FRAMEWORK FOR INTEGRATED DESIGN OF WATER AND LAND MANAGEMENT SYSTEMS

Towards robust water-space partnerships as a basis for adaptive water management

Report of the NeWater project -
New Approaches to Adaptive Water Management under Uncertainty

www.newater.info

Title	*Framework for integrated design of water and land management systems*
Purpose	Working paper that provides a common understanding of research topics and challenges for Work Package 1.4 'Integration of IWRM (integrated water resources management) and spatial planning'
Filename	NeWater_D141_V13.doc
Authors	P.E.V. van Walsum, J.C.J.H. Aerts, J. Krywkow, A. van der Veen, H. der Nederlanden , M. Q. Bos**,** B.T. Ottow
Document history	
Current version.	13
Changes to previous version.	HdN
Date	28 okt. 05
Status	'Final'
Target readership	NeWater
General readership	NeWater
Correct reference	Van Walsum, P.E.V., J.C.J.H. Aerts, J. Krywkow, A. van der Veen, H. der Nederlanden, M. Q. Bos**,** B.T. Ottow. *Framework for integrated design of water and land management systems; towards robust water-space partnerships as a basis for adaptive water management. Report to the NeWater project*, Wageningen, 2005.

Paul van Walsum, editor
Alterra, Wageningen UR.

October 2005

Prepared under contract from the European Commission

Contract no 511179 (GOCE)
Integrated Project in
PRIORITY 6.3 Global Change and Ecosystems
in the 6th EU framework programme

Deliverable title:	Framework for integration of spatial planning and IWRM at three scale levels
Deliverable no. :	D 1.4.1
Due date of deliverable:	Month 9
Actual submission date:	30.10.2005
Start of the project:	01.01.2005
Duration:	4 years

Executive Summary

Overview

Water and space are inextricably linked. External pressures thus result in chains of impacts and responses that are intertwined and interactive. Recognizing this, the development of methods for integrated design of water and land management systems is seen as one of the key elements in NeWater, and is the focal point of Work Package 1.4 'Integration of IWRM (integrated water resources management) and spatial planning'. The goal of this 'working paper' is to provide a common understanding of the research topics and challenges. We aim to develop new methodologies for the water-space interface, which can contribute to the concept of adaptive water management (AWM). For this the following objectives have been identified:

- to elaborate on current developments in water management with a focus on the Netherlands by assessing current policies and scientific methods (Section 2);
- to describe how stakeholder involvement is connected to water-space issues and the crucial role that partnerships play for putting AWM into action (Section 3);
- to support adaptive water management by providing a multi-level modelling system (Section 4);
- to indicate how the models can be used for aiding risk management under uncertainty (Section 5);
- to indicate in what case studies the methodology will be tested and implemented (Section 6).

The project has started in January 2005 and will run until December 2008.

The water-space interface

From the beginning of the nineties both the water and the spatial planning sectors in the Netherlands have started to develop cross-sectoral policies and measures to face the new challenges of climate change. However, this was initially done from two different perspectives of water and space management. Now the trend is towards further integration at the policy-making level and at the level of practical implementation. This vertical integration is facilitated by the so-called *strata* approach that integrates the planning layers of (a) the land and water systems (b) the networks and (c) the occupants.

Multifunctional land-use is seen as a key option for increasing the adaptive capacity of the regional systems, both in terms of water, ecology and of economy. The flexibility of being able to change emphasis from one function to the other enhances the adaptive capacity of the regional systems.

To enable the integrated design of land and water management systems we see it is a research challenge to develop tools that can at the same time take into account the horizontal ('chorological') and vertical ('topological') interactions within/between the planning layers as described above.

For being adaptive it is necessary to know what is needed in order to accommodate the temporal variability that is so important in day-to-day life. Otherwise it is not known in which direction to adapt. Added to that, the temporal trajectory – transition – from the current state to the future one should also be a central research issue and be addressed accordingly. Otherwise the desired future state will be elusive. For the transition we consider the building of water-space partnerships as a crucial step.

Building the water-space partnerships

The manner in which stakeholders are prepared (or not) to share costs and benefits has great consequences for the appropriate design of a water and land management system. In the case of a 'perfect partnership' all costs and benefits can simply be added up. But even if there is not a perfect partnership it can have sense to present a design based on it, just for providing a reference point in the negotiations. Then the costs for a negotiated partnership can easily be compared to the costs of a perfect partnership. By showing the stakeholders the consequences of their negotiation activities on welfare they can make better founded decisions.

The research challenge with respect to the building of partnerships is to facilitate that process through offering the suitable type of tools at the right moment.

Multi-level modelling

To provide useful decision support for adaptive water management the modelling has to be integrated and at the basin scale. But many processes that determine the adaptive capacity of a system actually take place at field scale. And it is technically not possible to use very detailed process descriptions for a large basin. Multi-level modelling techniques that reach across conceptual and spatial scales can help in meeting this challenge. At the 'top' level we will have an integrated model, obtained by further developing and extending the existing 'Waterwise' model.

The interaction between the (multi-level) model and the stakeholders must be seen as a learning process. The model will be capable of displaying optimal management strategies in conjunction with spatial planning options and stakeholder preferences.

As yet, the applications of Waterwise have been prototypes, lacking the stakeholder interaction that is needed for the results actually being used in decision making. The modelling with respect to the transition from the current state to the future one has so far been limited to a standard cost coefficient for changing the type of land use. For the NeWater project it is essential to make a more in-depth analysis of transition processes, by linking up with other types of modelling in the decision support cycle.

Including risk as a management concept

The term 'risk' is here used for the product of [probability] x [damage]. The risk concept is new for water management in the Netherlands. Precautionary flood measures for maintaining public safety are simply based on safety norms. Deficiencies of this approach are (1) the focus on a specific flood frequency and (2) the uncertainties in the probabilities of future events.

The research challenges are to include aspects of risks and uncertainty in our approach in order to:

- define what is needed for being adapt*ed* to the prevailing or (expected) future external conditions, made available in the form of scenarios (climate variability and global economy);
- provide tools that can help in making the water and land management system adapt*ive*, by helping to design strategies for dealing with the risks, and especially the uncertainties in the risks, both the direct and the indirect ones ('knock-on' effects of system failures).

We hope to do this by including the concept of 'Total Risk' in our modelling, and by providing tools to design strategies based on risk diversification. As a source of inspiration – or perhaps even more directly – we will be looking into the 'portfolio' theory that is known from managing risks in the stock markets.

Case studies

In order to aid the further development and testing of the above given approach, we propose to use a 'local' case study in the water board *Stichtse Rijnlanden* in the Netherlands, i.e. the *Kromme Rijn* catchment of 30 000 ha. Participation in the Nile basin study is under discussion.

Table of contents

1 Introduction

1.1 Water and land management

Water and space are inextricably linked. External pressures on either water resources or the use of space result in chains of impacts and responses that are intertwined and interactive. Notwithstanding this reality, water and spatial planners have in the past usually handled the connections in a perfunctory manner, by treating each other as a rigid boundary condition and disregarding the external effects. Impacts of climate change and global socio-economic changes have revealed the limitations of these sectoral approaches, especially in view of the involved uncertainties. The NeWater project (Pahl-Wostl and Kabat, 2004) specifically addresses water management under uncertainty by attempting to make operational the concept of adaptive (water) management (AWM). This concept aims at increasing adaptive capacity of the system rather than predicting future impacts and responses. The development of methods for supporting adaptive management through an integrated design of water and land management systems is seen as one of the key elements in NeWater, and is the focal point of Work Package 1.4 'Integration of IWRM (integrated water resources management) and spatial planning'.

1.2 Towards adaptive water management

The term 'adaptive' is in this paper used at two levels. At the 'tactical' level of day-to-day water management it is used for indicating that a system should be able to accommodate the inherent variability of weather conditions in a comfortable and intelligent way. At the 'strategic' level of medium to long term planning it indicates that a system should be responsive to climate and socio-economic changes.

The ability to accommodate the day-to-variability of external pressures can perhaps better be denoted as the state of being adapt*ed.* Day-to-day level adapt*ive* management differs from 'reactive' management by not only responding to the prevailing conditions, but by also weighing the possibilities of what is still to come. Thus adaptive management at the tactical level takes an intelligent time-integrated view of the involved risks. At the strategic level *flexibility* is the key ingredient for a successful adaptive management concept. Flexibility can be provided by: (1) creating the institutional cross-sectoral partnerships required for making use of the available options, (2) by identifying as many as possible options for influencing the system functioning, and (3) by developing a risk-based management system.

Providing decision support for the above steps requires a broad multi-disciplinary modelling approach of the land-water system, which treats land use as one of the key endogenous variables. The crucial role of the spatial dimension requires that the modelling should be spatially distributed, and also be capable of incorporating aspects of risk and uncertainty.

1.3 This working paper

The goal of this 'working paper' is to develop a framework for designing and assessing combined land-water options under uncertainty. From this, we hope to develop new methodologies for the water-space interface, which can contribute to the concept of adaptive water management. For this the following objectives have been identified:

- to elaborate on current developments in water management and spatial planning with a focus on the Netherlands by assessing current policies and scientific methods (Section 2);
- to describe how stakeholder involvement is connected to water-space issues and the crucial role that partnerships play for putting AWM into action (Section 3);
- to provide an outline of a multi-level modelling system (Section 4);

- to indicate how the modelling system can be used for risk management under uncertainty (Section 5);
- to indicate in what case studies the methodology will be tested and implemented (Section 6).

2 The water-space interface

2.1 Introduction

In the following we first give a short review of water and land policy developments in the Netherlands, and the methods used for supporting decision making in the water-space arena. We then shortly define in rather general terms what we consider as research challenges. These challenges are further elaborated on in the chapters 3-5.

2.2 Water and land policy developments in the Netherlands

From the beginning of the nineties both the water and the spatial planning sectors in the Netherlands have started to develop cross-sectoral policies and measures to face the new challenges. However, this was initially done from two different perspectives.

The spatial planning sector took the first initiative by launching plans to use the predominantly agricultural floodplains along the river for wetland nature development, the so-called NURG program (VROM, 1991). But the extreme flood events of 1993, 1995 and 1998 soon revealed that just creating lush vegetation in the relatively narrow floodplains directly next to the river was counterproductive for facing the new challenge of increased flood risk. It also made clear that urban expansion as well as current risks to land-use functions had to be reviewed, which has had far-reaching consequences for the planning process itself: the spatial planning sector decided that 'water' should be one of the guiding principles for spatial planning, which has been assimilated by the political circles of many European countries. So it is now accepted that spatial developments with respect to agriculture, nature and urban expansion should only be allowed if due consideration is given to the implications with respect to water issues.

In the wake of the extreme flood events in the nineties and also the extremely dry year of 2003, the water sector realized that – especially in the long run, involving continued climate change – challenges to the water system cannot be solved by purely technical water management approaches. Beyond the broadening of existing floodplains along the rivers, the new notion has led to a search for areas that could be used as temporary storage basins for flood water. An example is the *Overdiepse Polder* that has been appointed as an emergency storage area within the larger national program 'Room for the River'. But finding extra space for servicing the water system has soon been met by various barriers, including fierce opposition by affected inhabitants, which has often lead to political deadlocks. However, in the case of the *Overdiepse Polder* the inhabitants responded by coming up with an alternative solution; that is of course a positive result, even though the suggested solution is mono-functional, thus involving higher costs because it means the buying of land that is only to be used for water storage.

These deadlocks have speeded up the establishment of partnerships at the interface of water and space. They are being established at all levels, starting at the national level. Two tangible results at that level have been achieved in the form of policy documents that both address water and spatial planning: (1) *Anders omgaan met water* ('Handling water differently') of the Ministry of Transport, Public Works and Water management (V&W, 2000); (2) *Nota Ruimte* ('Spatial policy paper'), of the Ministry of Housing, Spatial Planning and Environment (VROM, 2003). These strategic policy documents are meant as guidelines for the implementation of spatial planning measures at the province or municipality level.

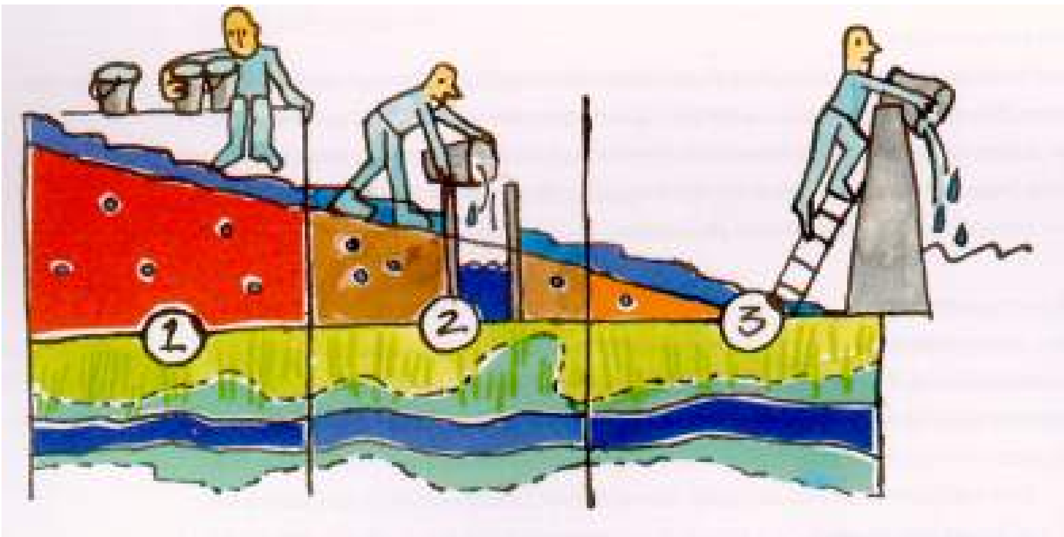

Fig. 1 The Dutch policy for the preferential order of measures to deal with excess rainfall: (1) holding on to it (2) storing it (3) discharging it

Due to above mentioned policy documents, water policy and spatial policies are constantly being fine-tuned. With regard to reducing flood risk, the following preferential sequence of measures has been put forward (Fig. 1), which demonstrates that the use of extra space for water management has now quickly gained acceptance at the national political level:

- holding on to the water as much as possible, by micro-scale buffering in the headwaters of a catchment;
- if that is not possible, storing it within the catchment, by meso-scale buffering along the transporting subsystem;
- if all fails, only then discharging it to the downstream area.

Any new regional plan is now subjected to a *Watertoets* (‘Water test’), to check the compatibility of new water/space policies with regard to their buffering capacity, desiccation effects and effects on water quality. Going even further, the provinces (12 in The Netherlands) have been asked to supervise the making of ‘river basin plans’ that for the period until 2050 have to give indications about how the expected challenges can be met, both in terms of water quantity and quality. Future regional planning will have to comply with them. Another avenue of policy implementation is the *Wateropgave* (‘Water task’), in the form of peak flow reduction targets that have been set for the water boards.

In the somewhat longer term, the implementation of above mentioned policies will be bundled with that of the EU-WFD (the European Union’s Water Framework Directive). During the previous decades, economic pressures such as needs for infrastructure and housing have dominated the spatial developments. The making of a turn towards water-based planning and development will not become reality by just publishing some new government guidelines and ‘do nots’. (An example of the latter is to not allow urban development in the floodplains if it reduces the water storage capacity.) In a drive to get water-based planning put into practice the national government of the Netherlands stimulates the combination of land-use functions – so-called multi-functional land use. The latter is also born out of sheer necessity, given the shortage of land due to the high population density. An example of multi-functional land use is the combination of water storage with wetland nature reserves. Another example is that agricultural grassland can be made to ‘service’ a neighbouring wetland nature area by making the field drainage less rigorous: the desiccation side-effects are then reduced (e.g. Bommel *et al*., 2002). In new urban areas we have seen grassed parks also being used as infiltration basins for rainwater.

Multifunctional land-use is seen as a key option for reinforcing the original identity of regions, and thus creating a landscape with an added value. The multi-functionality increases the adaptive capacity of the regional systems, both in terms of water, ecology and economy: once multi-functionality has been institutionalized and the reimbursements have been organized, a shift of focus from one function to another is relatively easy. That makes it easier to respond to changes in climate and global economy. But before starting the planning process, time is needed to get stakeholders involved and to convince people that cross-sectoral measures are necessary for dealing with future challenges. Timely participation is therefore a key issue in establishing robust partnerships and policies.

2.3 Methods for combining Spatial planning and Water management

Despite the fact that politicians have been eager to assimilate water as an important principle for spatial planning, the scientific community has been rather sluggish in providing methods and tools for making the new notion operational. We mention here the following approaches that have been suggested (Vonk Noordegraaf, 2003):
- the 'strata' approach, stemming from the geography community;
- the 'water system' approach, stemming from the hydrology community.

In the strata approach (VROM, 2003) the following 'layers' are discerned (Fig. 2):
- the base layer, consisting of the water systems and the biotic systems;
- the network layer, consisting of all types of networks, including traffic systems;
- the occupation layer, consisting of space for living, working, recreation, etc.

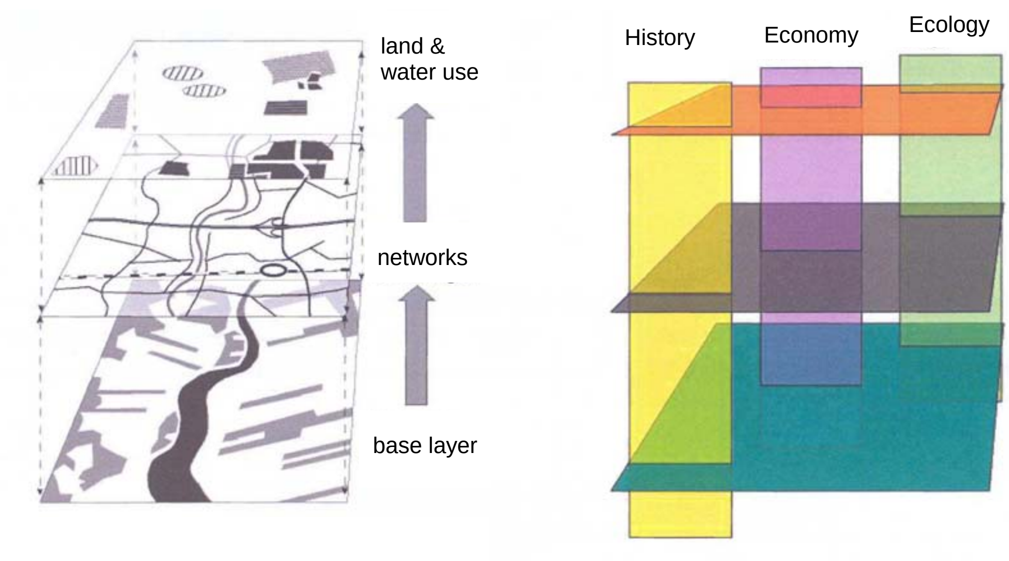

Fig. 2 The 'strata approach' for water-based land-use planning (*Nota Ruimte*)

The strata approach is an analytic tool that can be used in different ways, for different scale levels. It can help to show the implications of changes in one of the layers for the other ones. So it gives insight in what landscape ecologists call the topological (vertical) interactions. A strong point of the method is that it looks at the use of space from an integrated point of view.

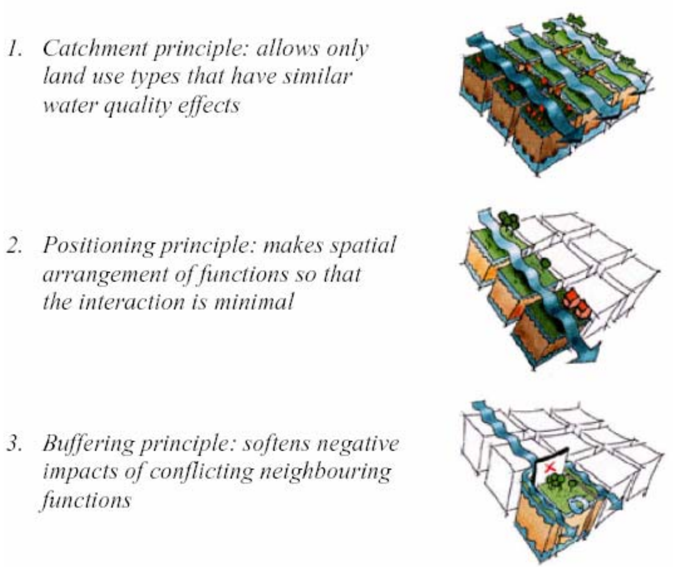

Fig. 3 Principles for water-system based planning (from e.g. Kamphuis, *et al.*, 1996)

In a water system approach (e.g. Kamphuis, et al., 1996) the spatial interconnections via the water system are taken into account. In its simplified form this approach is translated into certain principles, as illustrated in Fig. 3:

This approach has the advantage that it also takes into account the horizontal interactions via water as an integrating medium. In landscape ecology these are called the ‘chorological’ interactions. The disadvantage is that the interaction with other conflicting activities receives relatively less attention. In essence it is also a ‘static’ approach, meaning that it does take into account the temporal variability of the water system.

Apart from the above mentioned two approaches, diverse other ones are used in practice. However, these are often dominated by some central idea – vision – about how the ordering of functions in a landscape should ideally be. An example is the ‘Strategy of two networks’ (Aalbers and Jonkhof, 2003), which sees the networks for water and traffic as a carriers of the other functions. By focussing on the existing networks and the dynamics they generate, this type of approach contains elements that pertain to the transition from the current state to a future more adapted state.

2.4 Research challenges

To enable the integrated design of land and water management systems we see it is a research challenge to develop tools that can at the same time take into account the horizontal (‘chorological’) and vertical (‘topological’) interactions within/between the planning layers as described above. Multifunctional land-use is seen as a key option in this respect for combining functions vertically and horizontally. Servicing more than one function at the same location is in itself a form of integration. The flexibility of being able to change emphasis from one function to the other enhances the adaptive capacity of the regional systems.

For being ‘adaptive’ it is furthermore necessary to know what is needed in order to accommodate the temporal variability that is so important in day-to-day life. Otherwise it is not known in which direction to adapt. Added to that, the temporal trajectory – transition – from the current state to the future one should also be a central research issue and thus be addressed accordingly. Otherwise the desired future (adapted) state will be elusive. For the transition we consider the building of water-space partnerships as a crucial step.

3 Building the water-space partnerships

3.1 Essential role of partnerships

Key for developing flexibility is the presence of robust institutional partnerships between stakeholders, for different reasons. They allow for sharing of cost and benefits, for example upstream costs and downstream benefits, which opens up new horizons for implementation of measures. And adapting to unforeseen future conditions becomes easier, under the assumption that these partnerships are able to swiftly adopt new sets of adaptation measures ('strategies') when changing conditions ask for it. Recently, this concept has led to the development of new public private partnerships (PPP's) between water managers with private real estate investors (Gleick, 2003, Aerts *et al.*, in prep.). Furthermore, the Dutch water sector has developed partnerships with both the agricultural sector and partly with environmental managers, mainly to share land for multiple purposes (e.g. water storage on agricultural land). Key to the establishment of these partnerships is the role of spatial planners as they have the overview of the often competing claims for space from the different sectors, including those of water managers. The managers themselves play the role of negotiators between the stakeholders that are (in)directly affected by the regional system. By suggesting and facilitating management options that make efficient use of the integrated land-water system, the economics of the cost/benefit sharing will become more attractive for the stakeholders. This will lay the basis for robust partnerships in the water-space arena. Finally, apart from PPP's and cross-sectoral partnerships, cross-*scale* partnerships are important such as the cooperation between local and regional planners and their link to the national and EU level.

As implied above, cooperation between stakeholders is an essential condition for putting AWM into action. The degree in which stakeholders are prepared (or not) to share costs and benefits has great consequences for the appropriate design of a water and land management system. In the case of a 'perfect partnership' all costs and benefits can simply be added up. But even if there is not a perfect partnership it can make sense to present a design based on it, just for providing a reference point in the negotiations. Then the costs for a negotiated partnership can easily be compared to the costs of a perfect partnership. By showing the stakeholders the consequences of their negotiation activities on welfare they can make better founded decisions.

Even though a perfect partnership will never be attained, some sort of sharing of costs and benefits is needed as a basis for building cross-scale and cross-sectoral partnerships in the form of joint spatial planning and water management policies. This should be upheld by the appropriate financial infrastructure. The key to successfully achieving such a situation is to involve stakeholders in an early stage as they are able to provide input and feedback (professional knowledge as well as topographical knowledge) on the proposed portfolios of policies and measures and to provide expert judgment in cases no quantitative data are available (Smit *et al.,* 2000).

3.2 Participatory processes

A participatory process must be a forum for designing both the water management system and land-use planning in combination. Many aspects like the requirements of the WFD, economic and political interests of the farmers as well as the safety requirements can be discussed, and even translated into parameters or boundary conditions into a mathematical model such as Waterwise (see section 4). The model can be of help in developing different perspectives, and be able to evaluate and display the consequences of various land-use options in terms of risk and/or meeting the WFD requirements.

The Adaptation Methodology for River basins (AMR; Aerts and Droogers 2004) is a framework that integrates cross-sectoral objectives, effects from drivers such as climate change and the development and evaluation of portfolios (including measures and strategies). AMR allows for integrating risk management and adaptive management approaches with stakeholder interaction. It has been developed for assessing adaptation options at the river basin scale in an iterative process with stakeholders.

Fig. 4 shows the AMR methodology. The circle shows the participative – iterative – approach where stakeholders in a river basin play a key role in developing and evaluating adaptation portfolios, in all stages. In the AMR-cycle, stakeholders are confronted with (1) exogenous influences such as population growth and climate change, but also with developments in adaptive capacity on which they do not have any influence (e.g. GDP and dependency ratio, i.e. the ratio between young and elderly groups in a society). Next it assesses how these developments impact both (2) the water resources system and (3) the vulnerability and risk. The framework then allows for (4) deciding which potential adaptation portfolios can be applied to response to change in vulnerability and risks. And finally, (5) each of these strategies can be evaluated by measuring their performance against the pre-set decision.

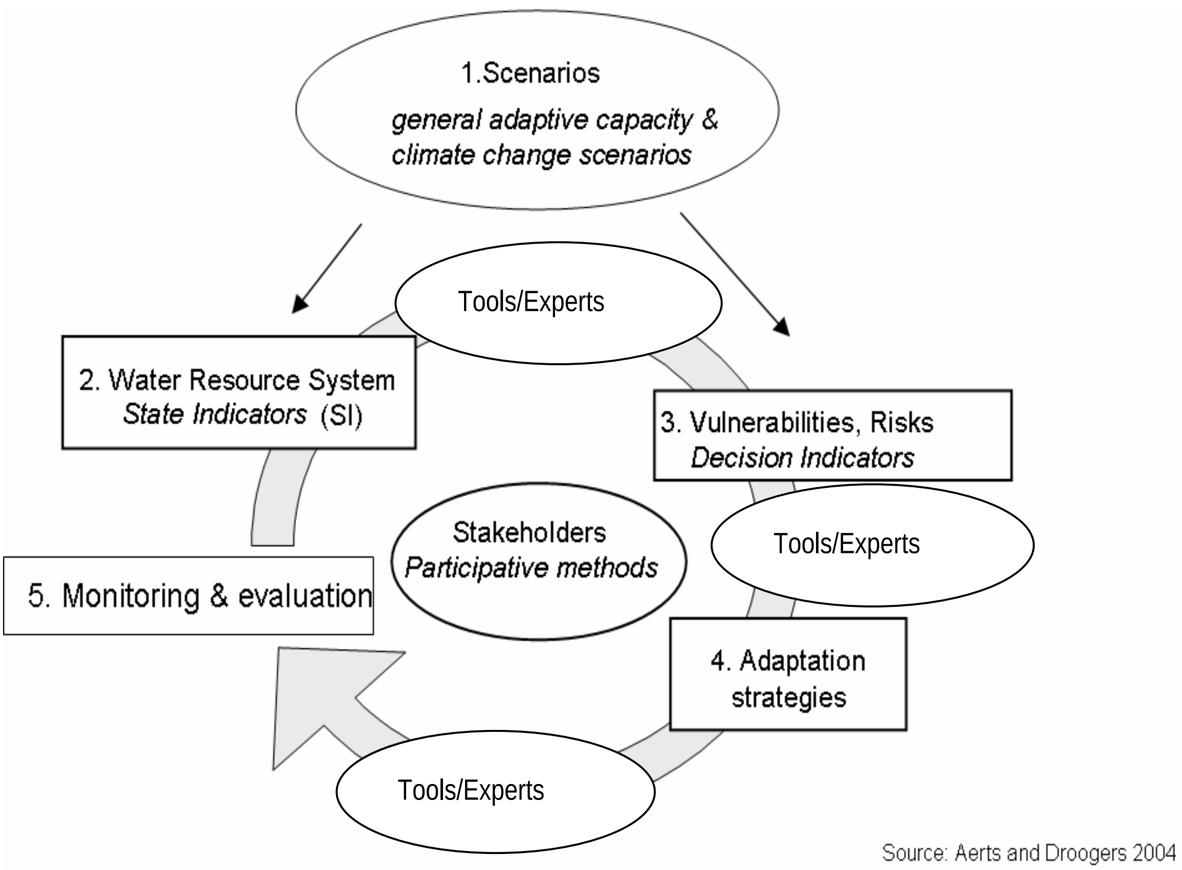

Fig. 4. Iterative process of developing and evaluating adaptation strategies: AMR (Adaptation methodology for river basins; modified from Aerts & Droogers, 2004).

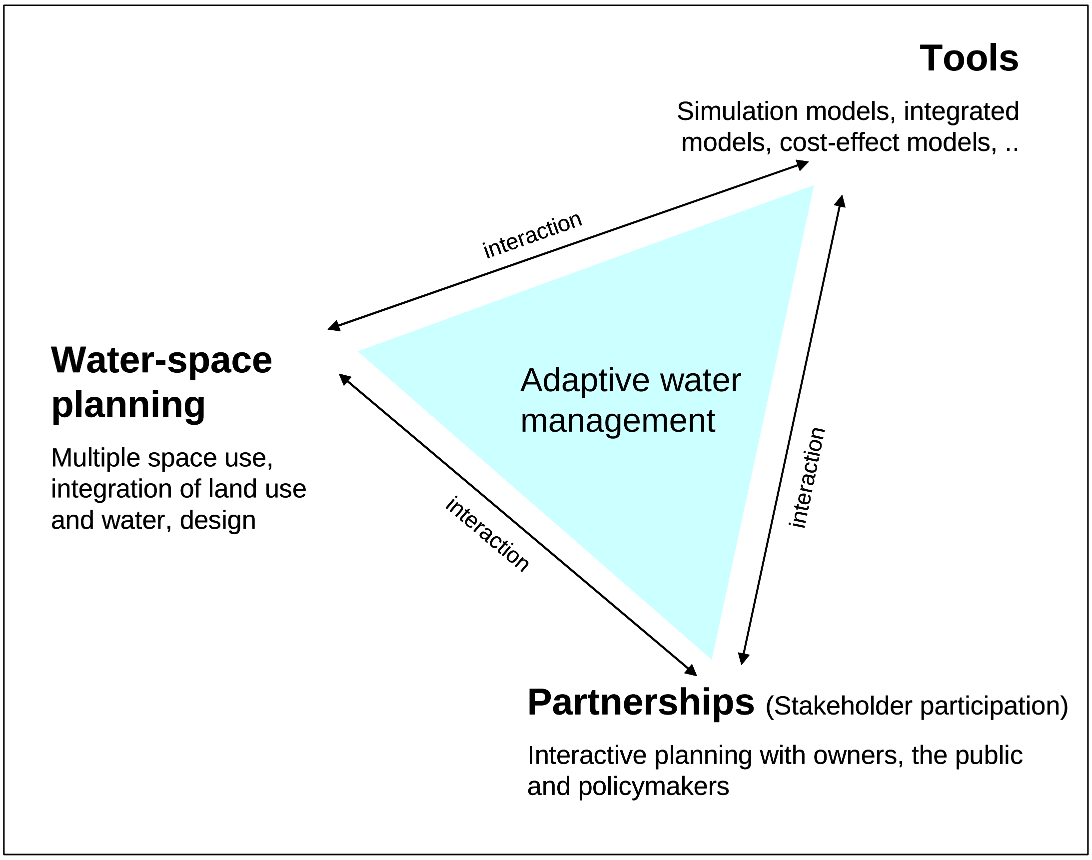

Fig. 5. Interaction between water-space planning, tools, and stakeholders

3.3 Research challenges

In each of the steps there are interactions involving stakeholders, water-space planners and diverse ‘tools’ (Fig. 5). The research challenge with respect to the building of partnerships is to facilitate that process through offering the suitable type of tools at the right moment.

4 Multi-level modelling for supporting adaptive water management

4.1 Introduction

For taking into account the integrating role of the water-space interface, the tools used for supporting AWM should be multi-disciplinary and operational at basin scale. However, many processes that determine the adaptive capacity of a system actually take place at the field scale. It is technically not possible to use very detailed process descriptions for a large basin. Multi-level techniques that reach across conceptual and spatial scales can help in meeting this challenge. The interaction between the (multi-level) model and the stakeholders must be seen as a social learning process among stakeholders. The used model(s) will be capable of displaying optimal management strategies in conjunction with spatial planning options and stakeholder preferences.

In the following we will give some examples of multi-level modelling and indicate how we intend to use them in our work package.

4.2 Simulation models

For modelling a regional hydrologic system the most straightforward method is to solve the coupled partial differential equations for groundwater, surface water and soil water, as it is done in the MIKE SHE modelling system (Refsgaard and Storm, 1995). However, that leads to a ‘heavy’ type of model that is less suitable for applying at the scale that is needed here. The regional hydrologic model SIMGRO (Van Walsum *et al.*, 2004) is an example of a model that is multi-level in the *conceptual* sense. It is a spatially distributed mechanistic model with a (nearly) unified saturated-unsaturated flow description at its core. Use is made of dynamic ‘meta-modelling’ techniques for the soil water and surface water. The meta-modelling relies on a previously accomplished series of computational experiments using more detailed models like SWAP (Kroes *et al.*, 2004). The results of these experiments are stored in a database of ‘soil physical meta-functions’ that can be used for all model applications using the same soil map for schematizing. In this way the regional meta-model makes *indirect* use of basic data like soil hydraulic functions. By following this method an acceptable degree of accuracy is achieved in the regional modelling at a relatively low computational cost. A further advantage of this approach is that it can also be applied when data availability is low. In that case the soil meta-functions are derived from simple concepts like ‘available soil moisture capacity’.

Recently SIMGRO has been coupled to the groundwater module of the MODFLOW code (Harbaugh *et al*., 2000). The extra computational load added by the SIMGRO top system (soil water and surface water) is less than the load of MODFLOW itself. When using the output of SIMGRO for nutrient leaching models like ANIMO (Groenendijk *et al*., 2004), the soil moisture state variables are first downscaled to the layers of the original SWAP schematization; this downscaling makes use of the database that was generated in doing the computational experiments (with SWAP).

For large basins it is necessary to simplify the model concept even further, as has for instance been done in the WP 2.2 for the Rhine case study and in WP 3.7 for the Nile case study (Smit *et al*., in prep.).

4.3 Integrated models

4.3.1 Mathematical programming as computational framework

For a broader integration than just within regional hydrology the use of simulation models is less suitable, because it leads to unwieldy models. Various techniques are available for a simplified integrated modelling. An example is the use of mathematical programming (e.g. Hillier and Lieberman, 2001). Many economic models are anyhow formulated in that manner, making it relatively straightforward to arrive at an integrated model if the hydrology is formulated in the same way. Such a type of model involves three types of elements:

- decision variables, corresponding to land- and water use options;
- constraints, providing a (simplified) system description;
- objective functions, relating to the decision indicators.

Mathematical programming of course has its limitations, especially in the representation of non-linear responses. But the latter restriction should not be exaggerated. By using piece-wise linear functions and the use of special 'integer' variables, a whole range of non-linear effects can successfully be modelled. And the fact that it makes use of 'optimization' should not as such be seen as a bias. It is simply a technique for exploring the available decision space in an effective and efficient manner. So neither the restrictions nor the technique itself should lead to discarding mathematical programming as a computational framework. But of course it should be complemented by approaches and tools that focus on the aspects that can not be formalized in the required format.

For handling the stakeholder interaction with respect to the indicators, the Multiple Goal Programming method (e.g. Laborte *et al*., 1999) is seen as a useful approach. In that approach the stakeholders are provided with information about the *range* that an indicator lies within. If they are not satisfied with one of these ranges, then they can specify that the lower limit of one or more of the indicators should be raised. That will have consequences for some of the upper limits of the other indicators, thus narrowing the available decision space. These influences on the ranges are made explicit by running the integrated model.

4.3.2 Waterwise

The 'Waterwise' model (Van Walsum *et al*., 2003; Van Walsum, 2005) is an example of a bio-economic mathematical programming model that covers regional hydrologic inter-actions, effects of land use on water quality, effects on agriculture, effects on nature.

The Waterwise model is 'fed' by results of computational experiments using simulation models. It is the next step up in the multi-level modelling hierarchy. For instance, 'micro-buffering' in the upstream areas is simulated by SIMGRO (or another simulation model) by introducing small culverts in dammed-up ditches (Fig. 6). The effect on the peak discharges is then determined (in the example roughly a 20% reduction) and included as a coefficient (of a land and water use option) in the matrix of the Waterwise model. For each possible measure the consequences of nutrient leaching are also stored as coefficients. The Waterwise model contains the structure of a basin network in the 'constraint section' of the model matrix. Hence a summation of the nutrient load coming from the upstream subcatchments can be made. Retention of nutrients in the surface water system has so far not been taken into account. This will be included in the form of a cascade concept that is being developed for the deliverable D1.4.3 of the NeWater project. For the processes in groundwater (transport and denitrification) a mixing-cell model is embedded in the matrix of the optimization model.

In terms of the methods described in Section 2.2, Waterwise can be seen as an upgrade of the strata method using the principles of the water system approach. Even though the incorporated sub-models are simplified, the ensemble of relationships can include dynamic

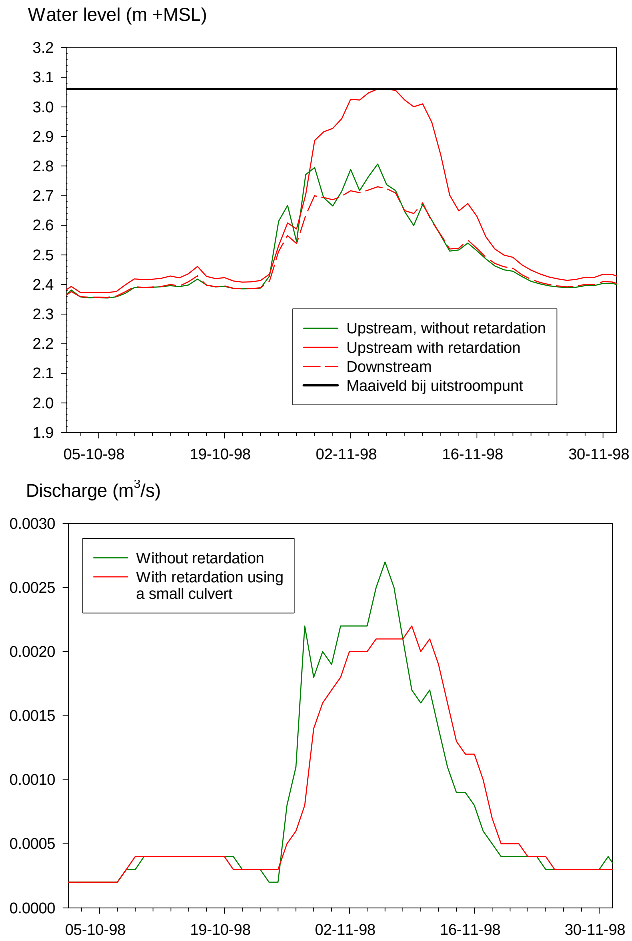

Fig. 6. Example of a computational experimental with a simulation model (SIMGRO), giving the effect of a micro-buffering measure

spatial interactions, like between upstream inflows and downstream water levels in the form of simplified response functions. By embedding these descriptions in a mathematical programming model it is then relatively easy to make the connection with models of the other strata (i.e. that of networks and occupation). Through this form of vertical integration it then becomes possible to make the two-way connection with other planning principles that should play a role for the development of a region. It is also at these other strata that some of

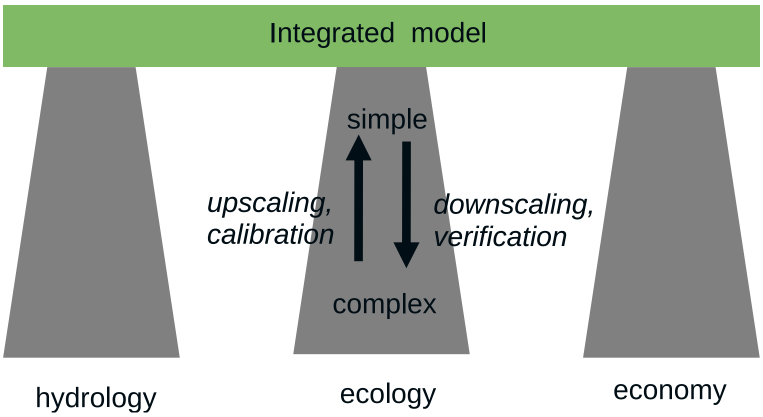

Fig. 7 Multi-level modelling with an integrated model connected to lower-level models

the envisaged multi-functional land use (i.e. recreation) becomes manifest. The land use should also be valued in that context. The Waterwise approach thus combines the horizontal integration within the water system and the vertical integration with the other planning strata. Then decisions can be based on an overall judgment by policy makers. Water serves as one of the guiding principles, but is not necessarily the dominant one.

The integrated model is fed by lower-level models. Vice versa, the lower-level models can be used for verifying promising strategies that have been generated using the integrated model. This two-way approach is illustrated by Fig. 7. For very large basins an extra level of modelling can be introduced, as for instance proposed by Haimes (1990).

4.3.3 Example of a case study

An example of results obtained through running the Waterwise model is given in Fig. 8. The system generated the spatial pattern in response to the following constraints:

- peak flow reduction of 20%;
- reduction of nature desiccation by 25%;
- reduction of N-loading needed for complying with the WFD-goal.

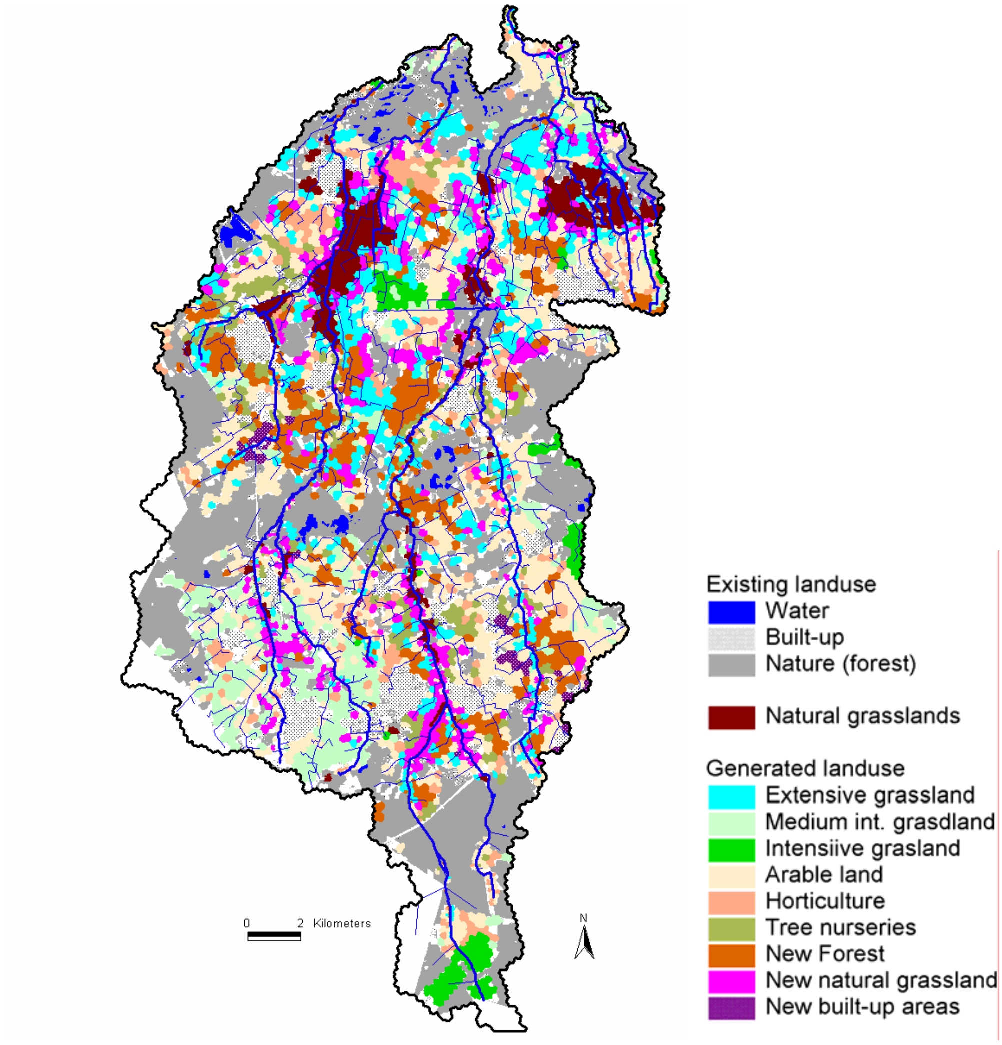

Fig. 8 Example of a land-use pattern generated by Waterwise for the Beerze & Reusel area (45 000 ha) (Van Walsum *et al*., 2003)

Subsequently, the Waterwise model minimizes the loss of agricultural income. In the example, the model chooses to convert a substantial amount of agricultural land to new nature areas in the form of new natural grasslands and new forest (see legend in Fig. 8). The new natural grasslands are positioned around the existing natural grasslands in order to have a beneficial effect, according to the 'positioning principle'. In this case there is synergy between the compatible functions. The same applies to the extensive grassland (low intensity agriculture). The new forest is beneficial for reducing nitrogen loading and also for reducing the peak flow. This is due to the increased evapotranspiration, which leads to lower groundwater levels, thus providing more storage capacity at moments with high rainfall. Forest thus increases the natural buffering capacity. The increased evapotranspiration is, however, not beneficial for the wet nature areas. For this reason the model has placed the new forest away from the existing natural grasslands (which is an example of 'antagonistic' functions and the positioning principle). Whereas a general nitrate reduction in order to meet the WFD limits would reduce the income of *all* farmers under a minimum level, the model finds a more sophisticated solution by determining those areas where a sufficient (from an agrarian point of view) amount of nitrate may be dispersed with the least effect on the entire system. It turned out that the optimization model can achieve the same WFD-goal at 40% less cost.

4.4 Research challenges

As yet, the applications of Waterwise have been prototypes, lacking the stakeholder interaction that is needed for the results actually being used in decision making. The modelling with respect to the transition from the current state to the future one has so far been limited to including a standard cost coefficient for changing the type of land use. For the NeWater project it is essential to make a more in-depth analysis of transition processes, by linking up with other types of modelling in the AMR-cycle (Fig. 4). Another weak point of the existing Waterwise applications is the limited modelling of risks that play such a central role in water management. Since we consider this is to be an issue in its own right we dedicate the next chapter to it.

5 Including risk management as a key element of AWM

5.1 Introduction

Methods for designing and assessing combined spatial plans and water management strategies can be found in the area of Risk Management. Risk management stems from research in the area of land-use planning and natural hazard mitigation. It emphasizes the fact that extreme events (floods, storms, droughts) have a certain probability of occurrence. Land-use planners are already used to the idea of working with probabilities. For example, during the last 25 years, insurers in the United States provide insurance against floods, that requires specific spatial information on spatial flood risks provided by spatial planning organizations (Burby, 1999). Also in mountainous regions, land-use planners use hazard-zoning maps in their daily planning activities (Flez and Lahousse, 2004). The problem for applying this method to the concept of adaptive water management is that climate and other drivers are not constant (‘the future is uncertain’) and hence probabilities of extreme events change accordingly. A challenge, hence, is to define risk management methods that address uncertainty and to see how it can contribute to AWM.

5.2 Risk as a management concept

Risk is defined as the multiplication of the event probability times the potential damage (Equation 1):

$$\textit{Risk} = \textit{Probability Event} * \textit{Potential Damage} \qquad (1)$$

The risk concept is new for water management in the Netherlands. Precautionary flood measures for maintaining public safety are simply based on safety norms. These norms state that a dike should resist a flood event that occurs once in a period of x years. For instance, for dikes in the main Dutch river area, the safety level is such that a dike should resist a flood event that occurs (on average) once in 1250 years. Note that the probability is based on extrapolations of historical records.

A problem, however, is that the safety norms are based on the situation of about 50 years ago, when the capital and the number of people behind the dike that has to be protected was much lower (Bouwer and Vellinga, 2005). It is obvious that both capital and population have increased dramatically in the last 50 years and that the risk for the same flood event that occurs once every 1250 years has increased as well. Moreover, there are more risks than floods only (e.g. droughts, shipping accidents, etc), which means that there is a need for an integrated view on managing various risks and subsequently, that (packages of-) measures should address them.

A risk management approach would allow for priority setting of possible measures, saying that each area is subjected to risks, but that some areas may be at higher risk than others.

We see two major deficiencies in the above described approach:

- the focus on a specific probability or return period of e.g. 1250 years can lead to a system design that actually *increases* the risk with of events with e.g. a return period of 2000 years;
- the assumption that we know probabilities of future events is not valid (climate change), neither do we know how the damage function will develop.

5.3 Increasing the adaptive capacity through risk diversification

5.3.1 Portfolio theory

Given the uncertainties listed above it is argued in the NeWater project the focus of water management must be shifted towards developing an adaptive management style, here interpreted as enhancement of the *current* adaptive capacity of the water management regime.

The design problem confronted here has analogies in the stock market. In financial markets portfolios of stocks are combined in such a way that they spread risk. The price paid is that on average there is a lower return in the short run, but ensures continuity of a business at the longer time scale. This Modern Portfolio Theory (MPT; Markowitz 1952) is for example used in most mortgage constructions. In the case of water management the aversion for extreme risks is not only fuelled by the desire to spread (known) risks, but also by the large uncertainty with respect to the damage inflicted by the indirect effects of extreme events. Climate change has additional implications for these uncertainties.

In our methodology for integrated design we do not directly use the methods of MPT; we just use some of its basic ideas. The kernel of our methodology is (1) how to choose robust portfolios where the 'stocks in a portfolio' are replaced by measures (e.g. a combination of water management and spatial planning measures) and (2) how to measure the return of the portfolios in terms of 'avoided damage' against the uncertainties associated with each portfolio. The advantage of this approach is that the future itself is no longer a subject of research. The method aims at increasing adaptive capacity by choosing portfolios of measures that are robust under an ensemble of extreme events.

As a first step towards finding adequate portfolios of measures we take a time-integrated view on risk, by defining the Total Risk as:

$$\textit{Total Risk} = \sum [\textit{Probability Event} * \textit{Potential Damage}] \qquad (2)$$

In this summation (over the whole probability distribution) double counting of the same events should be avoided (Reinhard *et al*., 2004). Starting from a continuous damage function as presented in Fig. 9, the probability axis is divided into discrete intervals. If for instance the first interval represents an (average) frequency of 1/500 (yr^{-1}), and the second interval of 1/200 (yr^{-1}), and the respective damages are D_1 and D_2, then the contribution of the second interval to the Total Risk is D_2*(1/200-1/500). That is because in the 500-year event also a 200-year event occurs, which is already included in the damage of the 500-year event.

5.3.2 Modelling

Including the Total Risk concept in the model Waterwise requires the duplication of the model equations for each of the chosen discrete intervals of the probability-damage function. The optimization model can then *simultaneously* incorporate the consequences of certain measures for various possible weather conditions. Waterwise then produces a map of modified land and water use functions. This spatial configuration of measures is thus designed in a manner that is analogous to the basic idea behind the risk diversification of Modern Portfolio Theory: Waterwise designs a land and water system that has a complex response function when subjected to external pressures. In fact this means that the adaptive capacity – for accommodating the inherent variability of the system – has been increased through designing a spatial *variety* of the measures.

The above described method does not yet take into account the *uncertainty* about the external pressures. If these uncertainties are available in the form of ‘scenarios’ (for climate, global economy, population, etc.), then it is possible to further duplicate the model equations for each of them, within the *same* model implementation. In this manner the design method avoids the customary ‘what if’ method that is often used in climate change studies: we now intend to consider the implications of all scenarios *simultaneously,* i.e. by including the possible weather events of *each* scenario. So we want to include the uncertainties as an integral part of the design method.

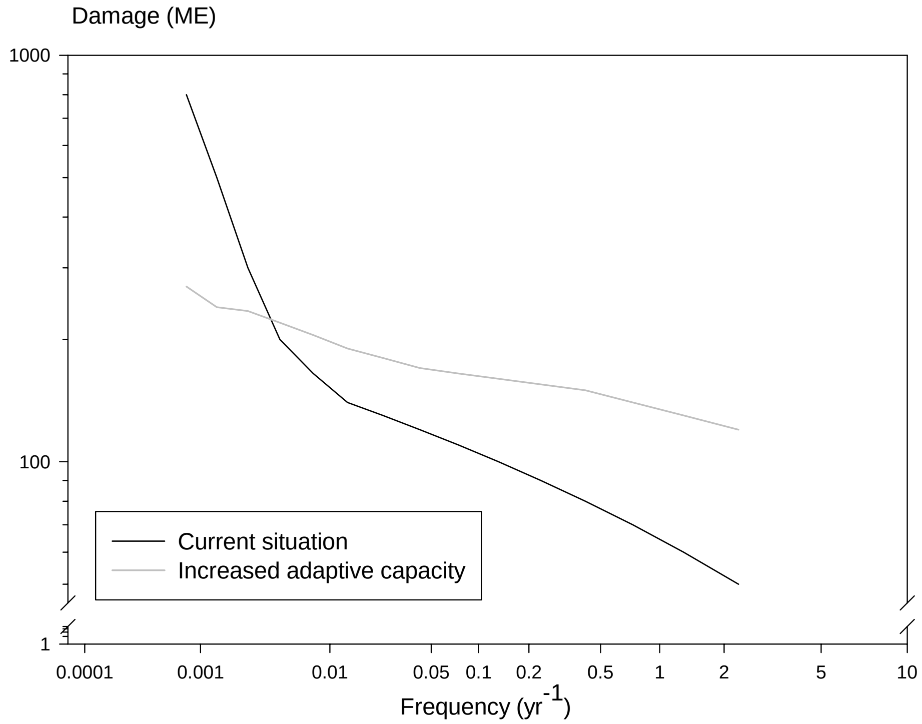

Fig. 9 Increasing the adaptive capacity of a land and water system by creating a more flat damage function curve for the response to extreme weather events

If the uncertainties are not available in the form of scenarios, then a design strategy is to ensure that the part of the damage-probability function curve holding most of the mass of the Total Risk becomes relatively flat, as illustrated in Fig. 9. On the one hand that leads to a computation of a Total Risk that is higher than the ‘most efficient’ alternative (the alternative with the highest return hence with the lowest potential damage). On the other hand the Total Risk becomes less sensitive for the uncertainties in the probabilities. That in itself increases the adaptive capacity of the system.

5.4 Risk quantification

5.4.1 Probability of flooding

For return periods of a few decades the risks of extreme events can be determined from monitoring, as has been done within the EU ESPON project for the map given in Fig. 10 (ESPON, 2004). For the more extreme events information has to be obtained in a different manner. Extrapolation on the basis of probability distributions has often been practiced in the past. Apart from the danger of (unfounded) extrapolation, the main disadvantage of that method is that it can not predict what will happen if *measures* are taken.

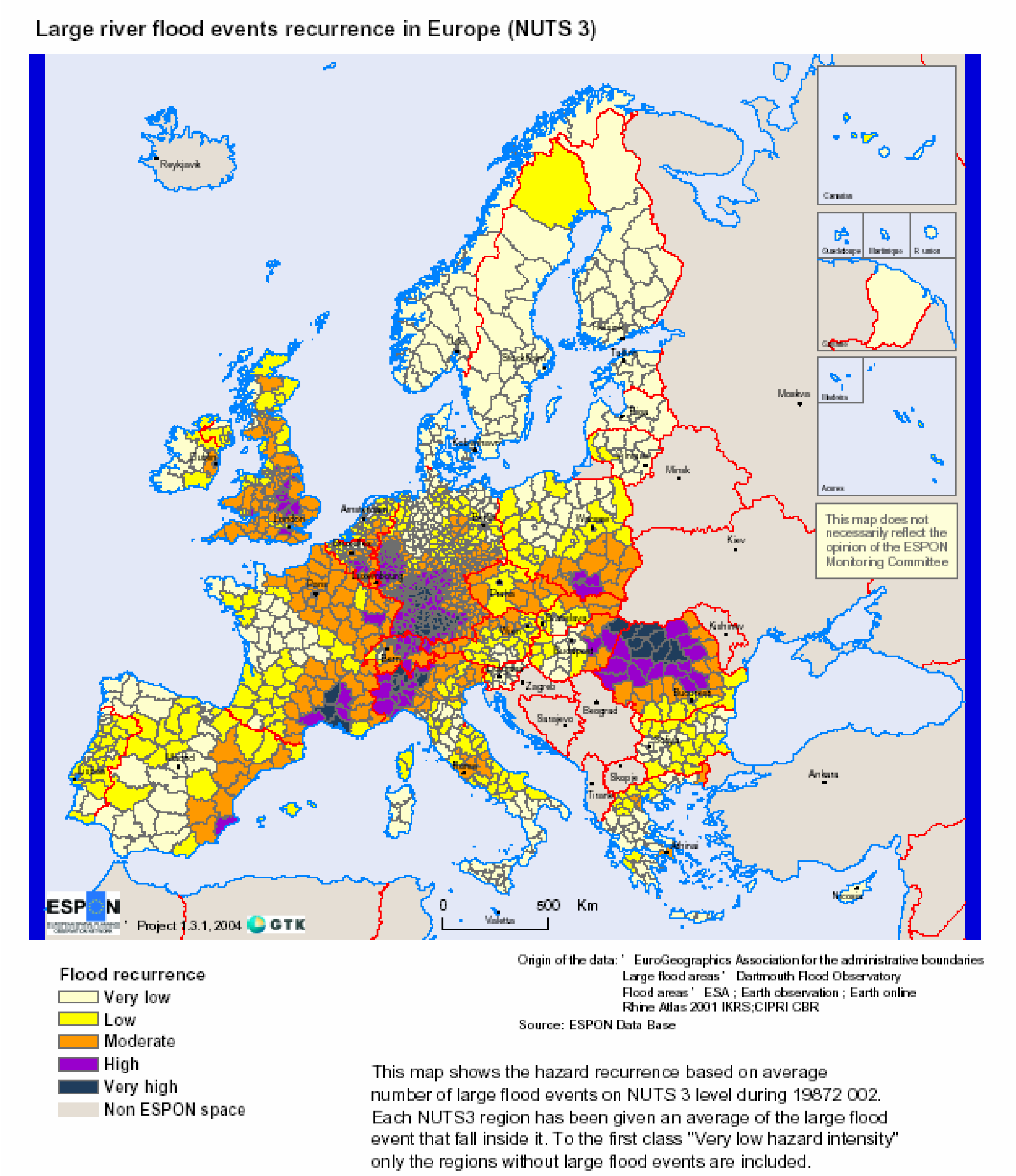

Fig. 10. Example of a Pan European Risk map for flooding.

If a long time series of meteorological information (and other relevant drivers) is available it would in principle be possible to quantify risks by doing straightforward simulation runs. However, even if such a time series can be obtained (e.g. by using a so-called weather generator), then the required computational effort of doing the run for the long time series is usually prohibitive. An alternative is to make short simulation model runs just for the extreme events. This so-called method of stochasts has been made operational in combination with the SIMGRO-model (Veldhuizen and Van Walsum, 2005). In their application the various stochasts were combined, pertaining to a 9 day extreme event at some time in the future. To do this, for each of the stochasts a discrete number of realizations were defined. For instance, 15 possible realizations were defined for the total precipitation, ranging between 50 and 190 mm for the 9-day period. The associated probabilities were derived from the probability curves as given in Fig. 11, for 3 climate scenarios (KNMI, 2003).

The various realizations of the separate stochasts were combined, forming so-called events. For the *Langbroekerwetering* study this lead to 1000 combinations per climate scenario. Each of these events was then run through with the SIMGRO model. For each of the model cells the results were put in ascending order in terms of inundation depth, yielding cumulative frequency functions. These results were then used for plotting risk maps and for providing coefficients of the Waterwise model.

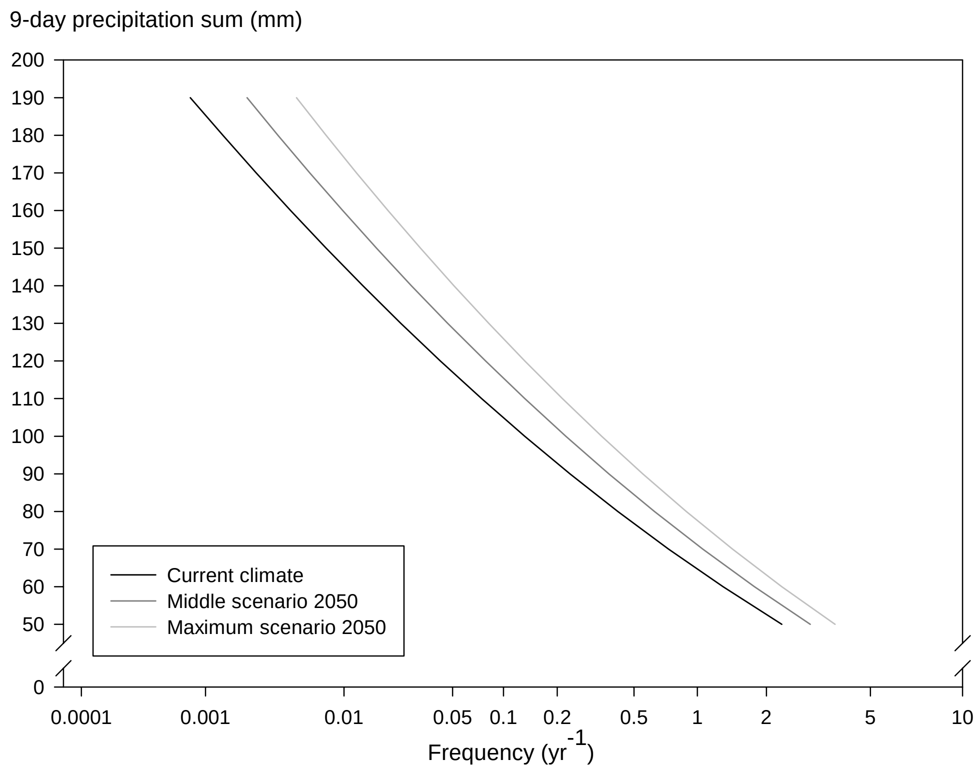

Fig. 11. Probability function for a 9-day precipitation sum, for the current climate and for two alternative scenarios for 2050 (KNMI, 2003). The probability is expressed as the inverse of the return period, i.e. in the form of an expected frequency.

5.4.2 Damage functions

The hydrologic probability functions should be coupled to economic damage functions. Van der Veen *et al.* (2001) surveyed the Dutch literature on the methodology of estimating damage. It was concluded that there is no generally agreed methodology, let alone a settled definition of damage. This conclusion has been made due to the fact that (1) There is no agreement on the economic points of departure; financial appraisals are mixed up with cost-benefit analyses (CBA). In the latter the usual concept is economic costs, which relates to opportunity costs in welfare economics. CBA is a helpful means to weigh alternative measures against flooding, whereas a financial appraisal is often a base for investigating the sum of money to be recovered from insurance companies; (2) There is confusion on the time and spatial scales: financial appraisal limits itself to a single organization, whereas CBA requires well-defined borders, such as a nation, or the European Union; (3) Stock concepts are confused with flow concepts; (4) The borderline between direct and indirect costs is often not well defined.

For the direct costs of regional flooding and other deviations from optimal conditions a comprehensive methodology is given by Reinhard *et al*. (2004). Apart from the loss of productivity due to a concrete flooding event, the measures taken for abating the effects of future flooding also count as costs. These costs differ from the 'event-costs' in the sense that – once the investments have been made – the costs are permanent and independent of what actually happens in terms of weather and other inherently variable conditions.

In the case of flooding there are also the indirect 'knock-on' effects. These are usually the biggest component, and also the hardest to quantify (Van der Veen and Logtmeijer, 2005.

5.5 Research challenges

Summarizing the above considerations and ambitions, we aim to include aspects of risks and uncertainty in our approach in order to:

- define what is needed for being adapt*ed* to the prevailing or (expected) future external conditions, made available in the form of scenarios (climate variability and global economy);
- provide tools that can help in making the water and land management system adapt*ive*, by designing strategies for dealing with the risks, and especially the uncertainties in the risks, both the direct and the indirect ones ('knock-on' effects of system failures).

We hope to do this by including the concept of 'Total Risk' in our modelling, with the aim of designing strategies based on risk diversification. As a source of inspiration – or perhaps even more directly – we will be looking into the modern 'portfolio' theory that is known from managing risks in the stock market.

6 Case studies

In order to aid the further development and testing of the above given approach, we propose to use a ‘local’ case study in the water board *Stichtse Rijnlanden* in the Netherlands (Fig. 12); we will limit ourselves to the catchment of the *Kromme Rijn*, on the East side of the Amsterdam-Rhine canal, covering roughly 30 000 ha. Commissioned by the waterboard, regional SIMGRO-models are now in an advanced stage of being set up, covering groundwater, soil water, and surface water. For the *Langbroekerwetering* area such a model already exists, as well as a Waterwise-model for water quantity aspects.

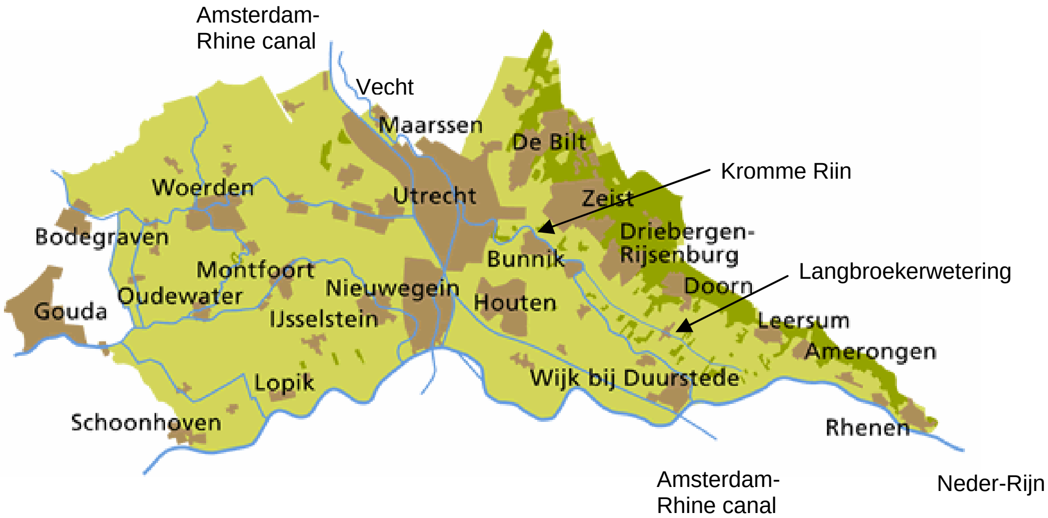

Fig. 12 Water board *Stichtse Rijnlanden*.

Under discussion is the participation in the Nile basin study.

7 References

Aalbers, C. and J. Jonkhof (eds.). 2003. Planning on principle; S2N, the Strategy of Two Networks revisited. Aeneas, Boxtel.

Aerts, J. and Droogers, P. 2004. Climate Change in Contrasting River Basins: Adaptation Strategies for Water, Food and Environment. CABI Books, London, 288pp

Bommel, K.H.M. van, J.R. Hoekstra, L.C.P.M. Stuyt, A.J. Reinhard, D. Boland en Den Haag, LEI, 2002, Rapport 3.02.07.

Bouwer, L.M. and Vellinga, P. 2005. On the flood risk in The Netherlands. In: Begum, S. et al. (eds.) Flooding in Europe: Challenges and Developments in Flood Risk Management. Kluwer Academic Publishers (in press).

Burby, R.J. 1999.Unleashing the Power of Planning to Create Disaster-Resistant Communities Journal of the American Planning Association 65 : 247-258

ESPON 2004. The Spatial effects and management of natural and technological hazards in general and in relation to climate change. 3rd interim report, March 2004.

Flez and Lahousse. 2004. Recent evolution of natural hazard management policy in France, the example of Serre-Chevalier (French Alps). Environmental Management. 2004 Sep;34(3):353-62

Gleick, P. 2003. Global Freshwater Resources: Soft-Path Solutions for the 21st. Century.Science 302, 1524-1528.

Groenendijk, P., L.V. Renaud and J. Roelsma, 2004. Prediction of Nitrogen and Phosphorus leaching to groundwater and surface waters; Process descriptions of the ANIMO4.0 model. Alterra Report 983. Alterra, Green World Research, Wageningen.

Haimes, Y.Y. 1990. Hierarchical multiobjective analysis of large-scale systems. Hemisphere Pub. Corp. New York.

Harbaugh, A.W., Banta, E.R., Hill, M.C., and McDonald, M.G., 2000, MODFLOW-2000, the U.S. Geological Survey modular ground-water model -- User guide to modularization concepts and the Ground-Water Flow Process: U.S. Geological Survey Open-File Report 00-92, 121 p.

Hillier, F.S. and G. Lieberman. 2001. Introduction to operations research. McGraw-Hill, New York.

KNMI. 2003. De toestand van het klimaat. (UK:'The state of the climate.') De Bilt, NL.

Kroes, J.G. and J.C. van Dam. 2004. Reference Manual SWAP version 3.0.3. Alterra-report 773.

Laborte, A.G., Roetter, R., Hoanh, C.T. 1999. SysNetTools: the multiple goal linear programming (MGLP) model and MaplLink. IRRI Technical Buelletin No.6. Manila (Philippines).

Markowitz, H. 1952. Portfolio Selection. Journal of Finance, 17, 1, March 1952.

Ministry of V&W-NL (Ministry of Transport and water infrastructure'). 2000. *Anders omgaan met water* (UK: Handling water differently). The Hague.

Ministry of VROM-NL (Ministry of Housing, Spatial Planning and Environment), 1991. *Vierde Nota Ruimtelijke Ordening Extra* (UK:'The 4th spatial paper extra'). The Hague.

Ministry of VROM-NL (Ministry of Housing, Spatial Planning and Environment), 2003. *Nota Ruimte* (UK:'The spatial paper'). The Hague.

Kamphuis, H., R. Kuiper, Y. van der Laan, A. van Dortmont. 1996. Plannen met stromen.

Kamphuis, H. et al. 1998. Planning with water: ten building blocks for policy innovation in spatial planning. Ministry of Housing and Spatial Development, The Hague.

Pahl-Wostl and Kabat, 2004. New Approaches to adaptive water management under uncertainty ("NEWATER"). Integrated Project in PRIORITY 6.3 Global Change and Ecosystems in the 6th EU framework programme.

Rijksplanologische Dienst. Ideeën voor de afstemming van ruimtegebruik, water en milieu. Ministry of Housing and Spatial Development, The Hague.

Refsgaard JC and Storm B. 1995. MIKE SHE. In: Singh VP (Ed) Computer Models of Watershed Hydrology. Water Resources Publication, 809-846.

Reinhard, A.J., P.J.T. van Bakel, A. Gaaff en K.H.M. van Bommel. 2004. Waarderen van water in een regionaal watersysteem. (UK:' Valuation of water in a regional system'). The Hague, LEI, 2004

Smit, A.A.M.F.R. and C.W.J. Roest, 2005. "Description of the Splash! Hydrology" (in preparation)

Smit, B., Burton, I., Klein, R. and Wandel, J. 2000. An anatomy of adaptation to climate change and variability. Climatic Change 45, 223-251

Van der Veen, A., and C. J. J. Logtmeijer. 2005. Economic hotspots: Visualizing vulnerability to flooding. Natural Hazards, Volume 36, Numbers 1-2, 65-80. Springer Verlag.

Van der Veen, A., N.S. Groenendijk, N.P. Mol. 2001. Cost-Benefit Analysis and Evaluation of Measures Against Floods, In: Proc. Workshop Delft Cluster "Wat als we nat gaan? Een beschouwing van de stand van zaken". Waterloopkundig Laboratorium, Delft, NL.

Van Walsum P.E.V., Helming J.F.M., Groenendijk P., Stuyt L.C.P.M., Schouwenberg E.P.A.G. (2003, submitted). Spatial planning for lowland-stream basins using a bio-economic model. IAHS/IWRM conference in South Africa, 2003.

Van Walsum, P.E.V., J. Runhaar, and J.F.M. Helming. 2005. Spatial planning for adapting to climate change. Water Science and Technology 51(5).

Van Walsum, P.E.V., A.A. Veldhuizen, P.J.T. van Bakel, F.J.E. van der Bolt, P.E. Dik, P. Groenendijk, E.P. Querner, M.F.R. Smit. 2004. SIMGRO 5.0.1, Theory and model implementation. Wageningen, Alterra. Alterra-Report 913.1.

Veldhuizen, A.A. and P.E.V. van Walsum. 2005. Faalkansanalyse Langbroekerwetering; een toepassing van de stochastenmethode. (UK: 'Failure analysis for Langbroekerwetering; an application of the method of stochasts'. Stromingen 11(1). Dutch Hydrological Society NHV, NL.

Vonk Noordegraaf, A. 2003. Plannen vanuit ideeen; de waarde van vier gebiedsbenaderingen in ruimtelijke planning. Alterra rapport 776. Alterra, Wageningen.