surprise and rapidly implement nonstandard highly local responses.
- Buffering: essential capacities are over-dimensioned such that critical thresholds in capacities are less likely to be crossed.
- Redundancy: overlapping functions; if one fails, others can take over.

The approach builds further on Wardekker et al (in press) that applied these resilience principles to adaptation of an urban delta.

## 2.3 Scientific deliverables and results

- scientific report on the conceptual framework for operationalising resilience.
- scientific article in peer reviewed journal on resilience indicators and policy options for climate change adaptation of the Groene Ruggengraat.

## 2.4 Integration of general research questions with hotspot-specific questions

This project will mainly contribute to the hotspots "Ondiepe wateren en veenweidegebieden" and "Zuid Westelijke Delta" and "Biesbosch", but the results are expected to be applicable to all hotspots that search for resilient ways to adapt nature area's to climate change.

## 2.5 Societal deliverables and results

- Resilience based step by step approach for generating indicators and policy options
- Indicators for resilience customized for nature area's
- Policy options for increasing resilience of Groene Ruggengraat

## 2.6 Most important references


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# 3 Project 5.2 Robustness analysis methods to support flood and drought risk management policy making

**Project leader: Prof. Eelco van Beek**

## 3.1 Problem definition, aim and central research questions

Decision-making about long-term water management is a complex process. It concerns designing, combining and deciding between various types of measures, together with different stakeholders working on different scales. Moreover, it is considered more and more important to take into account long-term changes in the system that may influence the effect of measures.

Decision-makers use a variety of criteria such as costs and benefits to be able to choose between strategies. In order to deal with uncertainties about future developments, additional criteria such as robustness and flexibility are suggested. Since a few years, decision-makers in the Netherlands have been referring to the concept of robustness (see for example: ARK (2007), Nationaal Water plan (2008), Ontwerp waterbeheersplan Zeeuwse eilanden (2008) and Ontwerp waterbeheerplan Brabantse Delta (2008)). They have the feeling that robust systems are preferable under the pressure of climate change, but cannot specify what makes a system more robust. Because a clear definition lacks, this leads to miscommunication among stakeholders resulting in a large range of robustness scores.

Because robustness is still not well defined, it is worth exploring its meaning and use for long-term flood and drought risk management. We hypothesize that the concept of robustness, when well defined, supports to explicitly deal with natural variability and future changes herein. This may support the development of strategies (combination of measures) and the decision between them.

The objective of the research is to improve the use of robustness in decision-making for long-term flood and drought risk management. We aim to enhance the applicability of the concept, by developing a practical method to assess alternative strategies for flood and drought risk management and guidelines to increase the robustness of systems.

The main research question is *whether and how the concept of robustness can aid decision-making about long-term strategies for flood and drought risk management.*

The following questions will be addressed:

1. What definition of system robustness is suitable for use in the management of flood and drought risk systems?
    - ▽ How is robustness defined in ecological, social and economic literature?
    - ▽ How does robustness relate to other, comparable, concepts such as vulnerability and resilience?
    - ▽ How is robustness used in practice?
    - ▽ Which definition is suitable for flood and drought risk systems?
2. Which indicators can be used to quantify robustness of flood and drought risk systems?

3. How can the robustness of flood and drought risk systems be increased?
    - relation with Modern Portfolio Theory? (Jeroen Aerts)
4. What is the added value of robustness as decision criterion in flood and drought risk management?

## 3.2 Approach and methodology

The definition of system robustness used in this study is: “the ability of a system to cope with disturbances”. In this study, the robustness of drought risk systems to natural variability will be assessed. Robustness is comparable to the concept of ecosystem resilience (Holling, 1973) and can be increased by increasing the resistance, measured by the maximal amount of disturbance that is needed to cause the system to react adversely, or increasing the resilience, measured by the amount of impact, the graduality of the impacts and the recovery capacity (De Bruijn, 2005).

**Approach:**
To develop the conceptual framework for robustness, we will make an overview of definitions and usages in literature and practice. As for literature, we consider robustness of ecological systems, robustness of economic systems and robustness of social systems. As for practice, we look into recent water policy documents from the Netherlands government (i.e. Nationaal Waterplan) and from Netherlands waterboards (‘ontwerp waterbeheersplannen’). This is done together with theme 1.

The concept of robustness applies to different problem owners. This is especially relevant for drought risk management: a farmer will be interested in the robustness of his yield to drought, while a province will be interested in the robustness of the regional economy to drought periods. Different perspectives will lead to different conclusions about which measures to take. With the case of ‘Groene Ruggengraat’ we aim to demonstrate the effect of different perspectives.

**Summary of approach** (* indicates cooperation with theme 1):

- *Literature review: How is system robustness defined in literature and how is it used in practice?;
- *Development of a conceptual framework for robustness;
- Individual discussions with hotspot representatives about the framework;
- *Design of a framework to analyse the cases;
- Casestudies: application of conceptual framework on drought risk systems:
    - System description;
    - Robustness analysis, including long-term developments;
    - Design and assessment of strategies;
- *Reporting insights in the form of guidelines;
- Workshop with hotspot representatives to discuss guidelines and casestudy-results;
- *Adjust robustness framework

### 3.3 Scientific deliverables and results

Two scientific articles in peer reviewed journals:

- one the conceptual framework and the Westerschelde (together with theme 1);
- one on the application in one or two drought risk management cases.

### 3.4 Integration of general research questions with hotspot-specific questions

This project will mainly contribute to the cases Groene Ruggegraat and Zuidwestelijke Delta
The conceptual frameworks for robustness will aid the assessment of drought risk management strategies in WP-6. The guidelines can be used by decision-makers who are concerned with the long-term planning of areas that are at risk of flooding and/or at risk of drought.

### 3.5 Societal deliverables and results

- Guidelines for the development of robust policy strategies for drought risk management;
- Indicators for the quantification of robustness

### 3.6 Most important references


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# 4 Project 1.1 Towards robust policy making for fresh water supply

**Project leader: Prof.dr.ir. W.A.H. Thissen**

## 4.1 Problem definition, aim and central research questions

As indicated in the theme 5 general description, decision making on long-term strategies for fresh water supply is confronted with a variety of uncertainties, including climate variability, various potential impacts of climate change, de degree and speed of climate change, economic and agricultural conditions, other relevant social developments. Different approaches exist or are under development that specifically orient to dealing with such uncertainties (ref. Dessai and Van der Sluijs, 2007). ). While the two other projects in the work package focus mainly on so-called robust or resilient design of socio- ecological systems as an answer to variability uncertainties (with a particular emphasis on natural systems in project 5.1), this project concentrates on so-called robust decision making (Lempert et al., 2003). Robust decision making is particularly suited to dealing with so-called deep uncertainties: situations where possible developments can be imagined, but no reliable estimates can be given about their probabilities and outcomes. This includes the types of uncertainties that are often dealt with using scenario-approaches, but also socalled wild-cards or surprise scenario's should be included, and situations in which there is no agreement about what models best represent system behaviour. An example of application of the approach to a regional water supply problem in California is given in (Groves and Lempert, 2010).

The approach – which is still under development – combines a broad analysis of uncertainties and their possible impacts (Lempert et al., 2003; Agusdinata, 2008) with an assessment of the performance of selected policy alternatives under a wide range of possible assumptions about the future. The insights thus gained enable analysts and policy makers to identify the conditions under which policies will perform well, and conditions under which policies might fail. They may then select a base policy that will do well under most circumstances, identify future conditions under which policy adaptations are desired, as well as the type of adaptations. The insights gained may also help distinguish between more flexible policy options that allow for easy adaptation as circumstances change, and less flexible ones which may lead to lock-in situations.

Central research questions in the project will be:

- what typical decision situations for regional long-term fresh water supply exist in the Netherlands?
- which uncertainties will have an impact on long-term fresh water supply and demand for these situations?
- what policy options do exist or can be thought of for these situations?
- to what extent and under what conditions is exploratory modeling and analysis suited as an approach to assess the performance of these various policy options under a wide set of possible futures?
- what criteria can be relevant for choosing among these policy options, with a particular view to how they deal with uncertainties (flexibility? Least-regret? Robustness?)

- what general recommendations can be given for the selection of a preferred policy strategy to deal with uncertainties, depending on the situation characteristics?

## 4.2 Approach and methodology

First step in the approach will be to identify a limited number of typical decision situations regarding fresh water supply in the Netherlands. For example, the situation in the western part of the country will be essentially different from the one in the high part of the country. Different factors and mechanisms come into play, and different associated uncertainties. While there will be a focus on the selected case studies which are all situated in the western part of the Netherlands (see WP6), at least one situation will be included that is representative for the 'high' part of the country.

Second, for each situation the relevant, long-term uncertainties will be identified. These include uncertainties about external developments (such as climate change and economic developments) as well as uncertainties about the internal functioning of the region to be studied (e.g., abut the impacts of future changes on water use, the quality of ecosystem services, the economic costs and benefits of local agriculture, etc.). The framework developed by Walker et al. (Walker et al., 2003) will be used as guidance in this effort.

Third, the spectrum of possible policy strategies for each selected situation will be identified. What options are available will of course depend on the characteristics of the situation. One might wait and see what developments will occur, decide to invest in flexibility options, over-dimension the capacity of water ducts, etc. etc. (see e.g. Klinke and Renn, 2002; Van der Sluijs, 2005).

Fourth, a framework will be developed for evaluation of policy options under uncertainty. In addition to the usual set of criteria such as costs, benefits, harm to the natural system, etc., special attention will be given to the uncertainty dimension. In coordination with the PhD (project 5.2), policy robustness indicators will be developed, and these may be different for the different case situations.

Fifth, where feasible the principles of Exploratory Modeling and Analysis (Agusdinata, 2008) will be used to explore the range of possible impacts of the policy options under a wide range of possible future circumstances. This will imply a conceptual analysis of the flexibility of different decision sequences (decision 'pipeline' approach), as well as the use of relatively simple computer models for a more extensive analysis. When available, use will be made of (simplified versions of) existing models. If new models need to be developed, this will require additional efforts, and model availability will have an impact on the number of different cases that can be explored in depth within the temporal and financial boundary conditions of the project.

Sixth, combining the results of the uncertainty impact analysis with the evaluation framework, a so-called adaptive policy strategy is developed (Walker et al., 2001). To start, a selection is made of the more robust policy options: those that will perform reasonably well under a wide range of possible circumstances. In addition, the conditions under which this policy will perform less than desired are identified, and measures or adaptations that would improve policy performance under such conditions are defined.

Interaction with and support of local experts and stakeholders in the cases will be important in most of not all of these steps.

Finally, attention will be given to the overall, more general lessons based on the situation-specific work. These will relate to both the utility of and possible improvements in the methodology, as well as to the policy content.

## 4.3 Scientific deliverables and results

The project will deliver:

- comprehensive insight into the various uncertainties of relevance for long-term planning in fresh water supply in the Netherlands, and their relevance to mostly regional policy decisions to be made in the short term
- a basic insight in what kind of policies will perform best, depending on the characteristics of the situation and of the uncertainties
- one or more evaluation frameworks specifically geared to evaluation of long-term water supply policies under uncertainty
- insights into the applicability and limitations of Exploratory Modeling and related approaches for long-term fresh-water policy making in the Netherlands, and general guidelines for their application

Results will be documented in reports for each of the cases that will be studied in depth, and in a number of internationally reviewed papers, partly in cooperation with the researchers of projects 5.1 and 5.3, and WP6.

## 4.4 Integration of general research questions with hotspot-specific questions

A selection of the policy dilemma’s faced by the hot spots, and by water management authorities in general, will be used as empirical case material for developing, applying and evaluating the approach. This will include at least the Haaglanden and the Zuid-Beveland cases that will be elaborated in WP6.

## 4.5 Societal deliverables and results

The policy makers in charge of decision making for the selected cases will get guidance in their quest for long-term robust policies
Other policy makers and analysts will obtain a methodology and guidance to systematically address deep uncertainties in their long-term strategy development
As a result, water supply policies will be more effective in the long run.

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