# Development of a management tool for the equal evaluation of economic, social and ecological effects of adaptation scenarios for attenuating the effects of climate change induced flooding

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**Abstract**
Climate change is expected to influence river flooding which may have important implications for socio-economic and ecological systems. Changed flood risks require a proper policy. Water managers need to develop and select those adaptation scenarios that maximise welfare. Doing so requires addressing various challenges; integrating climate change effects in flood modelling, development of assessment methods for flood risk to social and ecological systems, development of methodologies for the assessment of non-flood related impacts from adaptation scenarios and, finally, integrating all effects, both positive and negative, related to an adaptation scenario in a comprehensive decision framework.
The ADAPT project, which is financed by the Belgian Science Policy (BELSPO), aims to tackle these challenges by the development of a practical methodology, for assisting decision making about adaptation scenarios for attenuating the effects of climate change induced flooding, that builds on the integrated evaluation of economic, social as well as ecological effects. The study builds on two case studies, located in the two major Belgian river basins, for both the development and the illustration of the methodology.

**Keywords**
Adaptation measures, flood risk modelling, climate change, integrated decision support framework

## INTRODUCTION

Climate change is expected to influence rainfall and evapotranspiration which both impact river flooding. It is advisable that flood risk management strategies account for the possible influence of climate change on hydrological extremes. Currently, it is not common practise to do so in Belgium and abroad. (Grinwis M. and Duyck M., 2001; Boukhris et al., 2006)
In the framework of their climate policies competent authorities in Belgium aim at a cost-effective allocation of their resources. This is a good principle and therefore has to be the cornerstone of the development and evaluation of any flood risk management strategy. Water managers need to develop and select those adaptation scenarios – being simply one measure or the combination of several measures – which maximise welfare. The limited resources authorities dispose of should be allocated in an optimal way, ideally prioritising those measures that yield the highest benefits per Euro invested.
In current flood risk management practise decisions are based upon flood risk modelling, which – only for major projects – is complemented by a social cost benefit analysis (SCBA). In order to enable a sound evaluation an adaptation scenario's contribution to welfare all effects, both positive and negative, need to be taken into account. The need to account for all costs and benefits, however, touches an important shortcoming of existing flood risk assessment methodologies, and consequently also policy making, as indirect and intangible effects to social and ecological systems are often largely disregarded (Meyer and Messner, 2005). The same holds for the assessment of the non-flood related impacts from adaptation scenarios on society as

decisions are rarely based on the deliberate identification and evaluation of all relevant effects as is done in the framework of e.g. a SCBA.
Making the execution of a SCBA compulsory for projects over a certain size is not a panacea if the above shortcomings are not overcome. Doing so may increase consideration of non-flood related impacts, but it would not guarantee that the possible effect of climate change on flood risk as well as the indirect and intangible effects of flooding to social and ecological systems would be addressed properly. Although there exist general methodological guidelines for the execution of a SCBA or comparable analysis these offer still to vague guidance for tackling the effects of adaptation measures in a pragmatic and resource-efficient way. Considering all this the ADAPT project aims to meet the above challenges by the development of a practical methodology for assisting decision making about adaptation measures to climate change induced flooding.
The development, selection and fine-tuning of welfare maximising adaptation scenarios requires a CBA (cost-benefit analysis) based decision framework as it is a prerequisite to go beyond the simple ranking of two or more adaptation scenarios, which could be facilitated by a multi-criteria analysis (MCA). As a CBA is embedded in economic welfare theory it requires effects to be expressed in monetary terms. The problem is that not all effects can reasonably be expressed in monetary terms and therefore are at risk of being overlooked. Effects that can not be monetised need to complete the monetary evaluation. Consequently, the integration and equal assessment of very different types of effects, some expressed in money terms, others quantitatively and still others qualitatively, is an important challenge. (Brouwer and van Ek, 2004)
The methodology for assisting decision making about adaptation scenarios to climate change induced flooding will tackle the challenge of integrating the various effects by means of an extended CBA. This decision framework prioritises the use of monetised effects but offers a MCA based framework for presenting and dealing with non-monetary information in a balanced way as to make sure decisions – to the extent possible – are made on all information available.
The approaches used for addressing the various challenges – integrating climate change effects in flood modelling, development of assessment methods for flood risk to social and ecological systems, development of methodologies for the assessment of non-flood related impacts from adaptation scenarios on society and, finally, integrating all effects, both positive and negative, related to an adaptation scenario in a comprehensive decision framework – are discussed below.

## METHODS[1]

The development of the methodology for the ex-ante evaluation of adaptation measures to climate change induced flooding requires the use, development, optimisation and integration of a number distinct models and methodologies. Figure 1 provides an overview of the ADAPT project; highlighting interactions between the different models and methodologies, data flows and the links with the CCI-HYDR project, which is another BELSPO financed project. For the development as well as the illustration of the methodology, the project builds on two case studies: one in the Dender basin and one in the Ourthe basin.

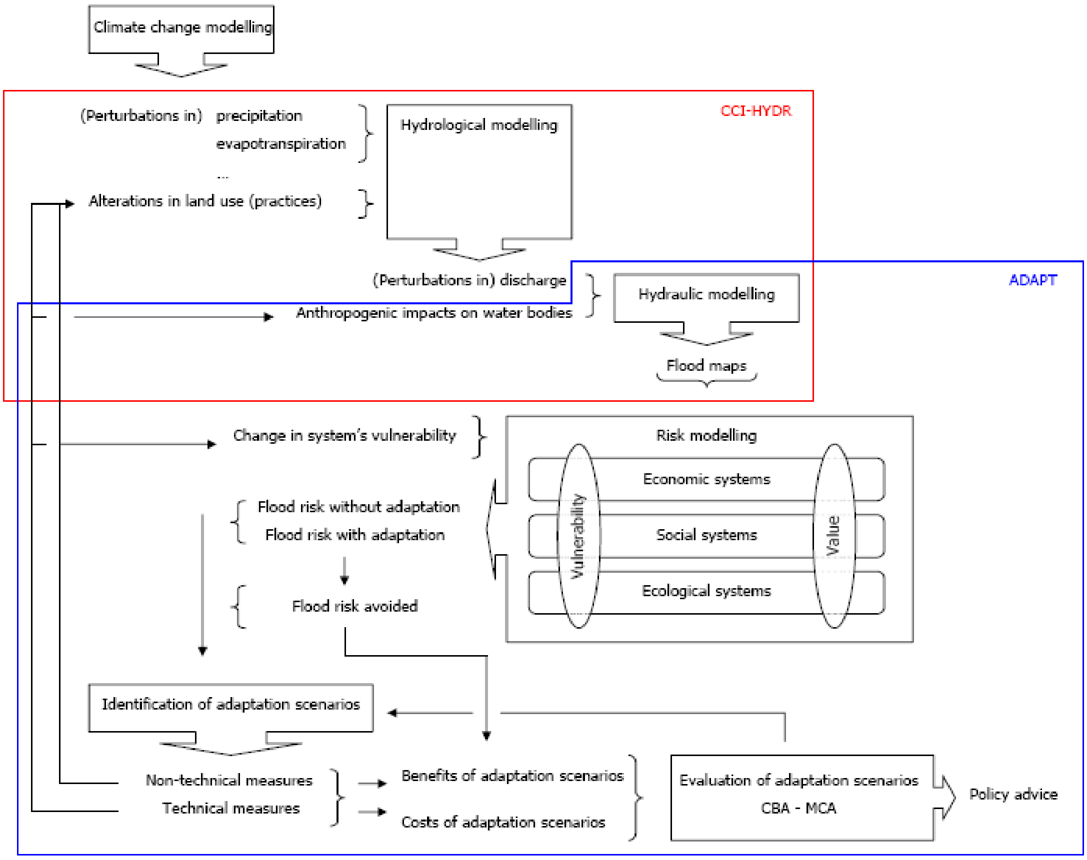
### Integrating climate change effects in flood modelling

The evaluation of adaptation scenarios for reducing the effects of flooding critically depends on the ex-ante modelling of flood chances and characteristics. This is done by means of a hydraulic model which takes the discharge into the river as an input and provides flood maps as an output.

1 This section is based on (Giron et al., in press). The ADAPT project is carried out by a team of five partners with complementary scientific backgrounds. CEESE – ULB, HIVA – KUL, ECOBE – UA and HACH – ULg are the partners of ARCADIS Belgium nv.

The hydraulic modelling approach is different for the two case studies. In the Ourthe case study hydraulic boundary conditions are set while for the Dender case study hydrological modelling is performed as an input for the hydraulic model.

**Figure 1** Overview of the ADAPT project and links with the CCI-HYDR project




In the framework of the CCI-HYDR project the likely effects of climate change on precipitation and evapotranspiration have been derived on the basis of climate change modelling. Via the expected changes in these two parameters the expected change of the discharge into the river has been simulated by means of hydrological modelling. In order to account for the uncertainty related to climate change a low, mean and high climate change scenario for Belgium has been derived and worked with. This approach has been used for modelling river flooding in a climate change context in our case study in the Dender basin. The use of historical hydraulic data from gauging stations, which is the approach used for the case study in the Ourthe basin, does not allow accounting for the effects of climate change on flooding unless direct assumptions are applied on the expected perturbations in peak discharge resulting from climate change. Based on the results of the CCI-HYDR project perturbation factors of a 5, 10 and 15 percent increase in peak discharge has been put forward. On request of the Follow-up Committee of the ADAPT project also a 30 percent increase in peak discharge has been simulated. (Boukhris et al., 2006)
The hydraulic models used are existing models that have been refined and adapted to better meet the needs of carrying out repeated runs for various climate change and adaptation scenarios. Flood maps have been modelled for a baseline scenario with and without climate change effects. Next, hydraulic models need to be adapted in order to be able to model the effect of adaptation scenarios on flooding. Finally, based on flood risk modelling and the evaluation of the costs and benefits adaptation scenarios are refined which may require new flood simulations.

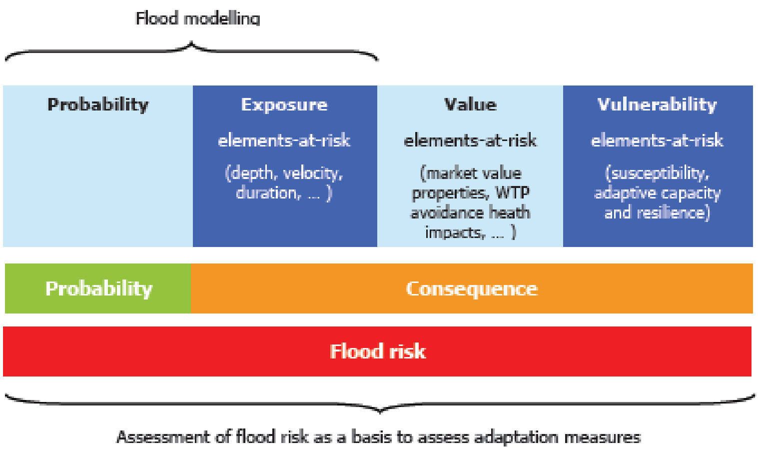
**Development of flood risk assessment methods**

Flood risk modelling assesses the impact flooding has on society. In order to overcome the focus on the direct tangible effects of flooding to economic systems, as in conventional flood risk modelling practice, three complementary flood risk assessment modules are developed, respectively focussing on the effects of flooding to economic, social and ecological systems. It is imperative that information requirements on the effects of flooding, which stem from the project's objective to make welfare maximising decision about adaptation scenarios, are downloaded to the development process of the flood risk assessment methods. In brief, the effects of flooding are best expressed in monetary terms but only if doing so would not increase overall uncertainty. Information on the absolute risk in a certain region has to be complemented by information on the spatial distribution flood risk and its underlying causes. In case the monetisation of effects is not sensible, comprehensive quantitative indicators and/or indices have to be developed. Effective indicators need to be relevant, easy to understand, reliable, sensitive, based on accessible data and measurable. In order to ensure indicators are as informative as possible, water managers are actively involved in their development.

*General flood risk assessment framework*

The central question when assessing flood risk is "What values derived from (well-functioning) economic, social and ecological systems will be lost as a result of flooding?" All relevant effects of flooding to economic, social and ecological systems have been identified, described, selected and attributed to one of the three risk assessment modules on the basis of an extensive literature review, expert knowledge and a comprehensive multi-partner effort. As many effects of flooding are linked minimal understanding of the interactions between the key effects is imperative. Therefore, the most important links have been described which is a prerequisite for assessing the likely impacts arising from (mostly) indirect effects. On the basis of this preliminary work, risk assessment methods have been developed, adapted and/or or selected for all relevant effects.

**Figure 2** Components of the flood risk assessment framework




*Based on (Messner and Meyer, 2005)*

The risk assessment methods of the different effects covered greatly build on the same flood risk assessment framework, presented in Figure 2. The concept of flood risk, which is function of the probability that a flood event will occur and the consequence associated with that event, is crucial when considering flooding in a policy context and thus of primary importance for the development of the assessment framework. Practically, risk is made up of four major building blocks: the *probability* of flooding, the *exposure* of the elements-at-risk to a flood with certain characteristics, the *value* of these elements-at-risk and, and the *vulnerability* of these elements-at-risk. These four elements constitute the key components of the assessment framework. The combination of the latter three elements constitutes the consequence of flooding. The assessment methodology for every distinct element-at-risk builds, in different ways, on all of these components.

Information on both the *probability* and the *exposure* is embedded in flood maps; for each return period considered the hydraulic modellers provide flood maps that comprise information on the different flood characteristics needed for running the different complementary flood risk assessment methods.

The assessment of the *value* of the elements-at-risk is generally less obvious. The elements-at-risk are not always of a direct tangible nature. Consequently, the value society holds for preventing elements-at-risk to be affected can not always be easily determined. The concept of value goes beyond the narrow concept of financial value and also accounts for effects to the functioning of social and ecological systems which are much harder to quantify, let alone monetise. People's preferences to prevent effects from occurring can only be partly related to observed economic behaviour. In particular the assessment methodologies for the social and ecological impacts are confronted with this burden.

The *vulnerability* of the elements-at-risk is function of their susceptibility, adaptive capacity and resilience to a flood with certain characteristics. In case an element-at-risk is not susceptible there is no impact or loss of value at all. In other words the element-at-risk does not contribute to flood risk. The adaptive capacity of an element-at-risk is an indication of a system's ability to decrease the susceptibility of that element to flooding over time. The resilience of an element-at-risk points at a system's capacity to recover.

The assessment of flood risk does not only depend on the projection of future flooding (both in terms of probability and exposure). Economic, social as well as ecological systems evolve constantly, meaning their vulnerability and value changes over time. In order to account for the possible evolutions in the vulnerability and value of the elements-at-risk, scenarios are developed for projecting future vulnerabilities and values. In practise, for calculating flood risk, the four components of the assessment framework are combined. This is, to an important extent, carried out in a GIS environment. Estimates of flood risk with and without climate change impacts will allows assessing the contribution of climate change to flood risk. Similarly, flood risk avoided (= the benefits of an adaptation scenario) can be calculated by subtracting flood risk in an adaptation scenario by flood risk in the baseline scenario.

*Economic flood risk assessment module*

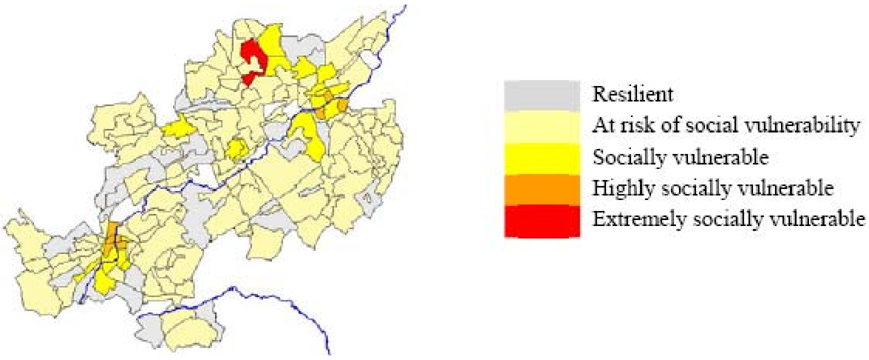
Economic flood risk modelling, which mainly focuses on potential damage to build-up property, is quite straightforward and therefore relatively uncontroversial. The vulnerability of the elements-at-risk is assessed by means of relative damage functions for the different economic damage categories considered. The damage functions used in the ADAPT project are extrapolated from existing models. Per damage category a number of functions have been selected, analysed and, if necessary, adapted to better fit the Belgian context. For every damage category or element-at-risk considered a corresponding market value has been derived on the basis of available market data. The economic flood risk assessment module allows for a full CBA because the output of the module is a monetary value.

*Social flood risk assessment module*

Social effects relate to the changes inundations have on the way people live, work, think and organise (Burdge, 1998). Disruption of physical and mental health, disruption of the financial situation, loss of items with a personal value, changes in risk perception, difficulties in meeting basic needs, problems in recovering the house, etc. are just a few examples of effects to people and their social network.

The vulnerability of people, and their social network, to flooding is many times more complex than the vulnerability of tangible assets. People's vulnerability can simply not be approximated via a simple depth-damage function. In the ADAPT project social vulnerability to flooding is being approximated by an index of a number of well-chosen personal characteristics: age, health status, income, family structure, nationality and property type. For each of these personal characteristics, one or more indicators have been chosen. The social vulnerability assessment methodology provides a robust indicator of people's social vulnerability. Most indicator values are readily available on district level for the whole of Belgium. Indicators are given a certain weight, which may vary according to the effect considered, and vulnerability categories are defined. On this basis vulnerability maps are constructed. Figure 3 provides an insight in the spatial distribution of people's vulnerability to flooding in two municipalities in the Dender basin.

**Figure 3** Social vulnerability map of the municipalities of Geraardsbergen and Ninove




Based on an extensive literature review and expert judgement the seriousness, being a measure of the value potentially at risk, of various social effects has been determined and expressed by means of semi-quantitative scales. A limited number of effects e.g. the health effects of flooding can however be monetised via the use of monetary factors borrowed from valuation studies. RPA estimated British families living in flood risk areas are prepared to pay an annual premium of about £ 200 in order to prevent health related effects of flooding (RPA, 2005). The social flood risk assessment module adds to the effects monetised, but definitely requires the use of an extended CBA framework as not to overlook the effects that can not be monetised.

*Ecological flood risk assessment module*

The ecological effects of flooding relate to ecosystem service provision, the benefits people derive from ecosystems, being affected by flooding. In the framework of the ADAPT project the ecological effects are approximated by the impact on hydrological functioning, biodiversity maintenance, carbon sequestration and nutrient cycling.

Just as the social flood risk assessment methodology, the ecological flood risk assessment methodology is experimental. For each ecosystem function at risk a specific knowledge table has been drawn up on the basis of an extensive literature review and focus group discussions with experts. Each knowledge table provides information on the degree to which a key ecosystem function, serving as a proxy for the ecosystem services it underlies, performed by the vegetation types in the areas-at-risk are vulnerable for different flood characteristics. As for the social vulnerability assessment methodology these knowledge tables serve as a complex, multi-dimensional damage functions.

What are hydrological functioning, biodiversity maintenance, carbon sequestration and nutrient cycling worth? The main problem for including the ecological impacts of flooding in a CBA based decision framework is that the impacts to ecosystems often can not be quantified very accurately, let alone monetised as the corresponding services are not valued in markets. Alternatively, the likely value of ecosystem service provision is scored by means of a simple quantitative scale for every vegetation type in the area-at-risk.

The ecological benefits of flood prevention are expressed by a quantitative scale. The ecological flood risk assessment module therefore requires the use of an extended CBA as to not overlook the effects that can not be monetised. Besides, the ecological flood risk assessment module provides an insight in the spatial distribution of ecosystems' vulnerability by means of vulnerability maps.

**Development of assessment methods for non-flood related impacts of adaptation scenarios**

The wider costs and benefits of adaptation scenarios should not be disregarded as they also impact on welfare. In many instances stakeholder involvement is of particular importance for the identification as well as the assessment of these costs and benefits. The procedure consists of a checklist for facilitating the identification of the effects per individual measure. Robust monetary factors will be drawn up for assessing the most important effects. The assessment of related costs and benefits will be carried out on the basis of the guidelines for carrying out socio cost benefits analysis.

As an example, the construction of a controlled flood area may require the expropriation of land and houses. Cities can not grow unrestrained. The revenue potential of the land is decreased as extensive grazing is possibly the only revenue generating land use left. Besides, the construction of extra dikes may hamper the view of the houses located close by. Houses may also be confronted with a rise in the water table. A controlled flood area, however, also offers opportunities for creating/restoring ecological values, at least if water quality is fine. Tourism and recreation may benefit as well. All these effects ideally need to be accounted for. (Brouwer and van Ek, 2004)

**Integrating effects of adaptation scenarios in a comprehensive decision framework**

Finally all effects assessed are combined in an extend CBA to enable the evaluation of adaptation scenarios. This decision framework prioritises the use of monetised effects but offers a MCA based framework for presenting and dealing with non-monetary information in a balanced way as to make sure decisions – to the extent possible – are made on all information available. Only those adaptation scenarios that are expected to contribute to welfare are worth implementing. Benefits of adaptation scenarios therefore should outweigh associated costs.

First, all effects that have been expressed in monetary terms are combined in a balance sheet. In case of a net benefit the project is accepted if it the project evaluator judges the net benefits outweigh any negative effects that have not been monetised. Similarly, a project is rejected if the project evaluator judges the net costs are not compensated by the positive effects that have not been monetised. In order to assure project evaluators make defensible judgements, indicators and indicator values of the non-monetised effects need to be well-understood by the project evaluators.

Second, residual flood risk is mapped to investigate whether the adaptation scenarios developed can be optimised. Scenarios for which modifications are suggested need to be modelled and evaluated again. This typically is an iterative process and may be repeated as many times as needed.

Third, scenarios for which costs do not outweigh the benefits are rejected.

Fourth, all projects that are expected to contribute positively to welfare will be compared and ranked in terms of their net contribution to welfare, their absolute flood risk reduction as well as their cost-effectiveness. This exercise is facilitated by means of a MCA based framework on the basis of which the most interesting scenario can be put forward. A set of criteria are scored for every scenario. The scores on each criterion are standardised and each criterion is attributed a certain weight. The standardised scores on the different criteria are weighted and summed for each scenario. Next, the different scenarios are ranked.

## RESULTS AND DISCUSSION

Most uncertainties in the results of the present flood simulations arise from model results and assumptions on the perturbation factors affecting the discharge. Therefore, to make progress on climate change adaptation, there is a need to improve climate models and scenarios at a detailed regional level, especially for extreme weather events. (Boukhris et al., 2006)

The methodologies that have been developed for the assessment of social and ecological systems’ vulnerability to flooding provide a solid basis for going beyond the current focus of flood risk assessment methodologies on economic assets. Scientific underpinning of various relationships, however, has to be gradually improved. Valuation of the ecological and social values is a different story. Attention should be directed to the development of a pool of primary and secondary valuation studies out of which monetary factors can be extracted. Next, knowledge gaps need to be identified and a strategy for tackling these knowledge gaps by means of original valuation studies has to be developed. However, the simple quantification of possible benefits to social and ecological systems, necessary for applying monetary factors, also proved to be difficult in certain cases.
The more effects are expressed in monetary terms the easier the evaluation of a scenario’s contribution to welfare becomes. In order to allow for the optimisation of adaptation scenarios the spatial distribution of flood risk is an indispensable aid to the evaluation in a CBA based decision framework. The added value of the method for the projection of the spatial distribution of flood risk, developed in the framework of the ADAPT project, will become ever more informative when knowledge on the value of the social and ecological elements-at-risk improves.

## CONCLUSIONS

The ADAPT project addresses a number of key challenges as to improve and facilitate decisions about adaptation measures against flooding. The key objective is to provide water managers with a practical methodology and a set of instruments to ensure decisions about adaptation measures benefit society as much as possible. During discussions with water mangers, the team has been able to convince water managers of the need to go beyond simple flood modelling as the sole basis of identifying, developing and deciding about flood risk management options.

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