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SCIENCE FOR A SUSTAINABLE DEVELOPMENT

TOWARDS AN INTEGRATED DECISION TOOL FOR ADAPTATION MEASURES – CASE STUDY: FLOODS
"ADAPT"

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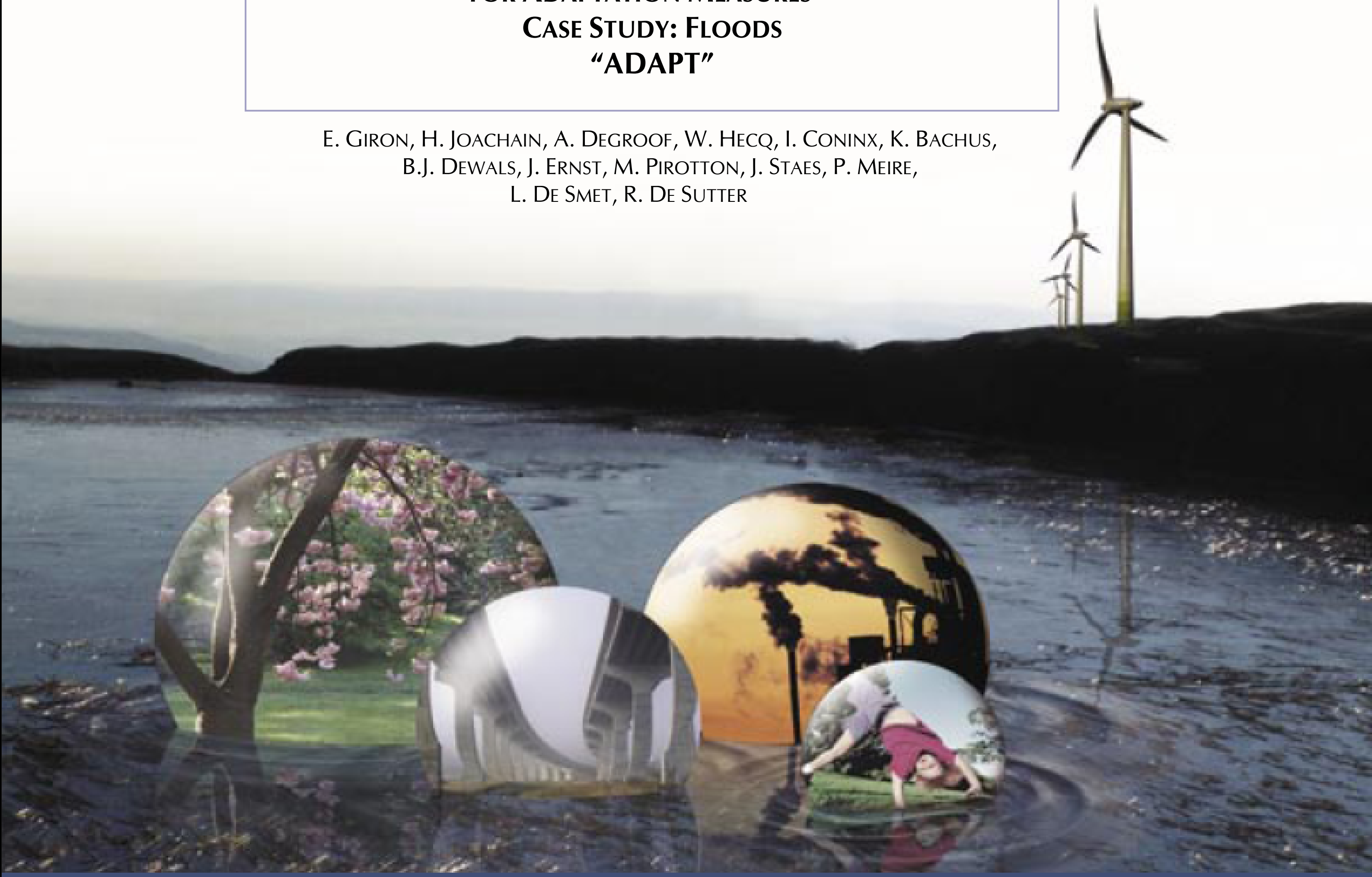

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FINAL REPORT

TOWARDS AN INTEGRATED DECISION TOOL FOR ADAPTATION MEASURES – CASE STUDY: FLOODS
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1 SUMMARY

1.1 Context

Since the beginning of the Industrial Revolution the scale of human impact on the natural environment has become increasingly more important, altering the balance in the climate system / human activities have impacted the natural environment in ever growing measure to the point of rocking the balance in the climate system and thereby triggering effects on temperature and precipitation, and consequently provoking heat waves, drought and flooding as well as a rise in sea level. Climate change is currently regarded as one of the most important threats to the environment and to human well-being. If the observed evolutions of our climate persist, climate change will put an increasing burden on society and on natural systems.

Policymakers can respond to the consequences of climate change in two ways. First, by taking *mitigation* measures, which are developed to reduce emissions of greenhouse gases, and thus aim to prevent or, at least, limit climate change. Secondly, by the development of *adaptation* measures in order to limit the impact climate change has on society and ecosystems. In the framework of the ADAPT project, a methodology has been developed to guide selection of optimal adaptation measures. The methodology is specifically focused on adaptation measures to face increased *flood risk* as a result of climate change, as motivated by the fact that climate change influences rainfall and evapotranspiration, both impacting river flooding.

Available results of Global Circulation Models (GCM) and Regional Climate Models (RCM) provide estimates of the possible changes in precipitation and evapotranspiration patterns as a result of climate change. Rainfall-runoff modeling may be used subsequently for translating those changes in climate parameters into changes in river discharges, accounting for expected evolutions in land use. Those projections are still affected by a significant level of uncertainty due to the climate and hydrological models themselves and, to a greater extent, to the discrepancies in the scenarios used for running these models. Nevertheless, in a number of European river basins, model predictions converge towards a clear increase in peak discharges both in terms of intensity and frequency. Therefore, coping with flood risk will remain a key priority and will increasingly require suitable flood protection.

According to international guidelines, the selection of cost-effective combinations of flood reduction measures and the identification of means to reduce flood consequences should rely on a risk-based approach, taking into consideration not only purely technical criteria but also economic, social and environmental factors. Currently, this is not a common practice in Belgium and abroad. The ADAPT project has been addressing this challenge by the development of a practical methodology for assisting decision making about the selection of cost-effective flood protection strategies in the context of climate change, based on the integrated evaluation of economic, social and ecological effects. In addition, the analysis should be conducted at a sufficiently detailed resolution level to provide valuable outcomes for local river authorities. Therefore, while most flood risk analyses are undertaken at a macro- or meso-scale, the ADAPT methodology relies, to a certain extent, on a micro-scale analysis. Since the project follows a multidisciplinary approach, the ADAPT consortium is composed of five partners of complementary scientific expertise, belonging to the three pillars of sustainable development, to meet the challenges of the integrated analysis of complex problems. Furthermore, the ADAPT project has been working in close collaboration with the CCI-HYDR project. The output of the CCI-HYDR project, which studies climate change impacts on hydrological extremes in Belgium, serves as input for the ADAPT project.

1.2 Objectives

After a review of current knowledge of the general climate change effects in Belgium, conducted during Phase I of the project, Phase II has been entirely dedicated to the development of a practical methodology for selecting optimal adaptation measures to cope with climate-induced increased flood risk.

Flood risk is generally defined as the relationship between flood frequency and induced damage. Flood hazard reflects the inundation intensity (such as water depth, flow velocity, rising rate, duration) for a number of discharge values characterized by their exceedance frequency. This latter may be deduced from hydrological modeling or statistical analysis of observed time series. Evaluation of flood impacts involves *exposure* analysis, i.e. inventorying affected assets (population, buildings, industries, rail and road networks …), estimating their value and *vulnerability*, describing to which extent the assets are affected by the inundation.

Different types of flood reduction measures can be used while addressing flood risks: technical measures directly limiting the flood characteristics (e.g. dikes, derivation channels, regulatory measures reducing the exposure (e.g. individual flood protections, ban on living in flood risk areas), as well as technical and non-technical measures decreasing the susceptibility of people and assets (e.g. domestic flood protection, flood warning, emergency plans, risk communication). Thus the ADAPT methodology enables us to assess the influence of various technical and non- technical flood protection measures on each of the three components of flood risk, namely hazard, exposure and susceptibility of population and economic assets.

For the development as well as the illustration of the methodology, the study relies on two case studies located in the two major Belgian river basins: (1) part of the river Ourthe (Meuse basin) and (2) part of the river Dender (Scheldt basin). Those study areas have been selected for their flood history, for the interest of their hydraulic, economic, social and ecological characteristics, as well as for their complementarities.

1.3 Methodology

The developed methodology relies on a four-step procedure, leading to the selection of most appropriate adaptation measures in terms of integrated cost-effectiveness:

- evaluation of flood risk and impact analysis;
- selection of flood reduction measures, and assessment of the corresponding avoided risk;
- estimation of the cost of each adaptation measure and ranking;
- conduction of an extended Cost-Benefit Analysis (CBA) to evaluate, rank and prioritize adaptation measures.

1.3.1 Evaluation of flood hazard

Flood hazard is obtained from ex-ante modeling of flood characteristics by means of hydraulic models, which take the discharge into the river as an input and provide flood maps as an output. The hydraulic modeling approach is different for the two case studies: for the river Ourthe, a detailed quasi 3D hydraulic model is used, while for the Dender, a 1D conceptual model has been exploited.

The flow simulations for the case study of the river Ourthe are conducted by means of the ***two-dimensional numerical model WOLF 2D***, based on the fully dynamic *Shallow-Water Equations* (SWE) and entirely developed at the University of Liege. The flow model is based on the shallow-water equations, solved by means of a finite volume scheme on multiblock structured grids. For the floodplains along the river Ourthe, topographical data are extracted from an aerial LiDAR (Light Detection And Ranging) *Digital Surface Model* (DSM), with a horizontal resolution of 1 meter and a vertical accuracy in the range of 15 cm (provided by the *Service Public de Wallonie*). The hydraulic simulations are all performed on a regular grid of 2m by 2m, which is detailed enough to represent the flow at the scale of individual buildings. The model outputs are dense 2D distributions of water depth and flow velocities in the inundated areas, which are key input data for the subsequent impact assessment. As confirmed by these simulation results, the complexity of topography in the urbanized floodplains requires a two-dimensional flow model as the most credible approach to reliably represent the dynamics of inundation flows. Consequently, the outcomes of hydraulic modelling constitute suitable inputs for the subsequent exposure analysis, performed at a micro-scale using detailed land use maps and a geographical database.

The study is performed for fourteen different discharge values, enabling a correct representation of the final risk curves. In the present situation, exceedance frequency associated with these discharges was obtained from a statistical analysis of long time series of observations. Perturbations in the exceedance frequency will be introduced to account for climate change, based on results of the rainfall-runoff model SCHEME run by RMI in the CCI-HYDR project.

The inundation modeling for the Dender case study is conducted using a **one dimensional conceptual model**, representing the river as a series of reservoirs and accounting for a general description of the drainage process without including details of hydraulic mechanisms. The model, as well as its variants that have been developed for the different flood defence measures, encompasses the river Dender in Flanders south of the city of Denderleeuw and the river Marke, the main tributary of the river Dender in Flanders. The conceptual model has a low computation time compared to a detailed hydraulic model and generally produces good results for the water levels in the inundated areas. Because of its nature, a 1D-conceptual model is also unable to produce output on some variables needed for the ecological impact assessment. The conceptual model calibration has been done on the basis of the detailed hydraulic models InfoWorks RS model of the river Marke on the one hand and the MIKE 11 model of the Dender on the other hand. This detailed calibration time series has been used for ecological impact assessment. Flood maps, providing the inundation depth along the main course of the Dender, have been computed for all four model variants for a 5, 10, 25, 100 and 250 year return period, given the current climate as well as a low, mean and high climate change scenario. For this the CCI-HYDR climate change scenarios have been used. The Hydraulics Division of the KUL has, in the framework of the cooperation between the CCI-HYDR and ADAPT project, both developed the conceptual model as well as carried out all simulations.

1.3.2 Impacts analysis

Impact analysis assesses the effects flooding has on society and the environment. In order to overcome the focus on the direct tangible effects of flooding on economic systems, as in conventional flood risk modeling practice, three complementary flood risk assessment modules have been developed, focusing respectively on the effects of flooding on economic, social and ecological systems. For this purpose, two complementary procedures have been developed, making the best of locally available data in each region, but basically relying on the same fundamental concepts.

Although several studies have demonstrated that ***social impacts*** may not be ignored, they are rarely considered in the evaluation of policy measures. Beside the quantification of casualties, people and socially valuable buildings affected, a methodology has been developed to assess social flood impact intensity. Three main aspects need to be considered when evaluating social impact intensity of floods, namely *(i)* the flood characteristics provided by hydraulic modeling, *(ii)* the exposure of the people and valuable buildings and *(iii)* the vulnerability of the people.

The *vulnerability* of people involves two aspects: susceptibility of the people and adaptive capacity. Susceptibility refers to the socio-economic characteristics of people. Social susceptibility is assessed here by means of a composed index, which depends on several indicators (available to statistical districts) such as the proportion of elderly persons, people who are ill, single parents, foreigners, people on a low-income and people living in houses on one level. The indicators are aggregated and weighted. The index obtained is used to identify the degree of social susceptibility. The adaptive capacity of society is also considered since the social flood impacts may be mitigated by preparatory, protective or curative measures. A composed index is used to quantify the adaptive capacity for a geographical area, reflecting the availability of measures such as private protection, flood forecasting and flood warning or psycho-social support. , An adaptive capacity score is then derived from these indicators. Based on water depth, flow velocity, water rise velocity and flood duration, a *flood index* is constructed and combined with the susceptibility index and the adaptive capacity score to obtain a *social flood impact intensity index* which indicates the intensity or severity of the social flood impact experience. Indeed, due to their intangibility, social flood impacts are hard to quantify separately and it is thus appropriate to use an aggregated index indicating the level of severity of the social flood impacts and enabling relative comparison between areas to prioritize risk reduction needs.

After exposure analysis, a relative *damage function* is applied for each affected asset to deduce ***economic damage*** as a percentage of its total value. Relative damage functions are considered as the standard approach to evaluate flood damage. They establish a link between induced damages and hydraulic parameters, i.e. mainly water depth and flow. This link is validated with available data from previous events. Other parameters may also be included, such as flood duration. Much care is required when selecting and applying a damage function, due to the diffusion of the large number of existing functions throughout the results. The present methodology concentrates on direct economic damage to residential buildings, as the results show that they are the main component of total flood damage for both case studies. Although a standard methodology is applied here for economic damage evaluation, the analysis remains innovative as a result of the scale at which it is conducted, preserving the detailed distribution of the inundation characteristics provided by the hydraulic models.

The ***ecological effects*** of changes in flooding regimes relate to changes in vegetation development. We present a methodology to evaluate the constraints of flooding characteristics on floodplain vegetation development. The most direct impact of inundation on vegetation is the drowning of vegetation through oxygen depletion in the root system. This mechanism was taken as the basis for the practical vulnerability assessment method. Flood vulnerability/tolerance maps are calculated for different vegetation communities and for different flood types (combinations of timing, regularity, duration and depth). It is demonstrated how flood time series are classified into flood type occurrences and are combined with the vulnerability maps. The cumulative impact is calculated and visualised for a study site. Changes in flooding regimes can have positive or negative effects on ecological values and/or the ecosystem services they provide. The disappearance of certain vegetation types also enables the development of other, perhaps more desirable vegetation communities. Nevertheless, flooding is only one constraint on vegetation development, whilst there are numerous other constraints that are far more important (management, groundwater regimes, nutrient availability, soil buffer capacity).

1.3.3 Evaluation of adaptation options

A first step for the evaluation of the direct costs of adaptation was to define the cost components to be taken into account. This task was carried out taking into account the European Commission's guidance document "Common Implementation Strategy for the Water Framework Directive", focusing on the implementation of the economic elements of the Directive, as well as other reports published by international agencies and specific studies on flood protection measures. It came out that financial costs, with their three major components (investment, operating and maintenance costs) formed the core basis for the evaluation of the direct costs of flood adaptation measures based on the discounted cash flow approach.

The second step was then to evaluate the cash flows linked to the adaptation measures. Since the literature review that was carried out offered limited insights into the costs of the adaptation measures at the micro-scale level, it was decided to follow an approach that was initially conceived as complementary to the literature review: interviewing entrepreneurs on the costs of the measures. The result of the enquiry was of a qualitative nature, with in-depth interviews of entrepreneurs, and provided assessments of the direct costs of adaptation that rest on their expert judgment.

In order to be able to structure and integrate all relevant information, so as to enable decision making which maximises welfare, an extended cost-benefit analysis (extended CBA) based decision support model was developed. This model has been used to evaluate the scenarios considered for both case studies. In this model an MCA is used to rank the different scenarios. The problem, however, is that an MCA does not say whether the benefits of the scenarios considered do outweigh related costs (whether the scenarios create or destroy welfare). If the costs of a scenario surpass the expected benefits, the scenario should not be carried out from an economic point of view. In order to overcome this disadvantage, the model is extended with an implicit cost-benefit analysis. The welfare effect is assessed by the economic net present value (ENPV) of the project. Next, the model offers various options for carrying out a comprehensive Monte Carlo based uncertainty and sensitivity analysis as channeling uncertainties is an important part of the decision making process.

1.4 Results

1.4.1 Selected adaptation measures and flood risk impacts

Several adaptation measures have been selected taking into account the specificities of the two flood areas, as well as the technical maturity of the measures and their availability on the market.

For the Ourthe case study, the selected measures cover:

- the rehabilitation of an old canal (scenario 1),
- the permanent heightening of protection walls (scenario 2),
- the heightening of protection walls using mobile protection walls (scenario 3),

- the activation of a passive floodplain (scenario 4).

Scenarios 2 and 3 are, in fact, a variation of the same measure, and their effectiveness is therefore equivalent, but the investment costs vary. The baseline scenario is the current situation.

The results show that all adaptation scenarios considered reduce the economic and social flood risk irrespective of the climate scenario. The higher the flood risk in the baseline scenario, the higher the risk reduction. The activation of an old flood plain is expected to be the most effective measure for the reduction of the social flood risk, except for the high climate change scenario. The heightening of walls, either permanently or by means of mobile aluminium beams, is the most effective measure for the reduction of the economic flood risk and also offers good results for reducing the social risk.

Assumptions concerning the economic growth, population dynamics, project horizon and discount rate do influence the results, but the conclusions remain valid.

For the Dender case study, an alternative approach has been tested, and the scenarios are built on a combination of flood protection measures:

- Strict ban on building + dike heightening (scenario 1);
- Strict ban on building + dike heightening + replacement of the weirs (scenario 2);
- Strict ban on building + dike heightening + replacement of the weirs + construction of retention basins (scenario 3).

As well as scenarios for assessing the effect of complementary measures :

- Strict ban on building in flood prone areas + dike heightening
- Strict ban on building in flood prone areas + dike heightening + risk communication
- Strict ban on building in flood prone areas + dike heightening + risk communication + improved flood forecasting and warning

It can be observed from the results that the current situation, i.e. scenario 1, reduces both the social and economic flood risk. This reduction, however, is very limited. In a low climate change scenario the expected social flood risk even slightly increases. The other two adaptation scenarios lead to an increase in both the social and economic flood risks, at least on the basis of the flood data that have been used for calculations. One should, however, not overlook the fact that the retention basins undo some of the negative effects on flood risk which the weirs are expected to generate. The construction of the weirs seems, at least from these results, not a good option for reducing flood risk along the Dender in the communities of Geraardsbergen and Ninove.

1.4.2 Ranking

For the Ourthe case study, the ranking of the scenarios on the basis of multiple evaluation criteria shows us that the rehabilitation of the old canal (scenario 1) is by far not the prefered option if only one measure has to be selected. The investment costs of this canal are simply much too high and the resulting reduction in flood risk is much too limited. The performance of the other scenarios seems to be quite similar. This is, however, a bit misleading since the rehabilitation of the old canal is an outlier which tends to camouflage the differences between the other scenarios in a multicriteria analysis. A closer look at the results shows that wall heightening (scenarios 2 and 3) outperforms the reactivation of the old flood plain (scenario 4). Since the net present value of the investment, operating and maintenance costs of a permanent wall (scenario 2) are expected to be only two thirds of the cost of a mobile wall made up of aluminium beams (scenario 3), permanent wall heightening is the best option to reduce the impacts from flooding along the Ourthe in our study area. Only if our current estimate underestimates the visual disamenity caused by a permanent wall, investing in a mobile wall will become relatively more attractive. This is not only the case when studying the current climate. All the above conclusions are equally valid for the three climate change scenarios.

For the Dender case study, the ranking of the scenarios on the basis of multiple evaluation criteria, shows that the current situation, the baseline scenario + dikes, (scenario 1), is by far the most attractive scenario. The scenario dikes + weirs + retention basins (scenario 3) is the least prefered scenario. The most dominant factor influencing the ranking of the scenarios is that of the investment,operating and maintenance costs. The avoided social and economic flood risks do not play a determining role in the ranking of the scenarios. All the above conclusions are equally valid for the three climate change scenarios.

1.4.3 Extended CBA

The extended CBA based decision model consists of three modules: an extended cost benefit analysis, a sensitivity analysis and a risk analysis. The development, selection and fine-tuning of welfare maximising scenarios requires a CBA based decision framework, as this is a prerequisite to go beyond the simple ranking of two or more scenarios, which cannot be facilitated by a multi-criteria analysis (MCA). CBA requires that the effects are expressed in monetary terms. Effects that cannot be monetised need to complete the monetary evaluation. A CBA is a tool to evaluate whether the benefits of a measure, project or policy outweigh the associated costs. Scenarios with a negative ENPV should better not be realised. The cost-effectiveness is also considered, which indicates to what extent the benefits of a project outweigh the associated costs and what benefits are realised for every invested euro.

For the Ourthe case study the permanent heightening of flood protection walls would yield a positive ENPV in all climate change scenarios considered, given the basic assumptions. The highest benefits are to be expected in the high climate change scenario. The scenario with the mobile walls will only contribute positively in economic terms in the high and mean climate change scenarios. The activation of the old flood plain should only be carried out if a rise in the high climate change scenario is expected. The rehabilitation of an old canal is not an interesting option. It would definitely reduce the balance between costs and benefits, given that it is a very expensive measure and is not expected to reduce flood risk more than the other measures considered, but rather do the opposite. Changing certain parameters does influence the results. A drop in the discount rate increases the ENPV of all scenarios, while an increase has a counter-effect. The opposite is true for economic and population growth - the higher the growth the higher the expected ENPV of the scenarios. A drop in the importance of the social flood risk relative to the economic flood risk will decrease the overall benefits and thus the ENPV of the scenarios. The ranking of the scenarios is not altered, given the changes in the assumptions just described.

With the exception of scenario 1, i.e. strict ban on building in flood prone areas, the scenarios considered for the Dender consist of multiple measures. This makes it harder to evaluate the contribution of individual measures. The current situation, i.e. strict ban on building in flood prone areas + dike heightening (scenario 1), reduces both the social and economic flood risks. This reduction, however, is very limited. In a low climate change scenario the expected social flood risk even slightly increases. The other two adaptation scenarios are expected to increase both the social and economic flood risks, at least on the basis of the flood data used. It can be noticed that the flood retention basins reduce some of the negative effects which the renewal/adaptation of the weirs is expected to generate. A scenario 0 "current situation" ranks first, but its ENPV is negative. The ENPV of scenarios 2 (strict ban on building with dikes + weirs and the scenario with dikes + weirs + retention basins is even much lower.

The construction of the weirs seems, at least from these results, not a good option for reducing flood risk along the Dender in the communes of Geraardsbergen and Ninove. One should be very careful with this conclusion as it is not in line with what can be logically expected. The replacement/adaptation of the old weirs should normally create a higher drainage capacity, at least party removing the bottleneck which they created. Nevertheless the replacement/adaptation of the old weirs will be very beneficial for their operational safety (reducing both the risk for the workers operating them and the risk of their failure). Furthermore, this investment would also be interesting for the navigability of the Dender. A similar picture can be drawn for the planned retention basins. Although these basins are expected to reduce flood risk along the Dender, they are primarily constructed for solving flood problems locally, along the tributaries of the Dender.

Changes in the values of the scenarios on certain decision criteria or in the weights attached to the decision criteria may possibly influence the ranking of the scenarios. The uncertainty and sensitivity analyses revealed that the chance is relatively limited that any other scenario would be more attractive than the permanent heightening of walls.

1.5 Conclusions and contribution to scientific policy support

In both case study areas three flood protection scenarios have been studied. Where the scenarios studied along the Ourthe are expected to be all effective in terms of risk reduction, this is not the case for the scenarios examined in the Dender case study.

In both case study areas climate change will effectively change flood risks. In a low climate change scenario flood risks are expected to decrease while in a high climate change scenario risks are expected to increase. Given the current climate and assuming a strict ban on building in both case studies the absolute flood risk is more than a factor 20 higher in the Ourthe case study. In addition, the expected increase in flood risk when climate change would hit hard is relatively much more important along the Ourthe than along the Dender.

Protection against flooding is becoming more and more expensive. Taking additional technical measures is not straightforward, as flood risks are generally relatively limited in Belgium. Quite often much has been done already to limit both the occurrence and impacts from flooding. In addition it is all the more difficult to get the necessary permits for implementing a measure that has a clear spatial impact. In response to these observations complementary, non-technical, measures should be looked at deliberately, focussing on prevention, awareness raising, disaster management and the creation of the necessary capacity to cope. In order to leave the conceptual discussion about such complimentary measures we have evaluated the possible benefits of a ban on building, risk communication, flood forecasting and warning.

Preventing the increase of the values located in flood risk areas has shown to be a very interesting measure both in terms of its likely effect on welfare as its cost-effectiveness. Limiting the values-at-risk should be the cornerstone of any flood management strategy. Both ordinary citizens and local and national authorities should be made well aware of the actual flood risk in order to ensure the acceptance of a strict clampdown on building.

The original methodology developed for flood risk evaluation, together with its application to two different (and complementary) real-life case studies has enabled us to draw a number of conclusions of practical importance for flood managers and water authorities. Some of the in-depth analyses of flood protection measures have notably emphasized the need to evaluate and select flood protection measures based on a wide range of discharges and not simply use one single flood design. Results of exposure analyses have also revealed that they already provide valuable support for orienting a wide range of practical decisions, with the advantage of being unaffected by additional uncertainties underlying socio-economic impact analyses.

More contributions of the project to a policy oriented at promoting sustainable development are highlighted in the ADAPT report, along with a number of practical recommendations for policymakers.

1.6 Keywords

Flood risk analysis; micro-scale; inundation modeling; land use maps; exposure; vulnerability; adaptive capacity; adaptation measures

2 INTRODUCTION

Climate change is currently regarded as one of the most important threats to the environment and human well-being. This was recently confirmed by the release of the IPCC Working Group II Report on 'impacts, adaptation and vulnerability' (IPCC, 2007). It is very likely that people will be confronted with a temperature increase, changes in the quantity, intensity and patterns of rainfall, heat waves, drought, flooding and sea level rise. Doing nothing to limit the threats will result in multiple damages that will put an increasing burden on our societies as is demonstrated by the Stern Review (2006) and IPCC (April 2007).

Generally two approaches are developed to respond to climate change. Firstly mitigation policy, which focuses on greenhouse gas reduction and therefore preventing or at least limiting climate change. Secondly adaptation policy, which focuses on reducing the consequences of climate change on socio-economic systems and ecosystems. The ADAPT project deals with this second aspect of adaptation policy.

A large range of measures to adapt to climate change is available, from preventive and source-oriented measures to effect-oriented and curative measures. Allocating resources within the context of climate change adaptation is highly complex, due to the prevailing uncertainties and high stakes. Therefore, decision support systems have been developed as tools to assist policy makers in their choice between different measures. Amongst those systems, economic cost-benefit analysis (CBA) is a widely used and recognised decision support tool in order to select the optimal measures (OECD, 2006). However, CBA has also its limitations. Not the least of these limitations lies in the fact that the effects taken into account in the analysis have to be quantified and expressed in monetary terms. Therefore, complementary approaches based on multi-criteria analysis (MCA) are useful to partly remove this limitation, by allowing non-monetary information, both quantitative and qualitative, to be taken into account.

The objective of the ADAPT project is to develop an integrated decision support tool that aims to evaluate the climate change impacts and the impacts of adaptation measures in terms of costs and benefits (avoided risks) and consequently enable the selection of the most optimal adaptation measures. The tool is developed based on the specific climate change impact on river flooding, which may be due to alterations in rainfall and evapotranspiration patterns. Innovative elements in the tool developed within the ADAPT project are firstly, the inclusion of climate change effects on river flooding at the meso-scale which "consider aggregated land use units, e.g. residential areas and industrial areas" (Floodsite, 2007, p. 29). This is currently not common practice in Belgium (Grinwis M. and Duyck M. 2001; Boukhris et al. 2006). Secondly, the tool considers not only material effects, but also social and ecological impacts. Decisions that are partial based on the material effect assessments may result in systematic errors (Meyer and Messner 2005). Thirdly, the tool enables the evaluation of technical and non-technical adaptation measures, while the emphasis has been put on technical measures in the project..

The integrated decision support tool is developed and applied on two case study areas in the main Belgian river basins (the Scheldt and the Meuse basin): (1) Geraardsbergen and Ninove which are located near the Dender and (2) Esneux which is situated near the Ourthe. A first prerequisite to carry out the flood risk analysis is the presence of hydraulic models in these two case study areas. The hydraulic model of the Dender has been developed by the Hydraulics Division of the KUL in the framework of the cooperation between the CCI-HYDR and ADAPT project, while the hydraulic model of the Ourthe case study is developed by the HACH team of Ulg. Secondly both case study areas are selected because of their flooding history during the past 20 years. Geraardsbergen and Ninove have experienced inundation in 1993, 1995, 1998, 1999, 2001, and at the turn of the year 2002-2003. Esneux has been flooded in 1991, 1993, at the turn of the year 1993-1994, 1995 and 2002. The third selection criterion is the social and political debate that is going on in these case study areas about the measures that should be taken to reduce flood risks in the future.

The ADAPT extended CBA – MCA decision tool for adaptation measures in the context of climate change induced river flooding: overview of the different stages.
The extended CBA - MCA decision tool is an ex-ante evaluation tool that mainly focuses on the estimation of climate change impacts on river flooding on the one hand and on economic, social and ecological impact assessment on the other hand.

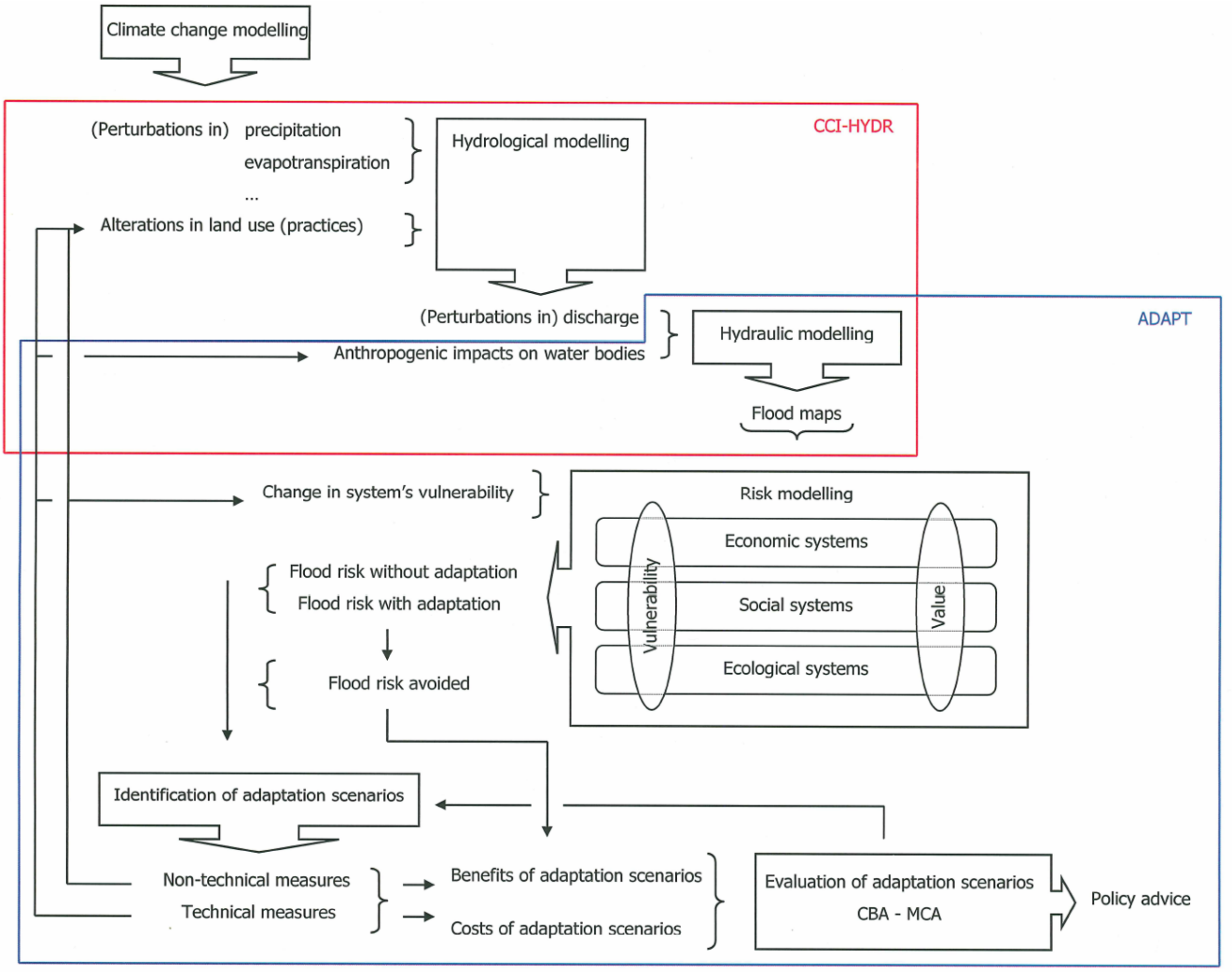


Figure 1: Analytical framework of the Adapt project

2.1 *Objective 1 (WP2.1) Evaluating primary impacts of global change induced flooding on river basins: Hydraulic modeling*

In the first stage of the decision tool, a hydraulic model is applied to estimate the impacts of climate change on river flooding. Flood maps are the output of the hydraulic models. The hydraulic modeling in the two case study areas is different. In the Dender case study, flood maps have been simulated by the Hydraulics Division of the KUL in the framework of the cooperation between the CCI-HYDR and ADAPT project, using hydrological modeling as an input for the hydraulic modelling. The CCI-HYDR project, also financed by the Belgian Science Policy, has projected the likely effects of climate change on precipitation and evapotranspiration in terms of three scenarios: a high, a mean and a low climate change scenario. Via the expected changes in these two parameters the possible change of the discharge into the river Dender has been simulated by means of hydrological modelling. For the Dender case study the hydrological modelling output is fed into a conceptual hydraulic model of the Dender. This model has a very low computation time without giving up much accuracy compared to the detailed MIKE 11 model of the Dender and the InfoWorks RS model of the river Marke, a tributary of the Dender, on the basis of which the conceptual model has been calibrated (De Boeck, 2008; Verbelen and Van Steenbergen, 2009).

The hydraulic model of the Ourthe basin is based on the use of historical hydraulic data from gauging stations. Climate change effects are accounted for by assuming changes in the expected peak discharge for fourteen different river discharges. For each climate scenario (the current climate as well as the three climate change scenarios) a return period has been attached to each peak discharge by the RMI in the framework of the cooperation between the CCI-HYDR and ADAPT project, making use of the SCHEME model. (Archambeau et al. 2004; Erpicum et al. 2007; Erpicum et al. 2008)

2.2 Objective 2 (WP2.2) Evaluating secondary impacts of global change induced flooding on ecosystem and society: flood risk assessment

Flood maps are the output of the hydraulic modeling. The second step in the decision support tool is the ex-ante assessment of flood risks. In particular, the risk modeling procedure estimates the impact of flooding on the economic system, the social system and the ecosystem. The risk modeling procedure of the each of the different effects is built on a comparable flood risk assessment framework.

Flood risks are the result of the function of flood event probability and consequences. The consequences of flood events depend on the exposure of the elements at risk, the values of the element at risk and the vulnerability of the elements at risk. Information on probability is embedded in flood maps, while information on exposure results from a combination of flood maps and land use data.

The assessment of the value of elements at risk is generally less obvious due to the intangibility of some effects. The way society value the effects is not easy to determine. In particular social and ecological impacts are confronted with this difficulty and as a consequence, they are not always expressed in monetary terms.

The last building block of flood risk is vulnerability of the elements-at- risk. This is a function of susceptibility, adaptive capacity and resilience to flooding. Acknowledging the diverse use of these concepts within different disciplines, the concepts used within the Adapt project should be defined Vulnerability is defined as the ability to cope with flooding, in other words to prepare, to resist and to recover from flooding. This ability is affect firstly by the susceptibility of the element-at-risk. Some elements-at-risk have a low ability to cope with flooding due to specific characteristics. Adaptive capacity is an indicator of a system's ability to decrease the susceptibility of that element to flooding over time. The resilience of elements-at-risk refers to the system's capacity to recover.

Extensive literature review, statistical information, interviews of local people, expert knowledge and comprehensive multi-partner effort are the basis of data collection on these building blocks. The output of the flood risk modelling is a quantitative or qualitative estimation of the risk. In addition, GIS modelling is used to illustrate the spatial distribution of the flood risks and their underlying causes.

2.3 Objective 3 (WP2.3): determining adaptation measures

The output of flood risk modelling is the critical input for the identification of potential adaptation measures. The risk modelling output provides an insight in the spatial distribution of flood risk and thereby allows for the identification of those sites where action is needed. Ideally calculated flood risk is complemented with locally available information. Local authorities and people living in the area-at-risk often hold valuable information on the causes underlying the flood problem. Studying adaptation measures requires a thorough insight in the flood problem and thus calls for going beyond the simple analysis of modelled flood risk.

2.4 Objective 4 (WP2.4) : evaluating adaptation measures costs

Once the adaptation measures have been selected, it is necessary to evaluate the direct costs of the selected measures, in order to proceed to the extended cost benefits analysis. Considering the micro scale adopted for the project, it is important to provide estimations of the direct costs that reflect as accurately as possible the cash flows linked to the selected measures. In order to do so, it is not only necessary to take general guidelines on cost benefit analysis in the framework of environmental measures into account, but also to make a review of the literature and to complement it with interviews of entrepreneurs that can provide expert judgement on the average costs linked to the selected measures.

2.5 Objective 5 (WP2.5) : Evaluation of adaptation scenarios by means of an extended cost benefits analysis

The main challenge is to integrate and to equally assess effects since some of them are expressed in monetary terms, while others are quantitatively or qualitatively expressed. To handle this challenge the developed decision support model takes the form of an extended CBA. This decision framework prioritises the use of monetised effects but offers an MCA based framework for presenting and dealing with non-monetary information in a balanced way, so as to make sure decisions are made on all available information. The model also provides the possibility to submit the outcome of the analysis to an extensive sensitivity analysis and Monte Carlo based risk analysis.

The first part of the report explores the methodology of the decision support tool. Chapter III.1 describes the purpose and methodological aspects of the extended decision support tool. Chapter III.2 considers the various building blocks of the decision support tool, as there are the flood risk calculation, the flood risk model development and the economic, social and ecological impact assessments. In chapter III.3, the adaptation costs evaluation methodology is explained. The methodology is applied on two Belgian case studies: Geraardsbergen and Ninove, and Esneux.

2.6 Objective 6 (WP2.6): recommendations on adaptation of measures

Deciding about the way how to deal with flooding and its effects can be very complex. Maximising welfare, given limited resources, comes down to balancing all pro's and contra's of the envisaged strategies; also considering the acceptance of the measure by the public as well as the consistency of the measures with other sectoral claims and strategies. The fact climate is changing only increases uncertainty and thus the complexity of any deliberation.

First a brief summary of the added value of the project for promoting and facilitating sound decision making about adaptation to flooding in a climate change context is presented. The emphasis, however, is on a number of recommendations that touch policy making in various ways. A first set of recommendations concern the impact assessment methods that have been developed and/or improved as there is still margin for improving them. The priorities in this respect are highlighted. The same has been done for what concerns the mapping and channelling of uncertainties in an integrated decision framework. Besides, practical advise is provided on the involvement of people and stakeholders in the assessment and optimisation of adaptation scenarios. Another set of recommendations touch a number of key conditions for making sure water managers will effectively make use of the methods and results of the research project. Finally, a plea is held for robust, no regret measures and strategies.

3 METHODOLOGY AND RESULTS

3.1 ORIGINAL FRAMEWORK DEVELOPED FOR ESTIMATING FLOOD RISK ALONG BELGIAN RIVERS

3.1.1 Methodology for hydraulic modeling

Two approaches have been developed for estimating the flood maps in each case study: a 1D flow model and a fully dynamic quasi 3D model. The characteristics of these two modelling approaches are described here after.

3.1.1.1 1D flow model

This section describes the flow model used for the Dender case study.

The inundation modelling for the Dender case study is facilitated by a conceptual model that has been developed by De Boeck (2008) and Verbelen and Van Steenbergen (2009) under the supervision of Prof. Dr. Ir. P. Willems of the KUL. The model represents the river as a series of reservoirs and contains a general description of the drainage process, without including the specific details of process interactions. The main advantage of a conceptual model is it has a low computation time compared to a hydrodynamic model. This makes a conceptual model a particular interesting tool for studying adaptation measures. The disadvantage of a conceptual model is it has to be calibrated to either the results of hydrodynamic modelling or measurement data. Because of the limited availability of historical measurements necessary for the calibration of the model, this calibration has been done on the basis of the detailed InfoWorks RS model of the river Marke on the one hand and the detailed MIKE 11 model of the Dender on the other hand. It is important to keep in mind the hydrodynamic models are already an approximation of the real situation. (De Boeck, 2008; Verbelen and Van Steenbergen, 2009). In this type of models (Quasi 2D), floodplains are modeled as 1-dimensional floodbranches. Floodvolumes are calculated using DEM-based cross-sections. Flood extent maps are based on the water level results along the floodbranches, and geographically visualized by means of GIS routines. The use of the quasi-2D approach allows a significant reduction of the model calculation time in comparison with a more detailed full 2-dimensional approach.

Whatever method was used (conceptual or quasi-2D), the hydrodynamic river model required inputs from a rainfall-runoff model. For the Dender, lumped conceptual rainfall-runoff models were calibrated for each of the 12 subcatchments. They produce continuous time series of hourly rainfall-runoff discharges (e.g. from 1967 onwards). Simulation of the full series is only feasible for the conceptual river model; calculation times in the quasi-2D river hydrodynamic model would be unacceptably high. After simulation of the full series, a post-processing step is applied to extract independent high flow extremes from the full series. These extremes are statistically analyzed using extreme value analysis, for the range of relevant time scales (e.g. from 1 hour to 15 days), and to construct discharge / duration / frequency relationships. From these relationships, return periods of flood events of various magnitudes (including historical events, or hypothetical future events after climate changes) can be obtained. They also were used to develop synthetic hydrographs (the so-called composite hydrographs), which allows to reduce calculation times when simulating rainfall-runoff input in the quasi-2D hydrodynamic model. The details on the technical aspects of this complete methodology can be found in the CCI-HYDR project report.

Four variants of the 1D conceptual model have been developed. Each variant accounts for a different set of flood defence measures. All models encompass the river Dender in Flanders south of the city of Denderleeuw and the river Marke, the main tributary of the river Dender in Flanders. Flood maps, providing the inundation depth along the main course of the Dender, have been simulated for the four model variants for a 5, 10, 25, 100 and 250 year return period by Verbelen and Van Steenbergen (2009). Next to a set of simulations for the current climate, the inundation depth has also been simulated taking into account the possible effects of climate change. On the basis of a the perturbation tool developed in the framework of the CCI-HYDR project the historical precipitation and evapotranspiration data for the study area were both perturbated to arrive at values that correspond to a low, mean and high climate change scenario. These values were then translated into the corresponding discharge into the river for the return periods considered. These hydrological data were then fed into the conceptual hydraulic model to simulate flooding along the Dender for all four climate change scenarios. (De Boeck, 2008; Verbelen and Van Steenbergen, 2009)

For the analysis of extreme events and the fast calculation of scenarios, this is an excellent method. The conceptual model of the Dender produces good results for the water levels in the inundated areas. The validation that took place on the basis of simulations with the MIKE11 model, however, showed the water levels in the last reservoir are currently overestimated. This is due to an underestimation of the routing in this part of the river. (Verbelen and Van Steenbergen, 2009). The method, however, was found less useful (or at least had many limitations) for use in ecological impact investigations. These investigations indeed require statistical information not only on extreme events, but also on less extreme events. The full time series of rainfall-runoff discharges thus needs to be simulated in the river hydrodynamic model (the conceptual model thus would be required for that purpose) and statistically post-processed also for the lower events. Given that the statistical analysis on higher extremes is based on an extreme value theory (given the limited number of extreme events available in the time series) and for extrapolation purposes, the analysis for lower extremes requires a different approach (extreme value theory is not applicable below a threshold; but statistical analysis can be done empirically / non-parametrically given the larger number of less extreme events in the series). Another, more important problem is that the floodplain modelling methodology, as outlined above, is developed for the quantification and mapping of the maximum spatial extent of specific flood events (historical or synthetic, and independent on the flood season). For the ecological impact study also other variables such as the flood duration, the temporal evolution of the floodplain filling, the flood season, etc., are required. These outputs are by default not provided. The flood duration can be modelled with the quasi-2D approach but largely depends on parameters describing the drainage or soil infiltration capacity. These parameters need calibration, while calibration data on the duration of historical floods is most often not available. Also extraction of information on the flood season requires additional post-processing and validation.

Given the fact water management in Flanders is divided over several actors, depending on the navigability and category of the water course. There currently is no hydrodynamic model that integrates the Dender and its side branches, let alone the watercourses feeding the side branches. The development of a meticulously calibrated conceptual model could proof valuable to design an optimal flood management strategy on a basin wide level.

3.1.1.2 Fully dynamic quasi-3D flow model

This section describes the flow model used for the Ourthe case study.

Mathematical model

Since interactions between the main channel and the floodplain are important during flooding and may therefore not be neglected (McMillan and Brasington 2008), the assumption of one dimensional modelling would not be acceptable in many cases involving complex floodplain geometries, in particular in urbanized areas. Therefore, the present study was based on the detailed quasi-three-dimensional flow model *WOLF 2D*, developed at the University of Liege (Dewals et al. 2006a; Dewals et al. 2006b; Dewals et al. 2008b; Erpicum et al. 2009a; Erpicum et al. 2009b; Erpicum et al. 2009c).

The model relies on the depth-averaged equations of volume and momentum conservation, namely the "shallow-water" equations (SWE) (Chaudhry 1993). The bottom friction is conventionally modelled using an empirical law, such as the Manning formula. The model enables the definition of a spatially distributed roughness coefficient and provides the additional possibility to reproduce friction along side walls by means of a process-oriented formulation (Dewals et al. 2008b; Erpicum et al. 2009c; Roger et al. 2009).

The internal friction may be reproduced by different turbulence closures included in the modelling system, from simple algebraic ones to a complete depth-averaged k-ε model (Erpicum et al. 2009c).

Numerical implementation

The flow model deals with multi-block Cartesian grids. This feature increases the size of possible simulation domains and enables local mesh refinement close to interesting areas, while preserving lower computational cost required by Cartesian compared to unstructured grids for a same order of accuracy.

A grid adaptation technique is used to restrict the computation domain to the wet cells and a narrow strip surrounding them. The grid is adapted at each time step. Wetting and drying of cells is handled free of mass and momentum conservation error by means of an iterative resolution of the continuity equation.

The space discretization is performed by means of a finite volume scheme. Variable reconstruction at cells interfaces is either constant or linear, combined with a slope limiter, leading in the latter case to 2nd-order space accuracy. The advective fluxes are computed by a Flux Vector Splitting (FVS) technique developed by HACH-ULg. Besides requiring low computational cost, this FVS offers the advantages of being completely Froude-independent and of facilitating a satisfactory adequacy with the discretization of the bottom slope term (Erpicum et al. 2009a; Erpicum et al. 2009b). This FVS has already proven its validity and efficiency for numerous applications (Dewals et al. 2006a; Dewals et al. 2006b; Erpicum et al. 2007; Dewals et al. 2008b; Erpicum et al. 2009a; Roger et al. 2009).

Since the model is applied to compute steady-state solutions, the time integration is performed by means of a 3-step first-order accurate Runge-Kutta algorithm, providing adequate dissipation in time. For stability reasons, the time step is constrained by the Courant-Friedrichs-Levy (CFL) condition. A semi-implicit treatment of the bottom friction term is used, without requiring additional computational cost (Caleffi et al. 2003).

Automatic mesh refinement

In addition, the model includes an *automatic mesh refinement* algorithm (AMR). For steady-state simulations, the AMR tool consists in performing the computation on several successive grids, starting from a very coarse one and gradually refining it up to the finest one. When the hydrodynamic fields are stabilized on one grid, the solver automatically jumps onto a finer one. The successive solutions are interpolated from the coarser towards the finer grid. This fully automatic method considerably reduces the number of cells in the first grids, while increasing the time step, and thus substantially reduces the total run time, despite slight extra computation time required for meshing and interpolation operations (Dewals et al. 2008a; Erpicum et al. 2009a).

Topographic data

High resolution and highly accurate topographic datasets have become increasingly available for inundation modelling in a number of countries. In Belgium, a data collection programme using airborne laser altimetry (LIDAR) has generated high quality topographic data covering the floodplains of most rivers in the southern part of the country. Simultaneously, the bathymetry of the main rivers has been surveyed by means of an echo-sonar survey. Consequently, combining data generated from those two remote sensing techniques enables to obtain a complete Digital Surface Model (DSM) characterized by a horizontal resolution of 1m by 1m and a vertical accuracy of 15cm.

Those high quality topographic data combined with simulations performed on grids as fine as 2m by 2m enable to set the value of roughness coefficients to represent only small scale roughness elements and not to globalize larger scale effects such as blockage by buildings. It also enables to conduct inundation modelling at the scale of individual streets and houses.

Nevertheless, since inundation flows may be extremely sensitive to some local topographic characteristics, such as for instance the exact height of a protection wall, a key step consists in validating and enhancing the DSM by removing residual obstacles non relevant for the flow (e.g. vegetation), by integrating additional sources of topographic data (including limited field surveys) as well as the detailed geometry of flood protections and other hydraulic structures (such as weirs or water intakes).

Validation

Since 2003, the flow model *WOLF 2D* has been applied to conduct inundation modelling along more than 1000km of rivers in the southern part of Belgium. For this purpose, accurate Light Detection And Ranging (LiDAR) topographic data are used, obtained from an airborne laser remote sensing. They are characterized by a horizontal resolution of 1 by 1 meter and an elevation accuracy of 15 centimetres.

In this context, the model has been extensively validated by comparison of the numerical results with observed flood extents and measured water depths during recent flood events. Reference data were obtained at gauging stations, collected by field surveys or deduced from aerial pictures of the flood. Only the latest provide spatially distributed observations and are not restricted to pointwise comparisons.

Aerial pictures of floods, taken from helicopter, are available along the main rivers for most recent flood events which occurred in the Walloon region. Provided a proper photogrammetric processing technique is applied to correct the orientation of aerial images, this remote sensing technique turns out to be particularly suitable for validating detailed inundation modelling, as shown in Figure 2.

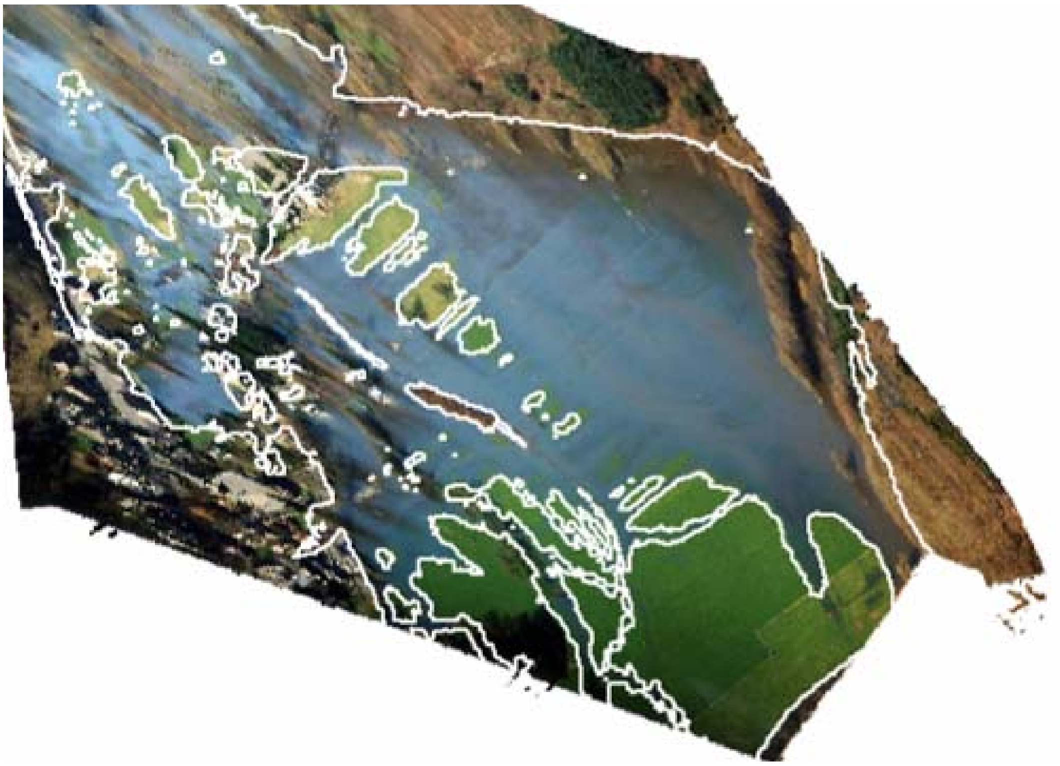


Figure 2: Oriented and resampled aerial image taken from helicopter during the flood, showing a satisfactory agreement with contours of simulated inundation extent (in white).

3.1.2 Methodology for social impact analysis

The experience of a flood event can scare people for life. The stress and anxiety people feel when water is coming into their house is very hard to recover from. The confrontation with a damaged house, destroyed household goods and a neighborhood full of dirt and mud make spirits sink. Other social flood impacts are physical health impacts like injuries, skin irritation or respiratory illness, loss of life, financial disruption of the household, migration, disruption in time spending, impoverishment of the neighborhood, changing risk perception, changing attitude and behavior, difficulties in meeting basic needs. Social flood impacts are mostly intangible impacts. Some of them are directly caused by flooding, but others are caused by the material damage or the recovery process in the aftermath. Social flood impacts are changes to the way people live, work, relate to one another or are organized (based on Burdge 1998 and Vanclay 2002).

Reviewing existing cost-benefit and multi-criteria assessments in the evaluation of flood measures makes clear that social flood impacts are seldom well considered, due to complexity and the difficulties to monetize.

The social flood impact tool (SFI-tool) in this project is developed based on existing knowledge and a complementary Delphi study to fill the knowledge gaps. Three types of output are delivered.

1. the number of affected people and affected buildings with a social, cultural and economic value
2. an estimation of the social flood impact intensity
3. an estimation of expected fatalities

To solve the knowledge gaps, a Delphi study was carried out in April-May 2009. The Delphi method intends to facilitate consensus between experts on current knowledge gaps and consists of a written questionnaire. Since filling knowledge gaps is the main purpose of the

Delphi study, representativeness was never a necessary condition of the questionnaire. About 30 academics and researchers in the field of social flood impacts, vulnerability and adaptive capacity in developed countries were selected and were asked to complete the questionnaire anonymously. A total of 8 experts participated to the Delphi study.

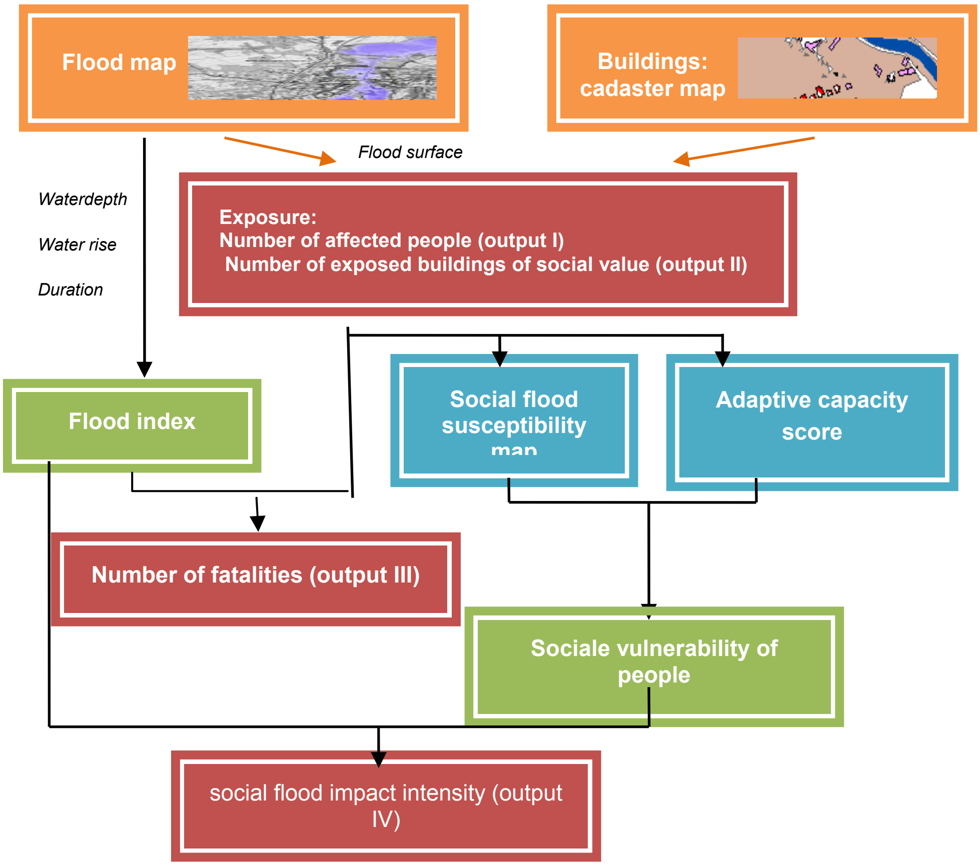


Figure 3: Social organisation in order to determine the SFI (Social Flood Impact)

3.1.2.1 Number of affected people and affected valuable buildings

The number of affected people is the type of social impact that is primarily considered in cost benefit analysis of flood measures. In this project, the affected people are estimated by the integration of flood maps and cadastral data according to the cadastral-based dasymetric system (CEDS). The cadastral-based expert dasymetric system (CEDS) methodology is developed by Maantay and Maroko (2008) and utilizes cadastral data as an ancillary data set to distribute the population within the flood risk area. The number of affected buildings that have a social and cultural relevant function is estimated in the same way. Three categories of buildings are discerned.

1. buildings where susceptible people cohabit: hospitals, home for elderly, day-care centre, caravan parks, asylum centres.
2. buildings with a social function: schools, policy station, fire brigade, town hall, social support services, infrastructure and utilities (water, waste, energy…), court, sport and leisure facilities, …
3. buildings and sites with a cultural function: cemeteries, monasteries, churches/mosques/historical monuments, …

3.1.2.2 Social flood impact intensity

Some of the people affected easily recover from flooding, while others suffer from flood impacts for months or years. This is concluded from studies of several flood events. This means that social flood impact experiences are very diverse among the affected people. There is a need to include this variety in the multi-criteria analysis.

The way people experience social flood impacts is determined by three driving forces. ((as adopted by Hilhorst (2004), Peduzzi et al. 2002, Granger 2003 and Schneiderbauer and Ehrlich 2004).:

- Flood characteristics (F)
- The exposure of the people (E)
- The vulnerability of the people (V)

The vulnerability of people is a function of on the one hand the susceptibility characteristics of people (Sp) and on the other hand the adaptive capacity aspects (AC)

$$SI= f (F,E,V(Sp/AC))$$

Composite indicators are used to quantify each of the elements. These are a aggregation of individual indicators into a single index which is based on an underlying theoretical/empirical model (OECD definition). Generally, composite indicator construction passes through three stages: indicator selection, weighting and aggregation. The next sections elaborates each of these driving forces.

a) Flood characteristics: the flood index

Broad scale questionnaires have indicated correlation between flood characteristics and social flood impacts. It is demonstrated that water level, water velocity, speed of water rise and duration of flooding affect social flood impacts. Threshold levels are defined based on literature. The risk to social flood impacts is highest when water level is higher than 30cm, water velocity is faster than 0.5m/s, water rises suddenly and the flood event takes longer than 12 hours. In case the threshold level is reached, the indicator scores 1. Weights are attributed based on the literature as well. The most important flood characteristic is water level.

b) Vulnerability of people

Vulnerability of people is determined by the susceptibility of the individuals and by the adaptive capacity of the society.

b.1 Susceptibility index

Susceptibility characteristics refer to personal socio-economic characteristics of the individual people that hamper them in preparing for, resisting to and recovering from flooding.

Indicator selection: an inductive approach

In particular large-scale quantitative analyses provide understanding in the correlation between susceptibility and social flood impacts (e.g. Werrity et al. 2007; Defra/Environment Agency 2003; Grinwis and Duyck 2001B). These findings are completed with qualitative case studies. (e.g. Tapsell and Tunstall 2001; Walker et al. 2006)

It is concluded that certain socio-economic characteristics hamper the coping capacities of people (e.g. Aysan 1993) like lack of resources, disintegrated social patterns, degraded environment and inability to protect it, lack of information and knowledge, lack of awareness, lack of political power and representation, certain beliefs and customs and weak buildings or weak individuals. Certain population groups in Belgium possess one or more of these socio-economic characteristics. These population groups are in other words more susceptible to flooding:

Population Group	Characteristics	Indicator
Elderly	• Weak health • Limited social network	Residents aged 75 and over as a percentage of all residents
Sick people	• Weak health • Limited social network • Lack of financial resources	• mobility problems: proportion of people suffering from restrictions in daily activities due to long term illness, handicap or chronic diseases • psychological distress: proportion of people suffering from psychological distress
Single parents	• few financial resources • limited time (resource)	Single parent families as a proportion of all families
Foreign born people *(the official UK term is 'non-nationals' or 'non-Europeans')*	• language inability results in lack of information • lack of awareness • certain beliefs and customs	Strata 3 nationalities as a proportion of all residents (Verhoeven 2000)
Financially deprived people *(the official term is 'people on a low-income' / 'low-income families'*	• limited financial resources • limited protection capacity	• no basic comfort: cobb-douglas calculation of houses without toilet, bathroom or central heating • no-car ownership: proportion of houses without a car • no-house ownership: proportion of houses that are rented
People living in one-storey houses *(bungalows)*	• weak buildings	one-storey houses: residents of one-storey houses as a proportion of all residents

Table 1: Belgian social flood susceptibility index

Data collection

Data was collected from the most recent Belgian population census, which is 2001. Due to privacy reasons, only aggregated data at the district level are available. Districts are defined according to social, economic and geographical characteristics and correspond to one or more streets. We mention the shortcomings of the available dataset because data on health status data and one-storey house data is absent at the district level.

Weighting and aggregation

Indicators are weighted according to their importance with regard to social flood impact intensity. The attribution of weights was one outcome of the Delphi study. The experts indicated that ill people and elderly are most susceptible towards flooding, followed by people living in one-storey houses and financially deprived people, and lastly, single parents and immigrants.
The indicators are aggregated by a geometric mean (Ebert and Welsh 2003)

Interpretation of the susceptibility index

The index scores between 0 and 1. Scores near 1 refer to areas with highly susceptible people, while scores near 0 refer to areas with lowly susceptible people. Average susceptibility in Belgium is 0.097. We argue that areas with scores higher than 0.2 can be considered as very susceptible areas.

b.2 Adaptive capacity index

Mechanisms might be available that increase people's ability to cope with flooding, like technical and knowledge, social, economic, institutional and cultural mechanisms. These mechanisms are included in the concept of adaptive capacity (Based on Brouwer et al. 2007).

Indicator selection: a deductive approach

Adaptive capacity is defined as technical and knowledge mechanisms, social mechanisms, economic mechanisms, institutional and cultural mechanisms. A normative framework is developed to identify several mechanisms and actions that, if deployed in a correct way, should contribute to the reduction of flood impacts. In addition, criteria were defined that should be met in order these measures and actions to be successful. The result is an analytical framework of 59 indicators. The scoring of each of the indicators depends on the fulfillment of the criterion. In case a criterion is not fulfilled, the indicator scores 0, when it is partly fulfilled, the indicator scores 1, and when it is completely fulfilled, the indicator scores 2.

Social mechanisms	**Institutional mechanisms**
Stakeholder involvement	Information dissemination of risks, protective activities and crucial information
Social capital	Definition of actions and responsibilities (e.f. emergency plan and emergency management
Economic mechanisms	collaboration
National relief fund	Logistics and staff
Insurances	Credibility of governmental officers
Knowledge and technical mechanisms	Spatial planning
Information flow between key actors in emergency management	Joint floodplain planning
Flood proofing of buildings/private protection measures	**Cultural mechanisms**
Flood proofing of infrastructure	Risk awareness and risk communication
Research and development	
Risk mapping	
Water monitoring	
Flood forecasting and flood warning	

Table 2: Description of some mechanisms

Data collection

The data on the indicators is collected by interviews of local officers (e.g. fire brigade, mayor, officer of disaster planning), document analysis (e.g. municipal meetings, policy plans), media analysis (news papers) and research articles.

Weighting and aggregation

The weighting procedure was one of the aspects of the Delphi study. The experts were asked to indicate to what extent the flood measures and actions could contribute to adaptive capacity. The result was that emergency planning and disaster management, social cohesion and joint floodplain planning are crucial elements for the adaptive capacity. The adaptive capacity scores are aggregated by an arithmetic mean since the indicators are ordinal scale.

Social flood impact intensity index

Indicators

To quantify the intensity of social flood impacts, data on flood characteristics, exposure and vulnerability are integrated. The data is standardized to a figure between 0 and 1.

Weighting and aggregation

The weighting procedure is one of the results of the Delphi study. Remarkably, there are two interpretations. Some experts argue that in particular flood characteristics determine social flood impacts, while most of them attribute social flood impact intensity to vulnerability. The indices are aggregated according to the arithmetic mean. High flood index, high susceptibility index and low adaptive capacity score results in a high social flood impact intensity, while a low flood index, a low susceptibility index and a high adaptive capacity score results in low social flood impact intensity.

Interpretation of the social flood impact intensity index

When combining exposure data with social flood impact intensity index, every house will possess an indication of the social flood impact intensity. The higher the score, the more severe the flood is expected to impact on the family living in the house.

3.1.2.3 Methodology for estimation risk to loss of life

Lastly, some methodologies to estimate the risk to loss of life are explored (Vrisou van Eck et al. 1999; Waarts 1992; Jonkman et al. 2008; Vanneuville 2006; Penning-Rowsell et al. 2005.).

Methodology of Vrisou van Eck, as used by the Flanders Hydraulic Centre

The methodology used by the Flanders Hydraulic Centre to estimate the number of fatalities is based on research of Vrisou van Eck (1999) and is calculated by the formula:

N = fd*fw*A

N: Number of expected fatalities
A: number of people / m² in flood risk area
Fd: drowning factor in relation to water depth Fd= exp(1,16*depth (in cm) – 7,3)
Fw: drowning factor in relation to water rise
Fw = 0 when water rise <= 0,3 (m/h)
Fw = 0,37 * water rise – 0,11   when water rise is 0,3<w> 3,0
Fw = 1 if water rise >=3,0

This methodology considers water rise and water depth as indicators to loss of life. However, Jonkman et al. (2008) argue that other aspects like the warning and evacuation time, shelter, the collapse of buildings, velocities and susceptibility affect loss of life as well. In their review of existing loss of life functions, it can be concluded that susceptibility and adaptive capacity aspects are rarely considered.

Flood hazard research centre formula (Penning-Rowsell et al. 2005)

The method of the Flood Hazard Research Centre tries to meet this knowledge gap. It estimates injury and loss of life based on flood characteristics like water depth, velocity and debris factor. In addition, it includes area vulnerability scores, which is comparable to the adaptive capacity concept in this context, and people vulnerability, with a focus on the sick and the old people. For an in-depth explanation of the methodology, I refer to the article of Penning-Rowsell et al. (2005) 'Estimating injury and loss of life in floods: a deterministic framework' in Natural Hazards (2005/36).

Discussion

The use of aggregated indices is considered to be useful to:

- compare flood risk areas in time and space
- communicate weak spots
- set policy priorities
- evaluate flood measures and policy that aims to reduce flood impacts

The scientific contribution of the social flood impact tool (SFI-tool) to current research (like existing social flood vulnerability indices like Feteke 2009; Cutter et al. 2003; Tapsell et al. 2002,) is that the methodology attempts to include *all* aspects that affect social flood impact experiences, such as flood characteristics, susceptibility and adaptive capacity aspects.

Further research priorities of the tools are related to three types of drawbacks we currently face:

- knowledge gaps: empirical knowledge on the correlation between social susceptibility and social flood impacts is limited and is merely concentrated in the UK. Empirical knowledge on the correlation between adaptive capacity and social flood impacts was not found. And finally, the correlation so far between vulnerability and flood characteristics is unclear as well. These knowledge gaps hamper an empirically founded weighting procedures
- data gaps: the methodology aims to estimate social flood impacts at the micro level (district level) but data at that level is not available for all indicators (e.g. sick people). Furthermore, due to time and budget restrictions, adaptive capacity is not evaluated in-depth by looking at past experiences. In addition, there is no broad-scale database on social flood impacts in Belgium, which hampers the validation of the developed methodology.

3.1.3 Methodology for economic damage evaluation

Within the context of economic aspects, the elements-at-risk are mainly the built-up property and the economic sectors such as business and agriculture. For the assessment of the value of these elements at risk, different actions are being carried out:

- Determination of the different categories of flood damage to be included in the economic analysis
- Inventorying of elements-at-risk (infrastructures, important socio-economic activities)
- Development of cost relationship for various categories of damages
- Costs assessment of the impacts identified (net present value)

The economic evaluation methodology will be focused on the evaluation of the use values and more particularly on direct tangible losses (expressed on market prices).

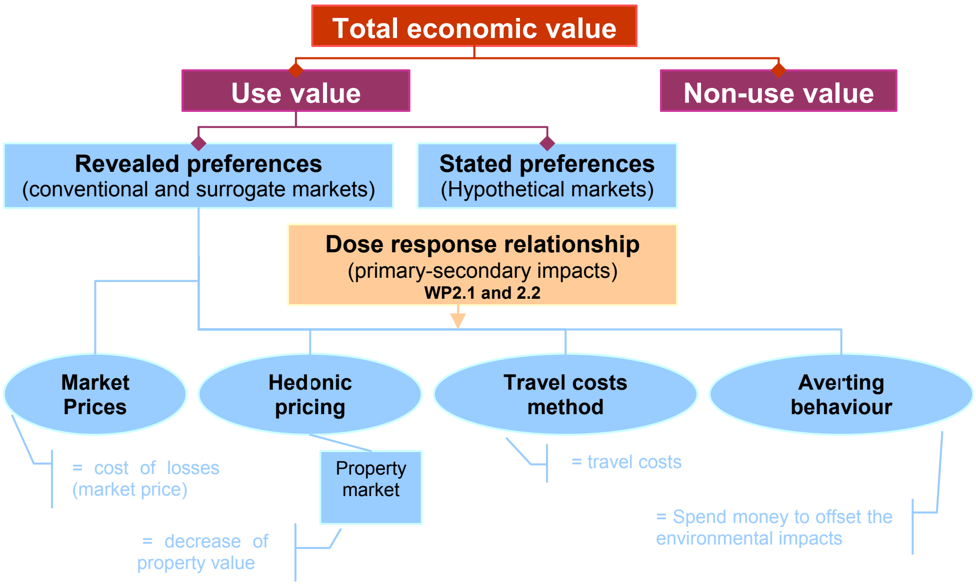


Figure 4: Categories of flood damage

3.1.3.1 Inventorying elements-at-risk

The study on economic vulnerability which was partly carried out during the description of the case study areas will be completed concerning the assessment of the damage costs. After inventorying the elements-at-risk (houses, industries, campsites) and analysing the economic costs of the impacts, the economic vulnerability of the studied zones can be highlighted. The type and extent of damage incurred through submersion by flooding will naturally vary according to the goods and activities affected. In other words, depending on the way in which the ground has been occupied and used in areas prone to flooding. The characterization of the issues is a fundamental stage in the modeling of potential damages.

3.1.3.2 Damage cost assessment

Five quite distinct stages were identified in the course of setting up this methodology.

Damage inventory and data collection

During the first stage, a maximum amount of information is gathered from different actors about the private and public goods which were damaged during previous flood events (damage cost per street, individual damage cost per good for certain localities…). These data were provided by the Disaster Fund.
In parallel, the data collection for the good characteristics of the commune of Esneux had been carried out (the surface area of each house, the cadastral income, …). These data have to serve to develop damage functions in order to compare these results with real data provided by the Disaster Funds. The Federal Public Service of Finance (Department of Income from Property) provided the cadastral data for the entire commune of Esneux. These data are required to draw up a GISmap for georeferencing damage.

Data treatment

During the second stage, several treatments of data were carried out. The data proceeding from the Service of Finance and the "Disaster Fund" will be processed along with the development of damage functions appropriate to our case studies and probably in the general case of flooding. The goal is to provide an optimal damage function, by aggregating the maximum number of characteristics concerning the flood event and the elements-at-risk (in our case, the houses).These data will be used, processed and compared in order to ensure optimal precision.

Statistical analysis

The third step consisted in analysing the data from a statistical angle, such as highlighting certain conclusions and trends. The data were therefore analysed for the commune as a whole, according to the type of goods that were damaged, but also according to the spatial distribution of the damage over the different villages in the commune. This treatment allows us to focus on the most relevant subjects and to have a clear view of the project s objectives.

GIS analysis

For the purpose of a cost-benefit analysis, the calculation of a unique value (total amount of damages or damages avoided) might be sufficient. But it is also very important to have a representation of where the damages occur and a spatial distribution of flood damages. The information, where hot-spots should be expected may be important for example for civil protection. Damages and risk mapping can be carried out nowadays relatively easily by means of Geographic Information Systems (GIS).

3.1.3.3 Existing damage functions for housing

The vulnerability of the elements-at-risk (depending on their susceptibility, adaptative capacity and resilience) is introduced in the risk analysis by means, of damage functions. Depending on the availability of data, the damage functions will be elaborated or adapted in order to allow the assessment of different categories of damages: houses, businesses, agriculture…. Different types of damage functions already established can be found in the scientific literature. The object of the development of these damage functions is to represent direct damages caused by flooding on the residential property as a function of certain characteristics (characteristics of the built-up property (with or without basement) and characteristics of the flood (water depth, velocity, duration of the flood).

In the current state-of-the-art of flood damage evaluation, water depth is often used and incorporated into damage functions, as it seems to have the most significant influence. Some approaches also consider other characteristics such as e.g. in the UK, where depth-damage functions are differentiated in short and long duration of flooding (Penning-Rowsell et al. 2003) or in the Netherlands, where also the velocity is incorporated into damage functions for residential properties (Kok et al. 2004). Since some of these variables are also difficult to measure or estimate, inundation depth is still the major variable for calculating flood damage today (Smith 1998, 40f)

There are two basic ways of calculating damages which require proper types of damage functions. In some approaches first the total value of elements at risk is evaluated. The actual damage is then calculated by means of relative damage-functions, showing the damaged share of this total value to inundation depth. Other approaches do not determine the total value of elements at risk at any time. Instead, the calculation of damages is carried out directly by means of absolute damage functions, which give the absolute value of damage depending on inundation depth. The value of the assets is already integrated in the damage functions.

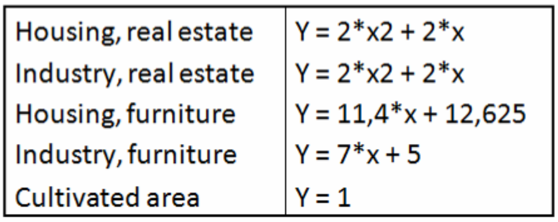
In the framework of this research, these established functions are validated by applying the experimental data (on case study of Ourthe basin). It is chosen to establish relations between absolute damages function and the water level recorded during past flood events, in relation to the first level of the building beyond basement level.

The methodology of the development and validation of these damage functions follows 3 steps: (i) a literature review, (ii) the application of a number of damage functions based on the results of hydrodynamic modeling for past flood events on the case study of the river Ourthe and (iii) the comparison of computed damage with reference values collected by the Belgian “Disaster Fund” after real flood events.

After a wide review of literature on existing damage functions, two damage functions are selected. The most appropriate for our study are:

“Rhine atlas” (CIPR, 2001)

For the different buildings and goods, a certain number of these functions (where “Y” is the percentage of damages and “x” the water depth (m) recorded during the flood event) have been retained whose results may still vary within a fairly wide margin (see also the document “Methodology to develop damage function” on http://dev.ulb.ac.be/ceese/ADAPT/public_section/download.php) The damage functions have had to be adjusted to the categories of use selected.



Housing, real estate	Y = 2*x2 + 2*x
Industry, real estate	Y = 2*x2 + 2*x
Housing, furniture	Y = 11,4*x + 12,625
Industry, furniture	Y = 7*x + 5
Cultivated area	Y = 1

Table 3: Damage functions

We chose firstly to determine damages in housing and for this reason have used the function “$Y=2x^2+2x$”. The damage function of the Rhine atlas provides a relative result in damage degree in percentage. The relative damage represents the percentage of the total value of goods that is lost as a result of the flood event. Consequently, combined with the monetary value of the elements-at-risk (the house value (HV) in this case), the relative damage may be translated into an absolute economic loss. This will allow us to make comparisons with these results and actual damages recorded and declared during the recent flood (2002) in our case study of the Ourthe basin provided by the "Disaster Fund."

The house value (HV) was studied and two empirical functions were determined to be inserted into the damage function (see the document "Evaluation of the house value" on http://dev.ulb.ac.be/ceese/ADAPT/public_section/download.php). The aim of damage functions is to predict the damages which will be incurred by introducing one of the features of a flood event (water level) and one of the features of the dwelling affected (value of the property). Within the context of the ADAPT project, we wanted first of all to establish a mathematical function for a selection of properties whose size was equivalent to the whole of the commune of Esneux, by using certain features of the property (habitable surface area, volume,…) and secondly, we wanted to estimate the value of a property individually. Since then we have tested all the assessment methods and have kept those which provided a result that was closest to the value (in €) of the price asked for at the time of sale. The methods for assessing property using a unit price per square metre and the surface area or using the cadastral income with our empirical function are the two methods which seemed to give values closest to the prices asked for in a sale. The two function tested to evaluate the house value are the following :

- HV = Surface (m²)*38,76 (€/m²)*30
- HV= 125.000+112*cadastral income (CI)

This will allow us to make comparisons with these results and current damages recorded and declared during the recent flood (2002) in our case study of the Ourthe basin provide by the "Disaster Fund."

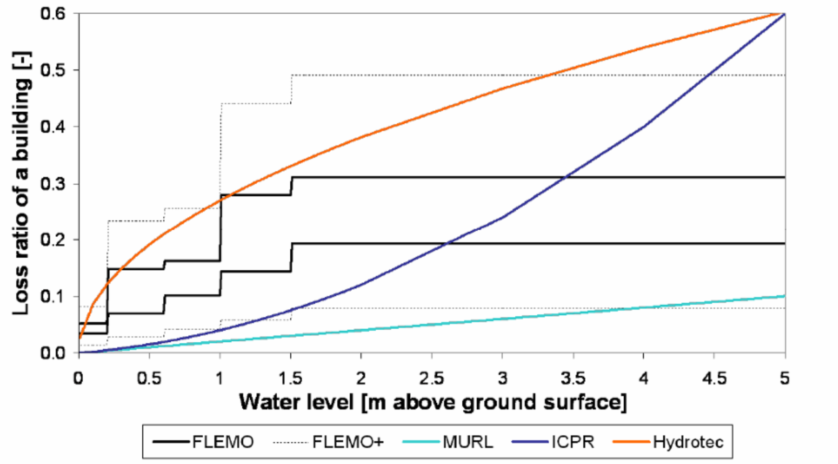
FLEMO Function: Flood Loss Estimation Model

The model is based on empirical data from 1697 private households in the German states of Saxony, Saxony-Anhalt and Bavaria that were affected by a severe flood in August 2002.

Large datasets about flood losses and influencing factors were collected by computer-aided telephone interviews in private households and companies (e.g. Thieken et al., 2005; Kreibich et al., 2007).

FLEMO and FLEMO+ can be applied to the micro and meso scale. Is based on a damage model of inundation depth, building type and building quality (FLEMO), and an extended version considering the additional damage factor "precautionary measures" and ""oil contamination" (FLEMO+).

The meso-scale damage model FLEMO+ including additional damage factors (oil contamination, precaution) yielded an improvement of the damage assessment (H. Apel et al, 2007).



Source: Thieken et al. – submitted to J. Hydrol.

Figure 5: Comparison between some damage functions taking into account the loss ratio of the building and the water depth

For the flood in 2002, meso-scale validations show that the new model outperforms other loss models currently used in Germany. However, when applied to other flood events FLEMOps tends to overestimate the losses (Thieken et al., 2008).

Damage function for industries

The available methods for the ex ante losses for industries are clearly less accurate than the available methods for calculating the damage to such residential buildings. The industry sector is complex and diverse. Moreover, the number of claims - on the basis of which functions are developed - is more restricted for businesses than for residential buildings. (Vanneuville et al, 2006)
The basic version of the FLEMOcs model takes into account the explanatory variables : water depth, economic sector and size of business (Kreibich et al, 2009). The FHRC has a specific damage function developed for small working areas (eg printing houses and furniture constructors) and warehouses. There are also three versions for each function : 'low susceptibility band', 'indicative susceptibility band' and 'high susceptibility band'. The difference between these three damage functions provides in principle a measurement of uncertainty for the considered loss function. (Penning-Rowsell et al, 2005)
Figure 6 gives an overview of the available damage functions for the industrial sector and includes both the damage to household effects (stocks and equipment/machines) as well as to the building.

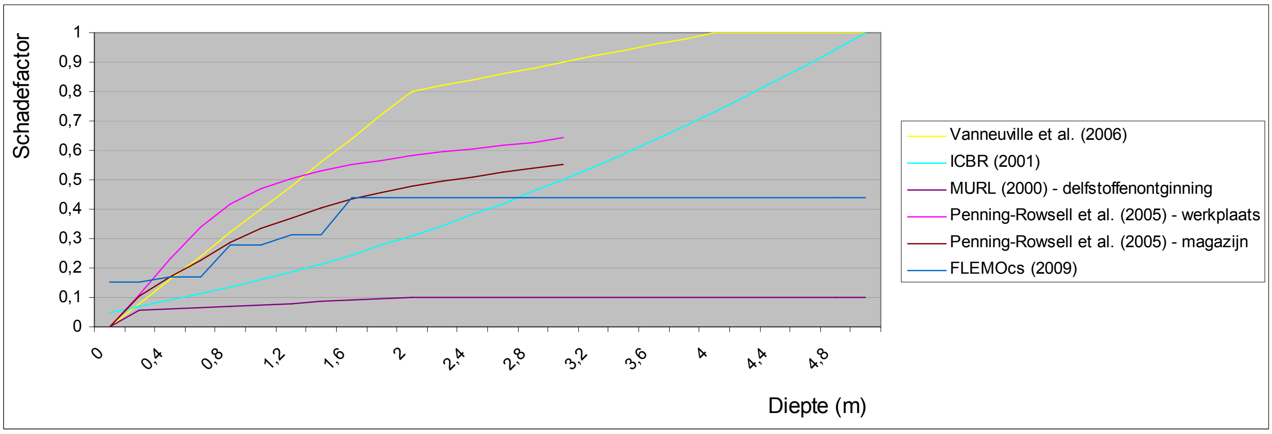


Figure 6: Overview of damage functions in industry

Existing damage functions for non-residential assets

The land use map, based on the regional plan and the different ways in which land is used, makes a distinction between pasture land and arable land. On the basis of the rural economy map showing various plots of land, arable land is broken down further into the different crops grown in a particular area. The basis for calculating the expected revenue loss is the net revenue from growing one hectare of a certain crop. These net revenues are taken from De Nocker et al (2007) and are supplemented by specific assumptions per culture. The most important assumptions are listed below.

Grassland

Grassland has a relatively high resistance to flooding. The grass usually recovers but with an interruption in growth. Flooding affects the quality of the harvest cut. The losses depend on the growth stage of grass and the duration of the flooding. Different grass species have different tolerance. For grassland there is no need to take water depth into account. It follows from this that the grass growing at the time of flooding would be cut and destroyed. Table 4 contains the average yield losses for intensive and extensive grassland.

Periode		***Loss in revenue (in €/ha) for intensive grassland***	***Loss in revenue (in €/ha) for extensive grassland***
Winter (October – March)	≤ 1 week	23	19
	>1 week, but ≤ 2 weeks	47	39
	> 2 weeks	123	104
Summer (April – September)	≤ 1 week	142	120
	>1 week, but ≤ 2 weeks	242	204

Table 4: Loss in revenue for intensive and extensive grassland

Other crops

In general, losses in crops are fundamentally related to the period of the flood event. For example, De Nocker et al (2007) state that in the summer period (from April to September) a crop of maize will be completely lost through flooding. Winter cereals are sown from the autumn onwards and would be lost through winter flooding. Potatoes, sugar beet, vegetables, fruit and trees are considered lost in a flood in the growing season. Table 5 summarizes the projected revenue losses for the crop.

Crop	***Periode***	***€/ha Loss in revenue***	***€/ha extra costs***
Maize	Winter (October – March)		266
	Summer (April – September)	1.159	53
Grain	Winter (October – March)	998	53
	Summer (April – September)	865	53
Arable crop	Total loss	2261	
Fruit and trees	Total loss	18,818	

Table 5: Loss in revenue and additional costs (in € / ha) for several crops in a single flood

3.1.4 Methodology for ecological impact evaluation

3.1.4.1 Introduction

We present a methodology to evaluate the constraints of flooding characteristics on floodplain vegetation. Flood vulnerability/tolerance maps are calculated for different vegetation communities and for different flood types (events). Flood time series are classified into flood type occurrences and combined with the vulnerability maps. The cumulative impact is calculated and visualized. The most direct impact of inundation on vegetation is drowning of vegetation through oxygen depletion in the root system. This mechanism will be taken as the basis for the practical vulnerability assessment method. Inundation is a driving force for many other processes that can alter the abiotic conditions of an ecosystem. Whether changes to vegetation communities are permanently or temporal is dependent on the characteristics of both the inundation and the inundated site. Also the ecosystem's biotic component is an important factor (e.g. succession stage). The theoretical assessment of ecological vulnerability to flood characteristics seems straightforward when the different mechanisms and variables are considered individually. However when assessing this vulnerability in climate context, we are confronted to practical challenges of data availability and model limitations.

- The timing of the flood is probably one of the most determining factors. Flooding during winter periods has lower impact because of lower water temperatures, which enables a higher dissolved oxygen content and a lower microbial oxygen demands (lower microbial activity) both decreasing the probability of oxygen depletion during floods. Inundations during winter have less effect on the survival of plant species the vegetation is not in active growth stage, which means that damage of eventual oxygen depletion is much lower. During active growth, flooding can have negative effects on plant survival. Especially species with a low regeneration capacity will experience negative effects. These species mostly occur on moderately moist to dry soils (Runhaar et al., 2004).
- Frequent flooding and/or permanently water logged soils will promote the settlement of species that are adapted to soil oxygen depletion. If current vegetation types are subjected to a frequent flooding regime, there will be a gradual shift to flood tolerant vegetation types.
- Flood depth is only determining for species that are capable to transport oxygen to their root system (like sedges and pitrus). If water levels exceed the vegetation height, this system of oxygen transport is disabled and of no use.

As a result of past climatic changes and geographical barriers (Alps, Pyrenees), European ecological communities have a relatively low percentage of flood-adapted species Compared to other parts of the World (Junk 2003). Frequent inundations will promote a high occurrence of adapted species. In areas that are flooded less frequently (less than once each year), there will be no selection of inundation tolerant species. The time the vegetation needs to recover from flooding depends on the vegetation type and thus the return period determines which vegetation types can occur given a certain regular return period. Vegetation types of dynamic systems can recover rather quickly, whilst vegetation types of low-dynamic environmental conditions (some forest types) can need recover times of decades to centuries (Runhaar et al., 2004). Bottom-line is that vegetation types can occur if their recovery time is less than the return period. Finally, the potential to recover and recolonise is also dependent on spatial aspects such as fragmentation-level, size of the area. The micro topography of an area can be determining to the survival of relic populations (patches), which can recolonise the area afterwards.

The impact of flooding on ecology is determined by the totality of all flood events. The elements at risk are thus exposed to a cumulative impact that is spatially differentiated. Concerning flood duration, frequency and timing, there is a wide range of classifications used in literature on floodplain ecology. In addition, they use rather qualitative descriptions of impacts on vegetation. It is evident that nature does not follow any arbitrary classification and associated assumptions and that uncertainty is an inherent part of ecology. In this aspect, there is also an indirect relation between climate change and phenomenology of nature. Rising temperatures do not only affect hydrology, but also the timing of the active growing season, soil microbiological activity and microbial species composition.

To make a pragmatic abstraction of a flood event, we classified 12 arbitrary flood type conditions (duration, timing, depth), for which an additional frequency/regularity classification is calculated. Each of the 12 basic flood types can occur frequent (annual), regular (bi-annual), irregular (every 2-5 years) or incidental (more than 5 years between occurrences). If a certain flood type occurs regular or frequent, vegetation is likely to adapt to these conditions.

3.1.4.2 Vegetation types and flood vulnerability

Many vegetation types can occur in potential and/or effectively flooded areas. But their occurrence is not necessarily related to flooding. In many cases, flooding characteristics are often of minor importance. In case of non-flood tolerant vegetation, it is often not known to which extent a vegetation type is recovering from past extreme events. A problem for the determination of flood tolerance is that many flood parameters are relevant to potential effects on vegetation (return, period, season, duration, depth, flow velocity, sediment load, dissolved nutrients, alkalinity, sulphate concentration, soil texture and soil moisture). For many of these parameters, there is little quantitative knowledge on the cause-effect relations of changes in these parameters. Many parameters are interlinked through various processes and therefore it is hard to distinguish cause-effect relations in the field. The knowledge on the flood tolerance of the different vegetation types is collected from different literature sources and expert judgment. All vegetation types that are potentially flooded are included in the knowledge tables. For each of the 82 vegetation types, we determined the ecological vulnerability to the different flood types (Appendix D). This included the sensitivity for "drowning" and the sensitivity for (internal) eutrophication and acidification. The Biological Valuation Map (BVM) is used as a basis for the vulnerability maps. The methodology for the determination of flood type impacts based on the Biological Valuation Map is visualized in figure 7. The vegetation classification units of the BVM are not recognized or are not even comparable to standardized international vegetation classifications. Therefore a translation needs to be done to the 82 vegetation types.

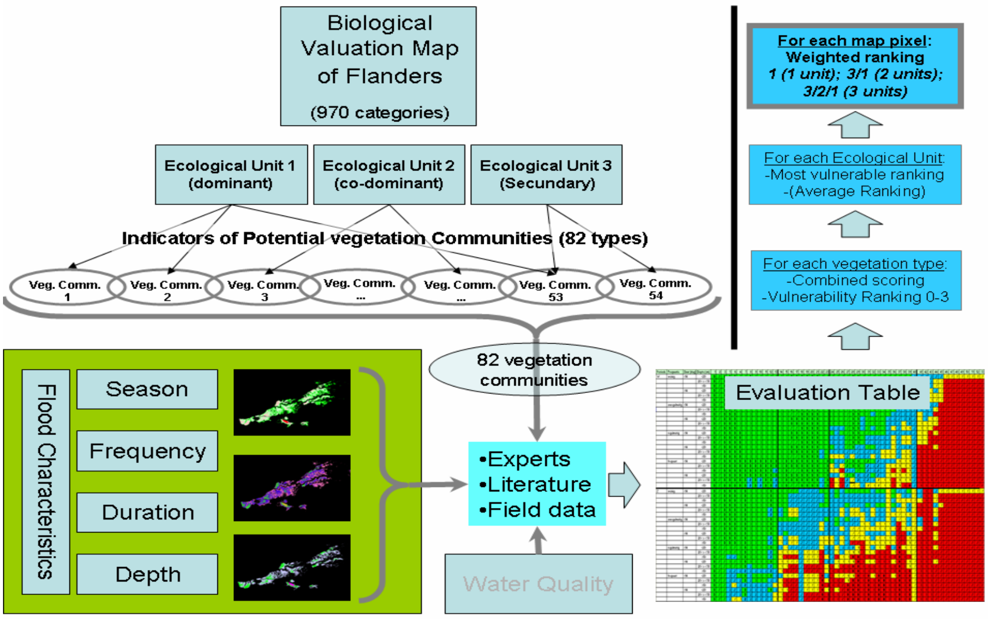


Figure 7:Basic methodology for the determination of flood type impacts on vegetation maps, derived from the Biological Valuation Map.

The ecological vulnerability analysis considers the first three layers of the BVM. Each parcel can thus have a combination of layers. Each of the 970 mapping categories can indicate up to 5 different vegetation types. In many cases, the vegetation types derived from the second and third layer of the BVM, are confirming the vegetation types from the first layer. Because the actual vegetation type in the field is uncertain, we incorporated this uncertainty by designing 5 different weighting schemes. The total Ecological vulnerability maps have been generated for the 48 different flood types and for 5 different weighting methods. The weighting method used further on in the report selects the most sensitive potential vegetation type for each of the three layers, which is then averaged. The ecological vulnerability maps, based on the biological valuation map, have been generated for the Flemish region and for each of the 48 flood types.

Post-processing of hydraulic data allows to map the relative number of occurrences of each flood type for a given time window (e.g. 25 years). The cumulative flood impact of the past 25 years is considered as the reference situation to which climate change and adaptation scenarios need to be compared. Therefore this reference situation should be normalized for interpretation and comparison to changes in flood conditions.

3.1.5 Methodology for integrating hydraulic modeling results with socio-economic damage and ecological impacts

A consistent methodology for evaluating flood risk has been developed for the Ourthe case study, taking benefit of data generally available throughout the whole Walloon Region. Therefore, the methodology is widely applicable to other rivers and catchments within the Walloon Region and, provided limited adaptations are incorporated, the procedure may apply to other regions and basins as well. Therefore, it was decided to use the methodology developed for the Ourthe case study as an example of the procedure of integrating hydraulic modelling results with socio-economic damage and ecological impacts.

The procedure consists in a modelling chain, combining detailed inundation modelling with high resolution land use data to evaluate the exposure and the inundation consequences, both in terms of social impact and economic damage. Strictly ecological impacts of floods are not yet incorporated in the analysis, primarily focused on urbanized areas.

3.1.5.1 Micro-scale approach

While such risk analyses are mostly undertaken at a macro- or meso-scale (FloodSite 2005), the developed procedure works at a micro-scale, meaning that the considered assets are the individual buildings or facilities. Such a refined analysis is relevant to reliably assess the effectiveness of local measures for protecting individual inundated areas. It also requires an overall consistency in terms of resolution and accuracy between the expected results and both the flow modelling and available input data.

Therefore, taking benefit of recent advances in the availability of data from remote sensing techniques (Van der Sande et al. 2003), the quasi three-dimensional flow model WOLF 2D (HACH-ULg) has been used to provide highly accurate flood maps detailing the distribution of water depth and flow velocity in the floodplains as well as representing the hydrodynamic interactions between the main channel and the floodplains. Consistently with the high resolution Digital Surface Models (airborne laser altimetry) exploited to represent floodplains topography, computational grids as fine as 2m by 2m were used, leading to accurate predictions of the flow pattern at the scale of individual buildings.

The obtained hydraulic results serve as direct input for the subsequent exposure and impact analyses. They are combined with high resolution land use database, exploited to identify each building or facility individually and to characterize their vulnerability using a social vulnerability index and economic damage functions.

3.1.5.2 Overview of the risk analysis procedure

In the developed risk analysis methodology, the main components of flood risk are sequentially evaluated following the procedure detailed in figure 8, which also highlights input data such as hydrological statistics, topography, land use, vulnerability and value of the goods. The procedure involves basically the four steps described below:

- first, quasi 3D hydraulic modelling is performed to translate the expected discharge for each return period (or exceedance frequency) into detailed inundation characteristics, including inundation extent, water depth and flow velocity;
- second, based on a geomatic analysis, inundation extent is combined with high resolution land use data to evaluate the exposure, i.e. identify the affected assets for each exceedance frequency both in terms of affected people and affected buildings or facilities;

- third, considering the social vulnerability of affected people and the societal adaptive capacity, the inundation characteristics enable to deduce the relationship between social impacts and exceedance frequency, thus the social risk;
- similarly, using appropriate damage functions as well as estimates of the value of the affected buildings and facilities, the direct economic damage is estimated as a function of the exceedance frequency, expressing hence the economic risk.

The paragraphs hereafter specifically focus on the description of the procedures developed for combining the different sources of geographic data required for conducting the analysis.

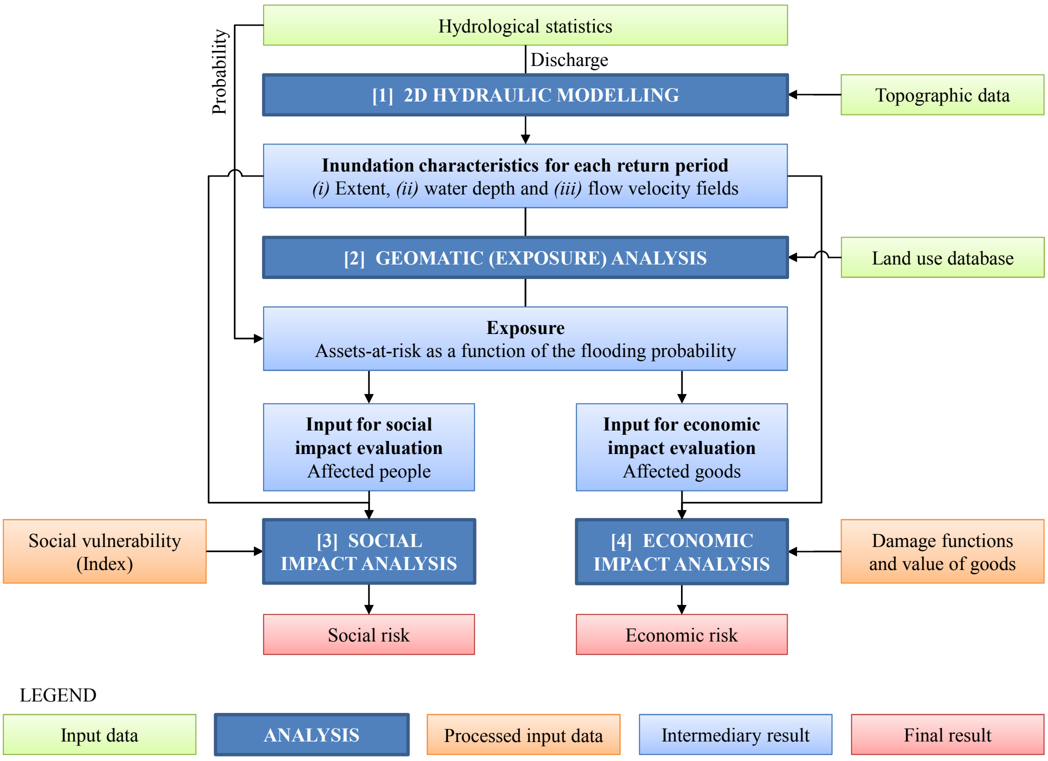


Figure 8: Methodology and flow of data for hydraulic modelling, exposure analysis and risk evaluation.

3.1.5.3 Hazard evaluation

Flood hazard is the relationship between exceedance frequency and flood intensity, expressed by inundation extent, water depth, flow velocity and, possibly, flood duration as well as rising rate. Hydraulic simulations necessary to compute inundation characteristics are described in section 2.

Prior to running flow simulations, boundary conditions have to be set. The discharge is prescribed at the upstream end of the simulation domain. Its value is derived from statistical analysis of the river flow time series, providing the flow rate associated to any exceedance frequency (generally expressed in terms of a return period in years). For the Ourthe case study, a Gamma distribution was adjusted based on a 30-year long time series of measured discharge values. Effect of climate change will later be incorporated through adjusting this Gamma distribution as a function of the results of the rainfall-runoff model SCHEME run by RMI in the CCI-HYDR project (Baguis and Roulin 2009).

Free surface elevation is prescribed as a downstream boundary condition, based either on the simulation result of a downstream reach or on a stage-discharge curve at a gauging station. Since relatively short reaches are considered, without main tributaries, the lateral inflows are neglected.

For each exceedance probability of excess or return period, the corresponding discharge was used in the detailed quasi 3D hydraulic model as an upstream boundary condition, while measured stage-discharge relationships were used to prescribe downstream boundary conditions.

Available observations also show that the considered lower part of river Ourthe is affected by long duration floods (above 12h) characterized by low rising rates.

3.1.5.4 Available data for vulnerability analysis

In order to deduce the exposure from the inundation characteristics, land use database are exploited, while other geo-referenced datasets are additionally needed to evaluate the susceptibility of elements-at-risk. The geometric and semantic characteristics of these datasets are briefly described hereafter and summarized in Table 6.

LIDAR	Raster	High	Low	Hydraulic modelling: topography
Top10v-GIS	Vector	High	High	Exposure analysis: type of assets
PICC	Vector	High	High	Exposure analysis: identification of assets
Statistical data	Vector	Low	High	Input for the social vulnerability index
Land registry	Vector	Medium	High	Input for estimating the value of the assets

Table 6: Main characteristics of the geo-referenced datasets exploited as input for the risk analysis procedure

Land use databases

In Belgium, there are several geographic land use data producers, the most important of which are: the Belgian *Institut Géographique National* - IGN and, for the Walloon Region, the *Service Publique de Wallonie* - SPW. Both provide accurate land use vector database, respectively named Top10v-GIS and PICC. The first one contains 18 layers related to information categories (e.g. land use, structure, hydrography...), while the PICC data set is based on stereoscopic aerial imagery restitution and a post processing enrichment with ancient database such as house number, street name…

Both PICC and Top10v-GIS data constitute detailed and accurate complementary spatial database at a very high scale (1:10000). The challenge is to extract the strong points from each database and to combine them into a single data set in order to identify with maximal accuracy the elements-at-risk (geometric aspect) and their type or use (semantic aspect).

Land Registry

The *Land registry* geographic database lists all private properties with their cadastral income, which constitute helpful inputs to estimate the economic value of the assets. Although geo-referenced, the land registry is characterized by a significantly lower geometric accuracy compared to *Top10v-GIS* and *PICC*. Therefore, land registry data are only exploited for their semantic contain, with the single purpose of estimating the economic value of the goods

Statistical data

The Belgian *National Institute of Statistics* (INS) provides database including socio-economic information needed for the evaluation of social and economic vulnerability, such as the number of inhabitants per statistical district as well as the number of elderly or financially deprived people, single parents or non-European residents. A statistical district covers typically 0.25 to 1km² and is the smallest level at which such socio-economic data are available. The latest Belgian national socio-economic population survey dates back to 2001.

3.1.5.5 Exposure Analysis

After determination of flood hazard, the next step consists in identifying the people and assets affected by the inundation, based on a combination of inundation extent and geographic database PICC. Subsequently, based on database Top10vGIS, each affected asset is classified into a category such as residential, public, commercial or industrial building, road or railway network ... This exposure analysis is based on an object oriented approach, in which the elementary objects are the individual assets (buildings).

Since the flow simulations are conducted based on a DSM, including over grounded structures, such as buildings, and not a Digital Terrestrial Model, water depths computed at the location of an inundated building are always zero, except if the building is overtopped, which would only occur for extreme flow conditions such as induced by dam break. A building is thus assumed to be affected by the inundation if neighbouring cells are wet.

Consequently, water depth and other flow characteristics affecting the buildings are not a direct result from hydraulic modelling, but they need to be computed by a specific post-processing. This assignment of flow characteristics (water depth and flow velocity) to each building may be performed in different ways by analysing the neighbourhood of each element-at-risk.

3.1.5.6 Methodology based on available data in Flanders

The methodology that is used for evaluating flood risk along the Dender is very similar to the methodology applied for the Ourthe case study that is presented above. Data have been used that are generally available throughout the whole of Flanders. The methodology is therefore widely applicable to other rivers and catchments in Flanders. For the purpose of the inundation modeling a Digital Elevation Model with grids of 4m by 4m was used. CadMap and the description of the function of the different goods according the Cadaster is used as the basis for objectivating the social and economic values located in the study area. Other input data were similar for both case study areas.

3.2 ORIGINAL FRAMEWORK DEVELOPED FOR ASSESSING ADAPTATION MEASURES

3.2.1 Selection of the adaptation measures

Several adaptation measures have been selected taking into account the specificities of the two flood areas, as well as the technical maturity of the measures and their availability on the market.

For the case study of the river Ourthe, the hydraulic effects of several local technical adaptation strategies have been computed by hydrodynamic simulations, showing the change (reduction) in flood characteristics as a result of the implemented flood defence measures. Those preliminary simulations have been run by HACH-ULg to demonstrate the feasibility of designing technical adaptation measures on the River Ourthe, in spite of the relatively limited storage capacity of the floodplains. Indeed, as a result of the narrow shape of the valley and the long duration of the floods in this lower part of the catchment area of the river Ourthe, flood control areas (FCA) have no chance to protect population and goods from flooding, since such areas would be completely filled with water long before the flood peak is reached. Therefore, the main riverbed and its floodplains must be designed to enable the flood discharge to flow through the most vulnerable localities without causing damaging overflows.

For the case study of the river Dender two sets of adaptation scenarios will be evaluated. A first set consists of three technical flood protection measures that are combined to three scenarios. Two of these measures, the replacement of the wears on the Dender and the construction of addition flood retention basins, will be executed in the years to come. In recent years flood management has undergone a paradigm shift towards giving rivers more space. The creation of additional storage capacity by the development of flood retention areas perfectly fits in this vision. Taking additional technical measures is, however, not straightforward as, especially (in the Dender basin) in Flanders, much has been done to limit both the occurrence and impacts from flooding. In addition it is ever more difficult to get the necessary permits for raising a measure that has a clear spatial impact. In response to these observations a second set of three scenarios focuses on complimentary measures like spatial planning, risk communication and flood warning and forecasting as this type of measures will become increasingly important.

3.2.2 Methodology for the evaluation of the direct costs of the adaptation measures

3.2.2.1 Introduction

In order to develop a methodology for the cost of the adaptation measures, a first imperative was to follow the guidelines described in the European Commission's guidance document "Common Implementation Strategy for the Water Framework Directive (2000/60/EC)". Indeed, one of the purpose of the Water Framework Directive is to "contribute(s) to mitigating the effects of floods and droughts" (Article 1), which is precisely the scope of the ADAPT project.

Other sources were of an equal importance to select the relevant cost components to be taken into account. Reports published by the EEA (1999) and the OECD (2006) provided, amongst others, guidelines on data documenting and cost-benefit analysis for environmental measures while studies focusing more specifically on flood prevention measures offered complementary insights. More generally, the "Guide to cost-benefit analysis of investment projects" commissioned by the EC (Florio et al., 2008) provided insights for the discounted cash flow approach used for evaluating the direct costs of the adaptation measures.

A further task was then to estimate the costs for the selected cost components.

In order to do so, a review of the literature was carried out. However, there were only few data to be found in the literature on the costs of the foreseen adaptation measures. Besides, the data found were mostly relevant at a macro-scale level, whereas the ADAPT project is conceived at a micro-scale level.

The literature review offered thus limited insights to estimate the costs of the selected adaptation measures at the micro-scale. It was therefore necessary to turn to an alternative method to estimate those costs.

An approach that was initially conceived as complementary to the literature review was then followed: entrepreneurs were contacted in order to provide expert judgement on the costs of the measures. This provided the necessary data on the costs of the measures, although those data should be used with care, considering the fact that they rely on expert judgement.

3.2.2.2 Costs components

This section is dedicated to identifying the cost components that are relevant for evaluating the direct costs of the adaptation measures in the framework of the ADAPT project. This work has been carried out on the basis of literature dedicated to environmental measures and flood mitigation. It provides thus a theoretical framework for the evaluation of the direct costs of the adaptation measures.

Selection of cost components

This section mostly draws on the general guidelines provided in the "Common Implementation Strategy for the Water Framework Directive" (further referred to as WATECO's guidelines), as well as on guidelines from the EEA (1999), the OECD (2006) and Florio et al. (2008). Those guidelines are complemented with reports and case studies focusing on environmental measures and flood prevention.

Unsurprisingly, it came out that **financial costs** with their three major components (**investment, operating and maintenance costs**) formed the core basis for the evaluation of the direct costs of flood adaptation measures. The other types of costs appeared less relevant (see also Defra and EA, 2006).

Indeed, amongst the other costs, **administrative costs**, such as defined in the WATECO's guidelines (2003, p. 18) referred mainly to "water resource management" (e.g. administering a charging system), and thus not to flood adaptation measures.

Along the same line, the **opportunity costs** (productivity losses that might be caused by the adaptation measures) can provide an alternative way of calculating the economic costs due to land use change (see, for instance, Brouwer and van Ek, 2004). Indeed, while the costs of expropriation and compensation payments are used to estimate the financial costs caused by land use change, lost earnings can provide an economic evaluation of those costs. However, the approach chosen for the CBA is based on the estimation of the financial cash flows due to the adaptation measures, rather than on the economic evaluation of the costs.

Regarding the **scarcity costs,** they mostly apply to water management as such and not to flood issues. For example, the over-abstraction of groundwater can lead to a cost for other users. Such costs are associated with the depletion of a resource beyond its natural rate. In the case of flood adaptation measures that is studied in the ADAPT project, this type of costs is therefore not relevant.

Finally, in the framework used for the ADAPT project, the **environmental impacts** are not incorporated in the cost-benefit analysis (CBA) but are taken into account in the multi-criteria analysis (MCA).

From what has been just exposed, the three major components of the direct costs for the adaptation measures are thus **investment, operating and maintenance costs**. Table 7 offers a synthetic view of the elements that could be taken into account for those costs. Besides, in estimating those costs, it is important to define the year to which the data apply, as well as to exclude taxes and subsidies.

	Unit	Quantity	Cost/unit	Total costs
Investment costs - equipment costs - associated costs - purchase of land - planning - site preparation - building and civil works **Operating costs** - material - labour - energy - additional: insurance, overheads **Maintenance costs** - material - labour - energy - additional: insurance, overheads				

Table 7: Data on the costs of the adaptation measures of the ADAPT project

Data processing

Once the data are collected, they should be processed in order to deal with inflation (when not expressed in base year).

Besides, a discounting rate should be chosen. The following formula can be used to express the costs as annuities:

$$total\ annual\ cost = \left[\sum_{t=0}^{n} \frac{(I_t + O_t + M_t)}{(1+r)^t}\right]\left[\frac{r(1+r)^n}{(1+r)^n - 1}\right]$$

where

t	is the period considered, in this case one year
I_t	is the total investment costs during period t
O_t	is the total operating costs during period t
M_t	is the total maintenance costs during period t
r	is the discount rate per period
n	is the number of years taken into consideration for the project

3.2.2.3 Literature review

The following step was thus to provide an estimation for the different cost-components based on a review of the literature. However, it came out of the literature review that there were only a limited number of research work that actually investigated the costs of the adaptation measures. Besides, and this was a major drawback, the relevant studies mostly adopted a macro scale, whereas one of the specificities of the ADAPT project is precisely to adopt a micro scale approach. This scale difference led to the fact that some costs that were relevant at the macro scale (like, for instance, infrastructure costs, see Brouwer and van Ek, 2004 for an analysis of costs related to floodplain activation at the macro scale) were not relevant at the micro scale chosen for the ADAPT project. Besides, the micro scale allows being much more specific in the evaluation of prices.

Those differences made that the literature found for adaptation measures at the macro scale level, while providing some general guidelines, could only be used in a restricted way as a basis for evaluating the costs of the measures at the micro scale level.

This scale issue, as well as the fact that we could not find any database on the costs of adaptation measures against flooding that were relevant at the micro scale level, underlines a gap in the data available for CBA analysis and policy support.

An approach that was initially conceived as complementary to the literature review was then followed: entrepreneurs were contacted in order to provide expert judgement on the costs of the measures.

3.2.2.4 Enquiry

The enquiry was based on the actual costs of the works to be carried out, and on the data needed, as shown in table 7.

As could be expected, the rate of reply to the enquiry was low, but it resulted in the identification and in-depth interviews of entrepreneurs that could provide expert judgement in the field of the 4 adaptation measures considered. The result of the enquiry was thus of a qualitative rather than quantitative nature. Our explicit demand to the interviewed entrepreneurs was to provide information based on average prices that are generally used in the profession for similar works. However, given the fact that the assessments are based on expert judgment, the results should be interpreted with the necessary care.

3.2.3 Decision support model

Authorities are charged to allocate the available resources to yield the utmost benefit for each Euro spent. In this context water managers are expected to develop and opt for those adaptation scenarios – be they simply one measure or the combination of several measures – which maximise welfare. In order to enable a sound evaluation of a scenarios contribution to welfare, all relevant effects – both positive and negative – need to be taken into account explicitly. This requirement, however, touches on an important shortcoming in the existing decision making practice. A partial inclusion of effects – most of the time the assessment of scenarios is solely based on material effects – may result in a suboptimal decision in terms of risk reduction.

Review of existing decision making practise reveals that not all relevant effects are assessed. Indirect and intangible effects of flooding to social and ecological systems are largely disregarded (Meyer and Messner, 2005). The same holds for the assessment of the non-flood related effects on society like e.g. visual disamenities from the construction of a dike. The problem with the indirect and intangible effects of flooding on social and ecological systems is that the methods for quantifying the extent of the effect are experimental.

A second observation is that the integration of effects is complicated as the effects quantified are expressed on a variety of scales. Some effects may be expressed in monetary terms, others are quantified on a tailor made ratio scale and still others are expressed semi quantitatively. Integrating the effects that are expressed on different scales requires explicit value judgements. Very often these judgements are not straightforward. Policy makers could make the necessary deliberations, but they are rather reluctant to take this responsibility. In principle the general public could be consulted, e.g. in the framework of a social cost-benefit analysis (SCBA). Doing so, however, is often a relatively laborious and expensive exercise. Because of this a SCBA is virtually only carried out for major projects. The number of effects that is explicitly considered, and thus the number of deliberations to be made, is therefore often kept to a minimum.

The ADAPT project deliberately seeks to extend the number of effects that is considered for the assessment of flood control scenarios. It does so by the development of assessment methods for quantifying the impact of flooding to social and ecological systems. The resulting increase in the number of non monetised effects, however, complicates the integration of the effects that characterise a scenario and consequently also the selection of the most desirable scenario.

In order to be able to structure and integrate all relevant information, so as to enable welfare maximising decision making, an extended cost-benefit analysis (extended CBA) based decision support model has been developed and is described in the following section. The model offers various options for carrying out a comprehensive Monte Carlo based uncertainty and sensitivity analysis as channelling uncertainties is an important part of the decision making process.

3.2.3.1 Description of the decision support model

The extended CBA based decision model consists of three modules: an extended cost benefit analysis, a sensitivity analysis and an uncertainty analysis. The features of these three modules are discussed below. The model developed and used for the evaluation of the various adaptation options requires specific data of the baseline scenario and adaptation scenarios as an input. The net effects of each adaptation scenario are calculated automatically, using various assumptions on the project horizon, discount rate, economic growth and various population dynamics.

Extended cost benefit analysis

The development, selection and fine-tuning of welfare maximising scenarios requires a CBA based decision framework in order to go beyond the simple ranking of two or more scenarios which cannot be facilitated by a multi-criteria analysis (MCA). A CBA requires the 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 cannot be monetised need to complete the monetary evaluation; it is extra information that certainly has to be taken into account. To handle this, the decision support model developed takes the form of an extended CBA. This decision framework prioritises the use of monetised effects but offers an MCA based framework for presenting and dealing with non-monetary information in a balanced way, so as to make sure decisions are made on all information available. (Brouwer and van Ek, 2004)

The extended CBA is divided into different steps. In the following sections, each step is described.

Problem definition and development of the decision matrix

The first step of the extended CBA consists in defining the problem. In our case the problem is "what set of measures is best suited to reduce flood risk from a welfare point of view?" On this basis the evaluation criteria are set and the scenarios are selected that are ought to solve the flood problem. Next, all scenarios are attributed a value for each of the evaluation criteria. The evaluation criteria used are all important effects which the flood control scenarios considered have on society. On the one hand there are the investment and operating costs of the measures of which the scenarios are composed. On the other hand there is the avoided flood risk to economic, social and ecological systems. If the scenarios considered have other important effects these should be integrated in the decision matrix as well. The quantification of the evaluation criteria per scenario is to an important extent based on the methodologies discussed in this report.

Standardisation of the basic decision matrix

Standardisation is used to facilitate the comparison of the scenarios on the basis of the various evaluation criteria. The order of magnitude of the values attributed to the different evaluation criteria in the basic decision matrix need to be made comparable. Important in this respect is that the relation between the values attributed to the scenarios for a given evaluation criteria is not altered.

Various standardisation methods exist, each having specific advantages and drawbacks. In the framework of the analysis of flood control measures the 'interval standardisation' is opted. This means the standardised values are derived on the basis of an interpolation between a specific minimum and maximum value. Here a linear interpolation is used. Sensible minimum and maximum values are carefully selected on the basis of the (possible) minimum and maximum values of the scenarios, the baseline scenario considered.

Attributing weights to the effects

In order to derive a ranking for the scenarios considered and to execute an implicit CBA of the scenarios considered weights have to be attributed to the evaluation criteria. The weighing of the different evaluation criteria has a significant effect on the results of the assessment. For the results to be policy relevant it is important that the weights correspond to the preferences of the public. Hence, this is the part of the decision making process where stakeholder and decision maker participation is most crucial.

Nine focus group discussions have been held (3 in the basin of the Dender, 3 in the basin of the Demer and 3 in the basin of the Maas). The focus group discussions organised in the basin of the Dender took place in the framework of the regular basin council of the Dender and the environmental councils of the communities of Geraardsbergen and Ninove. During these discussions the participants, interested civilians and various stakeholder representatives, were asked to individually score the importance of 12 attributes of adaptation measures on a 7 point Likert scale (ranging from not important to very important). In addition more than 30 policy makers have done the same exercise. The importance of the attributes has been derived by analysing the scores attached to them. Next, the importance of the attributes has been translated into criterion weights.

The attributes have been chosen so as to be able to unequivocally relate the avoided economic flood risk to the avoided social flood risk. The people that participated in the scoring exercise value the importance of the expected avoided standardised social flood risk to be about 85% of the avoided economic flood risk.

The investment, operating and maintenance costs are expressed in monetary terms and thus readily comparable with the avoided economic flood risk. Possible side effects like the social and economic effects of expropriation, the creation of chances for nature development, impacts on navigability, impacts on amenity values[1] etc. have also been covered by the scoring exercise. These effects, however, have generally been designated as being somewhat less important than the reduction of flood risk. The side effects of measures are often very case specific and do not have a particular correlation with the observed or avoided flood risk. For the evaluation of the flood protection measures we have assigned weights to these parameters. These weights have been proposed by the researchers and do not necessarily correspond to the judgement of the relevant public. The weights attached to criteria like the investment, operating and maintenance costs and the avoided economic flood risk that are expressed in the same units are unambiguously geared to one another.

Ranking

The standardised basic decision matrix and the weights are combined. This results in a ranking of the scenarios. The scenario with the highest score is preferred over the other scenarios given the input values (values attributed the scenarios per decision criterion in the decision matrix and the weights per decision criterion) used and the standardisation carried out.

Implicit cost-benefit and cost effectiveness analysis

An MCA ranks the different scenarios. The scenario score provides an idea of how scenarios relate to one another in terms of the general preferences for the scenarios considered. The problem, however, is that an MCA does not say whether the benefits of the scenarios considered do outweigh related costs (whether the scenarios create or destroy welfare). If the costs of a scenario surpass the expected benefits the scenario should not be realised from an economic point of view. In order to overcome this disadvantage of an MCA, the model is extended with an implicit cost-benefit analysis.

The evaluation criteria 'avoided economic flood risk' and 'investment and operating and maintenance costs' are expressed in monetary terms. Weights attached to the evaluation criteria of the decision matrix permit to relate non monetised criteria to monetised criteria. On the basis of the standardised values for each evaluation criterion, the minimum and maximum values for the evaluation criteria and the weights attributed to each evaluation criterion all values can implicitly be monetised.

Adding up all costs and benefits indicates whether a scenario is ought to have a positive contribution to welfare or not, given the input values and assumptions used. The welfare effect is assessed by the economic net present value (ENPV) of the project. Also the cost-effectiveness of the scenarios considered is standard calculated by the model. A scenario that produces large net benefits may require an important investment. Similar net benefits may also be achieved at a lower cost. This insight is analysed by considering the cost-effectiveness of the scenarios considered.

Sensitivity analysis

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[1] Those natural and physical qualities and characteristics of an area that contribute to people's appreciation of its pleasantness, aesthetic coherence and cultural and recreational attributes.

The ranking of the scenarios is reassessed on the basis of a sensitivity analysis. A sensitivity analysis is used for determining the 'critical' parameters / values. The critical parameters are those whose variations, positive or negative, have the greatest impact on a scenario's performance A sensitivity analysis does not require any information on the uncertainty of any input parameters. Consequently, the resulting information only provides an insight in the robustness/variability of the results.

The decision support model automatically tests the sensitivity of the ranking of the scenarios to changes in the weights attributed to the evaluation criteria of the basic decision matrix. Next, there is also the possibility to analyse the impact of changes in a specific value of the decision matrix.

Sensitivity of the results to changes in the weights

The ranking on the basis of the weights originally attributed to the evaluation criteria is complemented by a number of alternative rankings on the basis of changes in the original weights. The sensitivity analysis provides as many alternative rankings as there are evaluation criteria in the basic decision matrix. Every evaluation criterion of the basic decision matrix is attributed once 50% of the total weight. The other 50% is allocated to the other evaluation criteria on the basis of the original weights attributed to the evaluation criteria. The choice for a 50% change, which is arbitrary, only serves to check how the results change.

Sensitivity of the results to changes in the decision matrix

The objective of this feature of the model is to analyse how the preferences for the scenarios change as a particular value of the decision matrix is varied between a certain minimum and maximum value. The idea is to identify any critical transition values in the selected interval. A critical transition value for a particular value of the decision matrix is a value, keeping all other input parameters equal, for which two scenarios perform equally well. A slight increase or decrease in the value, however, leads one scenario to outperform the other and visa versa.

One particular value of the decision matrix is selected and varied between a certain minimum and maximum value. This minimum and maximum value can be freely selected. The scores of all scenarios considered are calculated 100 times for a slightly different decision matrix since the selected value varies from minimum to maximum. The evolution of the scores for all scenarios considered is plotted in a graph. This graph shows how the scores of, and thus the preference for, certain scenarios changes as the value of a specific value of the decision matrix changes. This is an interesting exercise to test the sensitivity of the scores and ranking to changes in key and/or uncertain values.

Uncertainty analysis

The ex-ante assessment of flood control scenarios is not without problems. The outcome of the scenario assessment is only a forecast. The results need to be formulated in a conditional way, "given that input parameters (the values of the decision matrix as well as the weights attributed to the evaluation criteria) used in scenario x are …". The input parameters are all somewhat uncertain. There are different types of uncertainty in the ex-ante appraisal of scenarios to limit the impacts of flooding: uncertainties in the knowledge of economic, social, ecological and physical systems, shortcomings in the way the economic, social, ecological and physical systems are modelled and, finally, data limitations. Tracking uncertainty is important for facilitating sound decision making.

Uncertainty analysis can be broken down into three phases:

- Identification of the various sources of uncertainty
- Quantification of the uncertainties identified

- Reassessment and discussion of the results in the light of uncertainty.

The uncertainty margin of the values of the scenarios for the evaluation criteria as well as the weights attributed to the evaluation criteria need to be inserted into the decision support model. The uncertainty margins specified per evaluation criteria and per weight are ought to correspond to the 95% confidence interval.

The influence of the uncertainties on the outcome of the scenario assessment is evaluated on the basis of a Monte Carlo based uncertainty analysis. The scores and ranking of the scenarios is calculated a 1000 times on the basis of the original decision matrix and weights which are randomly changed on the basis of the corresponding 95% confidence intervals. The output of this uncertainty shows the chance a certain scenario has to rank first, second, etc. when due consideration is given to uncertainty.

3.2.3.2 Discussion of the decision support model

The decision support model developed in the framework of the ADAPT project is not a novelty in the sense that it mainly puts into operation existing decision support methods. Nevertheless, the model definitely has an added value for assessing and prioritising flood control measures that are described by multiple, not readily comparable effects. This is certainly true for the projects for which there is no funding available to carry out a social cost-benefit analysis (SCBA). A SCBA is virtually only carried out for major investment projects or projects that may be subject to important social resistance. This implies that most decisions are likely to be less considered, overlooking effects that are or cannot be monetised.

The value of the extended CBA model is that it combines a completely automated MCA with an implicit CBA. Where it is impossible to say whether a scenario is desirable on the basis of an MCA, the implicit CBA tries to overcome this drawback. The model also provides valuable tools for mapping the sensitivity and the uncertainties of the results.

A crucial point, and a weakness of the method, is the standardisation of the decision matrix on the one hand and the weighting of the evaluation criteria on the other hand. These actions, however, are inherent to the assessment of scenarios that are described by multiple, not readily comparable effects. Both the standardisation and the weighting are somewhat arbitrary. The choice of the standardisation procedure and the definition of the most meaningful minimum and/or maximum values require careful attention as these can have a meaningful impact on the outcome. Attributing weights to the evaluation criteria comes down to fixing the importance of one criterion to another. The choice of the weights implies a value judgement that definitely has a crucial impact on the preference ordering of the scenarios. The problem is that the weights selected should reflect the preferences of the public. Reducing the arbitrary aspect of the results thus requires finding out from the public where their preferences lie.

A special point of interest for the popularisation of the tool, increasing the in-depth assessment of policy options, would be the determination of the monetary value of a unit of social flood impact that can be used in any assessment in Belgium. Recommendations on how to derive such a value are provided in the section policy support.

The spatial distribution of flood risk is not explicitly considered in the decision support model although this can be very useful for optimising the scenarios. The assessment framework developed by the ADAPT project, however, does include a complementary analysis of the spatial distribution of flood risk. The social, economic and ecological risk assessors complement the outcome of the scenario assessment on the basis of this extended CBA model with an analysis of the risk maps developed by them.

3.3 RESULTS OF APPLICATION OF THE ORGINAL METHODOLOGY TO TWO CASE STUDIES

Two case studies have been considered for the ADAPT project. The selection criteria of the case studies are:

- the historic of previous flooding events
- the extent of the damage caused
- the availability of the information about the stock at risk and the damage occurred

These two case studies have been evaluated at the micro-scale level (level of the houses)

3.3.1 Case study Ourthe

3.3.1.1 Hydrological / Hydraulic characteristics – Baseline scenarios

The first case study considered covers two neighbouring reaches of the lower part of river Ourthe in the Meuse basin (Belgium). These meandering reaches, between the municipalities of Esneux and Tilff, are situated a few kilometres upstream of the mouth of river Ourthe into river Meuse and the corresponding catchment area covers about 2900km² (see figure 9). The total length of the simulated reaches is 16km.

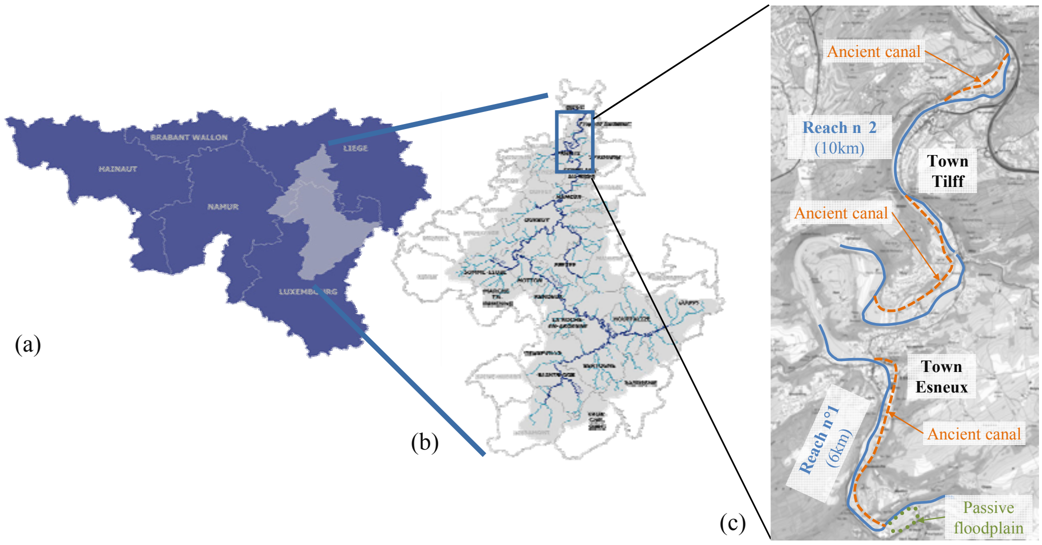

Figure 9: Location of the case study of river Ourthe: (a) Southern part of Belgium, (b) Sub-basin of river Ourthe and (c) case study area.

Historic flood events and validation opportunities

Over the past 20 years, four major floods were recorded along the considered part of river Ourthe: *(i)* in 1993, with a peak discharge of 742m^3/s; *(ii)* in 1995, 520m^3/s; *(iii)* in 2002, 570m^3/s and *(iv)* in 2003, 508m^3/s. Validation data are thus available but mainly as far as hydraulic modelling and exposure analysis are concerned (aerial imagery corresponding to the peak discharge of the flood, measures at gauging stations, field surveys).

With the aim of validating the hydraulic modelling for the studied area, these historic flood events were simulated using the flow model presented in section 2.3 and comparisons have shown a very satisfactory agreement between observations and numerical predictions, both in terms of inundation extent and water depths.

Long duration floods and steady-state approximation

The case study is located in the central part of the Meuse basin, where rivers are captured in the Ardennes massif, characterized by narrow steep valleys (de Wit et al. 2007). Consequently, flood waves along this type of rivers are hardly attenuated as a result of the combination of the steep longitudinal gradients and of the relatively narrow cross-sectional shape of the valleys, leading to relatively low storage capacity in the floodplains. As a result the floodplains are completely filled with water quickly after the beginning of the flood and a quasi-steady flow is then observed.

For instance, for typical historical floods occurring on river Ourthe, it has been verified that the volume of water stored in the inundated floodplains along a 10 km-long reach remains lower than one percent of the total amount of water brought by the flood wave.

Besides, comparisons have been made between inundation patterns predicted by unsteady flow simulations, for which the real flood hydrograph is prescribed as an upstream boundary condition, and inundation patterns computed assuming a steady-state flow (constant discharge close to the peak discharge of the hydrograph). Those comparisons have confirmed that the maximum flood extents predicted by the two approaches are in very good agreement.

Therefore, the steady-state assumption has been considered as valid for simulating floodplain inundation in the Ourthe case study and is systematically used in the simulations discussed in the subsequent paragraphs. An additional benefit of this assumption is reduced run time as a result of the possibility to exploit automatic mesh refinement.

Discharge values for a number of return periods were obtained from a standard statistical analysis of a 30-year long time series of measures at a nearby gauging station along river Ourthe. A two-parameter Gamma distribution was fitted based on the maximum likelihood method.

3.3.1.2 Socio-economic characteristics

Population

Age distribution is similar to the general age distribution at national level. About 22% of the population is younger than 20 years, while about 60% is between 20 and 64 years and about 18% is older than 65 years. Population density slightly differs with the Belgian level. Population density in Esneux is about 384 inhabitants/km^2. Besides the elderly, other population groups susceptible to floods are foreign born people and single parents. The proportion of foreigners is below the national average in this case study area. The proportion of single parents is higher in Esneux in comparison to the Belgian figure.

Population	**Esneux 2006**	**Belgium 2006**
Total population	**13,072**	
Population < 20 years	22.1%	23.1%
Population ≥ 20 and ≤ 64 years	59.7%	59.7%
Population > 65 years	18.2%	17.2%
Population density	**384 inhabitants/km²**	342 inhabitants/km²
Non-Belgian nationality	**3.9%**	8.6%
Single parents (2005)	**28.7%**	22.2%

Table 8: Organisation of the population

Source: FPS Economy, http://statbel.fgov.be/pub/d2/p204y2005_nl.pdf (consulted in 2009)

Housing

Esneux has 5586 private dwellings. The majority of these private buildings were built before 1980. Most of these private dwellings are owned. The proportion of rented houses in Esneux is about 26%. The price of most of the houses is increasing. The figures in table below illustrates that the prices of villas, bungalows and country houses is below national average in the case study areas.

Property market (€)	Esneux 2005	Belgium 2005
Villas, bungalows and country houses	158,251	257,967
Houses	134,648	133,768
Apartments, flats, studios	102,369	145,948
Plot of land	?	106

Table 9: Property marker

Source: FPS Economy, http://statbel.fgov.be/verkiezingen2006/downloads/com_gem_41018_nl.doc.pdf (consulted in 2009)

Income

Population wealth determines the susceptibility of the population. Figures in the table below illustrate Esneux has recognised a large increase in prosperity since 1993 with an income increase of 23% the average income was in 2003 about 28377, which is larger than the national average.

Average income (€)	2003	Evolution 93-03 (%)
Geraardsbergen	23,532	+10.6
Ninove	24,826	+14.7
Esneux	28377	+23
Belgium	24,455	+14.5

Table 10: The average income

Source: FPS Economy (consulted in 2007)

3.3.1.3 Adaptation scenarios

Four relevant adaptation measures have been identified for the Ourthe case study, resulting in four adaptation scenarios. The improvement in term of decrease of flood risk needs in a first step to be compared with a base line scenario which is developed here after. The following sections provide a short description of the four measures, a study of the flood risk evaluation, an evaluation of the avoided costs (using the damage function) and of the direct costs of each measure, and finally, the ranking of the four scenarios, using MCA-CBA.

Baseline scenario

Hazard

Fourteen different values of exceedance probability, or return period, have been considered, as listed in Table 11. The corresponding flow rates were used in the detailed 2D hydraulic model as an upstream boundary condition, while measured stage-discharge relationships were used to prescribe a downstream boundary condition. As a result of the hydraulic modelling, based on a grid size of 2m by 2m, inundation extents as well as 2D distributions of water depth and depth-averaged velocity components were obtained for each considered discharge.

ID	1993	1995	2002	2003
Return Period (years)	29	5	7	4
Exceedance probability (year^{-1})	3.5 10^{-2}	2.1 10^{-1}	1.4 10^{-1}	2.2 10^{-1}
Discharge (m^3/s)	742	520	570	508

ID	Q25	Q25+5%	Q25+10%	Q25+15%	Q25+30%
Return Period (years)	25	34	48	68	196
Exceedance probability (year^{-1})	4.0 10^{-2}	2.9 10^{-2}	2.1 10^{-2}	1.5 10^{-2}	5.1 10^{-3}
Discharge (m^3/s)	726	762	799	835	944

ID	Q100	Q100+5%	Q100+10%	Q100+15%	Q100+30%
Return Period (years)	100	154	239	371	1481
Exceedance probability (year^{-1})	1.0 10^{-2}	6.5 10^{-3}	4.2 10^{-3}	2.7 10^{-3}	6.8 10^{-4}
Discharge (m^3/s)	876	920	964	1007	1139

Table 11: Considered return periods and corresponding discharges for the case study of river Ourthe.

As an example, figure 10 shows the water depth and flow velocity distributions computed in the centre of the town Tilff, for two discharge values (876 m³/s and 920 m³/s) which are respectively just below and above the threshold discharge for overtopping of an existing protection wall. For the later discharge, a large area is inundated on the right bank of the river, whereas it was protected for the former discharge. This mechanism of overtopping of the protection will be shown to play an important part in the exposure analysis.

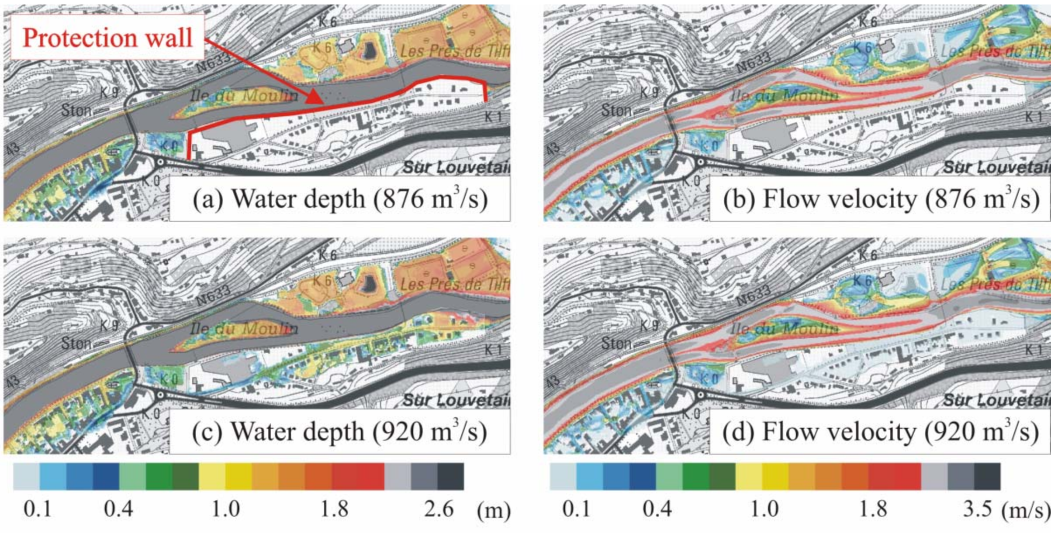

Figure 10: Water depth and flow velocity magnitude simulated for discharges just below (876m³/s) and just above (920m³/s) the threshold discharge for overtopping of the existing protection wall (flow from left to right).

Physical damage on the elements-at-risk

For the Ourthe case study area, several trends were observed:

- The housing damages are the most important
- Agriculture is more or less affected by flooding

- Not all villages of the commune are affected in the same manner or to the same extent. It appears that four villages are flooded with a recurring pattern. One of these villages represents the unit with the most affected goods and the greatest damage (the share of the damage cost for this village varies from 40 to 61% of the total damage costs for the commune). The distribution of flooding on a street level and the damage recurrence in these streets, we were able to identify the hot spots.
- Other sensitive areas to flooding are the different camp-sites along the river Ourthe. They are generally the first areas to be affected by the rise of the water level and represent an important zone of economic as well as social vulnerability.

3.3.1.4 Considered adaptation measures

The selected measures are the rehabilitation of an old canal (scenario 1), the heightening of permanent protection walls (scenario 2) or mobile protection walls (scenario 3) and the activation of a passive floodplain (scenario 4). Scenarios 2 and 3 are, in fact, a variation of the same measure, and their effectiveness is therefore equivalent, but the investment costs vary. The baseline scenario is the current situation.

Rehabilitation of an old canal (scenario 1)

The first measure consists in the rehabilitation of two sections of an old canal that was formerly used for inland navigation until early in the XX century, but numerous traces of the old canal course are still visible today. Figure 11 shows a comparison between the situation early in the XX century (left) and the present situation (right).

Figure 11: Old canal along the river Ourthe.

Based on information collected during field surveys, the present numerical surface model has been updated to introduce the former course of the canal (Figure 12).

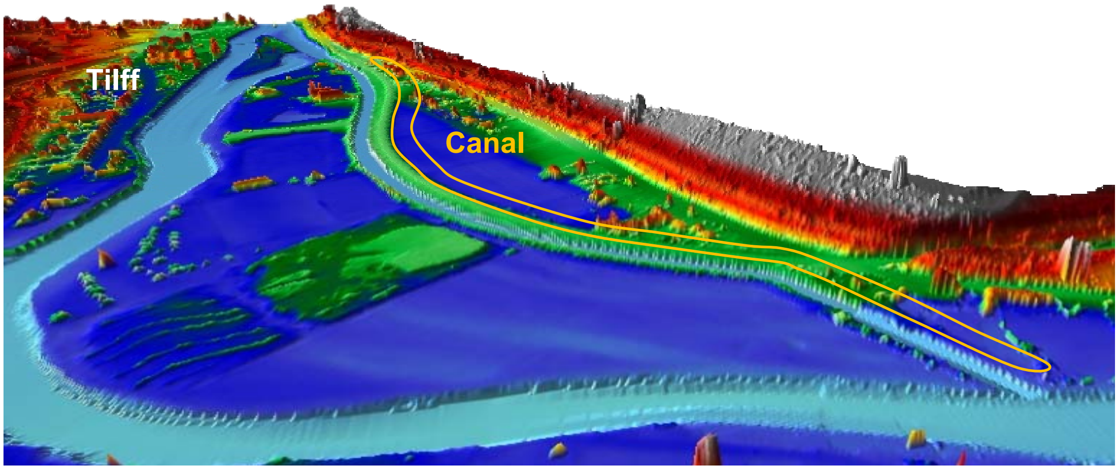

Figure 12: 3D sketch of the updated topographic model with the canal along river Ourthe

Based on historical maps and field surveys, the course of the ancient canal has been identified accurately and its section (width and depth) has been estimated. Next, considering the rehabilitation of the canal as a flood protection measure increasing the effective cross-section of the river, the Digital Surface Model used for hydraulic modelling has been updated to introduce the former course of the canal in the topography data used for hydraulic modelling.

Hazard

Figure 13 represents a typical cross-section of the river Ourthe downstream of Tilff, along with the free surface elevation computed for two different discharges (944m³/s and 1139m³/s), both without and with the rehabilitated ancient canal. In the former case, the right floodplain is inundated for both discharges in spite of an existing wall designed to protect a residential district up to the 100-year flood (876m³/s). In contrast, as a result of the increase by 18% in the available cross-section of the river when the canal is rehabilitated, the protection wall is not overtopped anymore and the right floodplain is protected from flooding. Nevertheless, for the higher discharge value overtopping of the protection wall is not prevented by the rehabilitated canal and this protection measure is thus found to remain effective only for a limited range of discharge values, as detailed below.

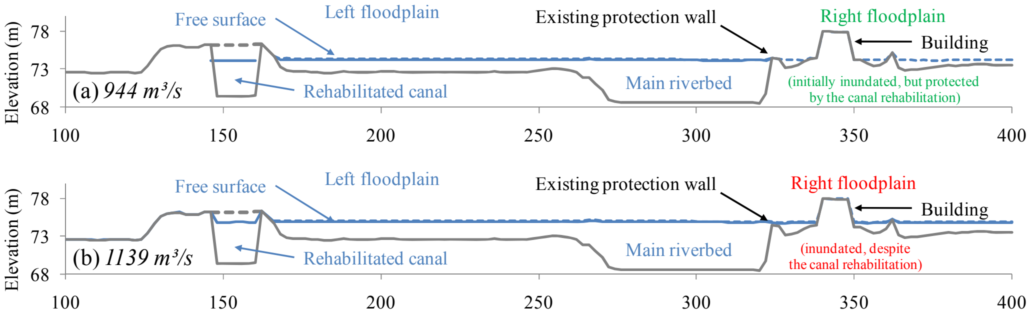

Figure 13: Typical cross-section (black lines) of river Ourthe in the case study area as well as corresponding free surface (blue lines) for two different discharges (a, b: 944m³/s; c, d: 1139m³/s) in the present situation (a, c) and considering the ancient canal

Permanent/mobile heightening of walls (scenario 2 & 3)

The second and third adaptation measures selected for the Ourthe case study consist in the heightening of existing protection walls in the centre of the town Esneux. The two sections of the existing walls that have to be heightened are shown in red in figure 14.

Figure 14: Situation of the permanent/mobile wall for the Ourthe

Source: PPNC - SPW, ULg

In scenario 2, the measure considered is the permanent heightening of the protection walls, while in scenario 3, mobile walls are used to heighten the existing walls. The use of mobile walls was investigated as an alternative to permanent walls for its limited impact on the townscape. For the permanent walls, the material considered was concrete, while, for the mobile walls, a system using inox poles and aluminium beams (see figure 15) was selected in order to evaluate the costs of the measures.

Figure 15: the mobile elements of the IBS systems consist of two components. The centre support posts, which are mounted at regular distances in case of a flood, and the dam beams that are stacked between the centre support posts.


Natural stone socket 9.30 m "Kölner Pegel"

Structure of the centre support posts

Support posts with dam beams

Complete flood protection wall

Figure 15: Mobile elements of the IBS

Two additional components are required for activating the protection function: screw fittings and pressing tools. This system of mobile walls has a height in excess of 4.0 m with just 4 system components (www.hochwasserschutz.de).

Figure 16 shows the differential of water depth between the protected and the base scenario in the case of the wall heightening in Esneux.

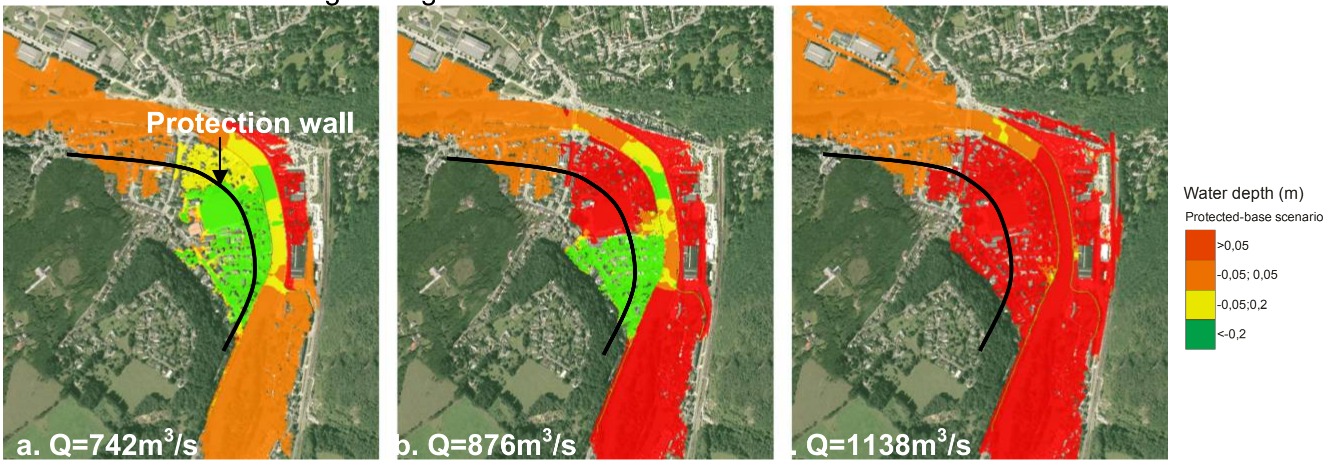

Figure 16: Sketch of the water depth differential between base and protected scenarios for three representative discharges for the wall heightening protection measure.

Floodplain activation (scenario 4)

As shown in figure 17, the last adaptation measure consists in modifying the topography of a passive floodplain (low flow velocity) to enable the development of higher flow velocities beyond the main riverbed. As a result, the effective width (and thus section) of the river is increased and, consequently, the water level upstream is reduced (by 50 cm in the example of Figure 17. The best modelling tool to reliably simulate the effect of such a measure remains a fully two-dimensional model, faithfully reproducing the velocity cross-distribution.

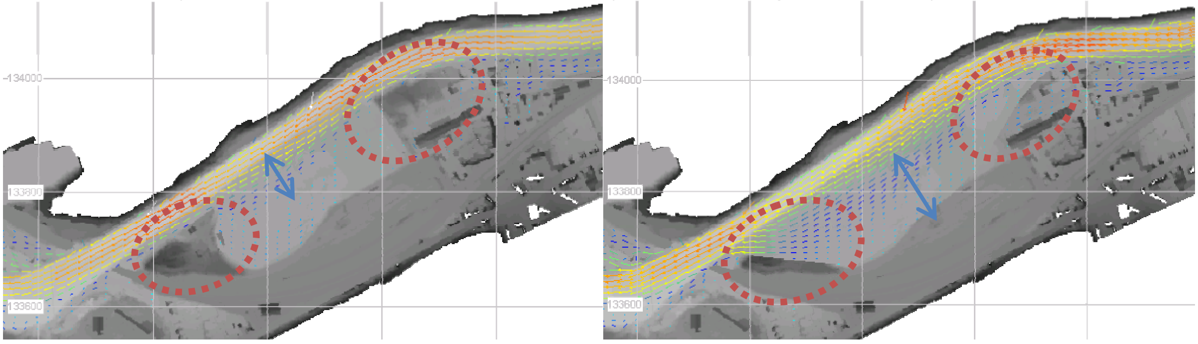

Figure 17: Velocity field (colour) and topography (grey) in Poulseur (upstream part of the case study of the river Ourthe). (a) situation without floodplain activation; (b) floodplain activation.

Topography changes (▪▪▪▪▪) and effective flow widths (——) are highlighted in recalibrating the topography of a non-urbanized floodplain in the upper part of the case study (Figure 18).

Hazard

The hydraulic effect of this topographic change is an increase in the overall local conveyance of the river, resulting in a decrease in water depth in an urbanized floodplain located upstream. As shown in Figure 19, the changes in the topography of the floodplain, originally characterized by low flow velocity, enables eventually the development of higher flow velocities beyond the main riverbed. As a result, the effective width of the river is increased and, consequently, the water level in the floodplain upstream is found to be reduced by 40cm in the case of a 100-year flood. The detailed 2D hydraulic modelling approach is particularly suitable for predicting the effect of such a measure, since it enables to properly reproduce the cross-distribution of velocity in the dynamically interacting main riverbed and floodplains.

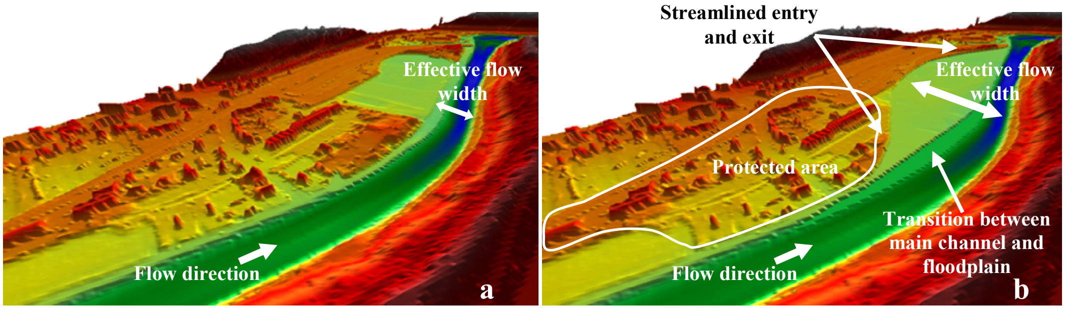

Figure 18. Digital elevation model near the activated floodplain: (a) present situation with passive floodplain, (b) activated floodplain.

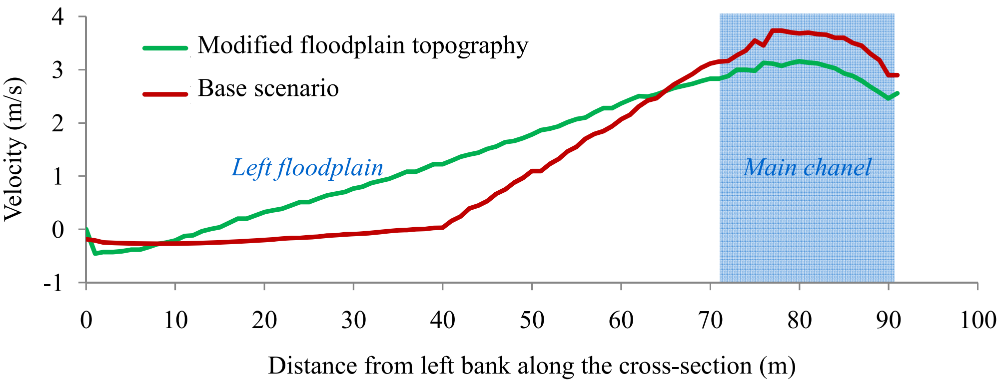

Figure 19. Cross-sectional distribution of flow velocity in the base scenario and considering a change in the topography of a floodplain in the upstream reach of the case study.

Figures 20 and 21 show flow velocity distributions computed in and upstream the activated floodplain. This figure is enhanced with the social impact computed for each residential building (high, medium or low social impacts). This information of hydraulic impact plays an important part in the impacts analysis and the hydraulic effects of the protection measure on the flow dynamic.

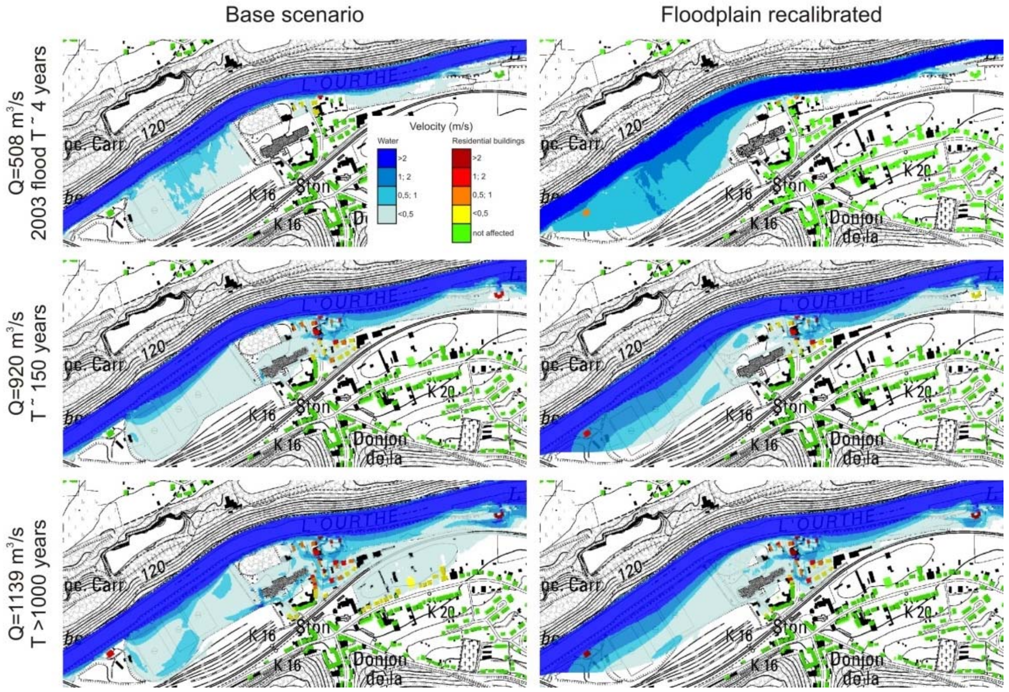

Figure 20. Flow velocity field in the base scenario and considering a change in the topography of a floodplain in the upstream reach of the case study and the velocity assigned to the buildings-at-risk.

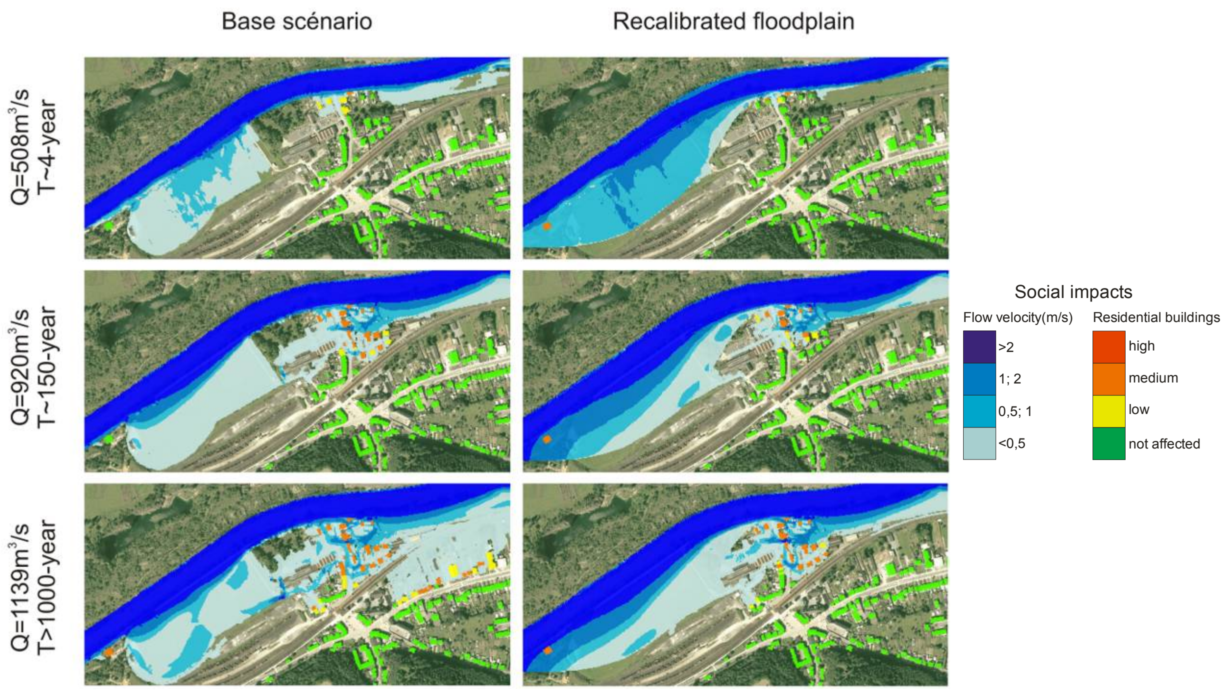

Figure 21. Flow velocity field in the base scenario and considering the topographic streamlining of the passive floodplain. The social impacts evaluated for residential building-at-risk are also displayed on maps.

3.3.1.5 Physical impacts of the adaptation scenarios

Two types of stock at risks elements have been considered in the modelling : the affected people and the buildings. Another complementary element has been considered: the social flood impact intensity**.** The results are presented here after.

Amount of affected people

Regarding the affected people, it is concluded that:

- the higher the discharge, the more people will be affected by flooding (see figures in annexes 3). The highest discharge calculated may result in about 2053 flood victims.

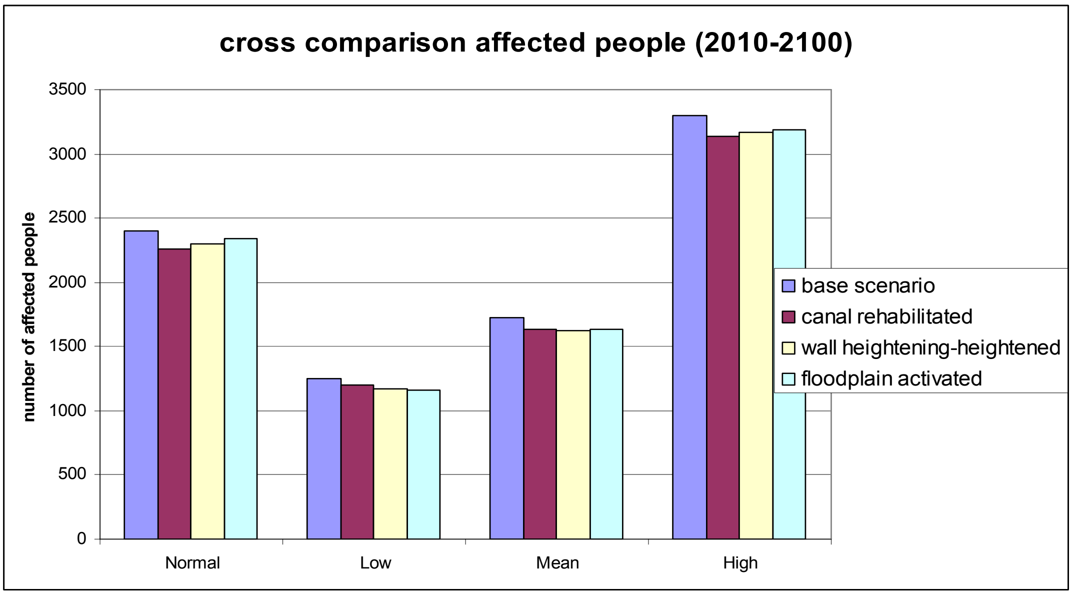

Figure 22: Cross comparison affected people (2010-2100)

- In a situation of low and medium climate change effects, the number of affected people is expected to decrease in comparison to the situation of no climate change effects. However in the high scenario, affected people will significantly increase up to 3299 flood victims during the period 2010 – 2100.

- The implementation of technical measures decreases the number of affected people. The most optimal measure in terms of affected people depends on the climate change scenario. In case of a low climate change scenario, an activated floodplain will result in the least affected people, while in the mean scenario the heightened wall scenario is the most optimal in terms of affected people. In the high climate change scenario, the canal rehabilitated scenario is most preferred.

Figure 23 represents the exposure curves (including the 14 modelled exceedance probabilities) expressed as the number of people affected by flood in the base and the protected scenario. The results are shown for each protection measure studied in the Ourthe case study, namely the protection wall heightening, the canal rehabilitation, and the activation of a passive floodplain

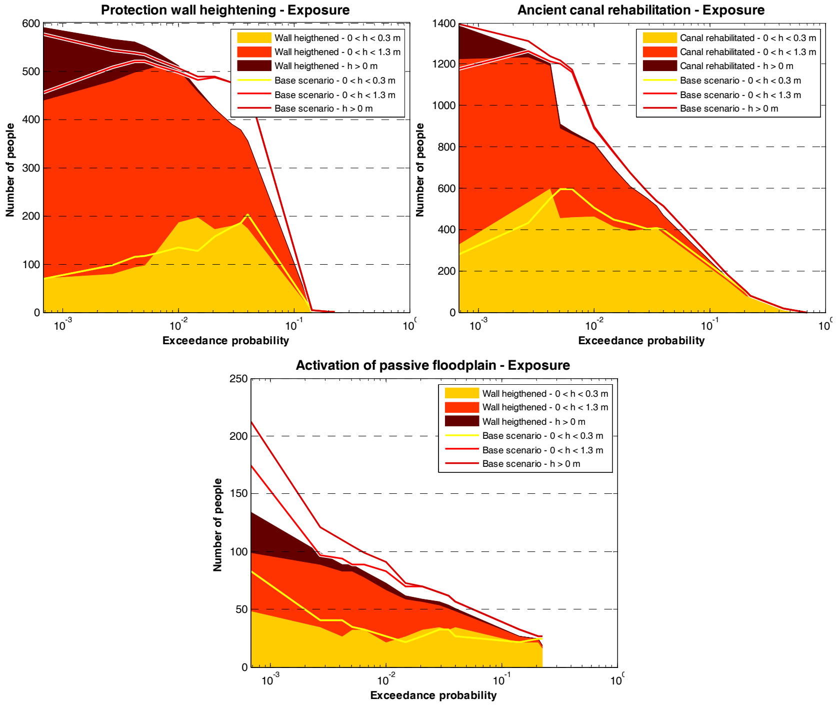

Figure 23: Cumulative curves of number of people affected by class of water depth, for the three structural measures on River Ourthe (scenario without climate change).

Amount and type of affected valuable buildings

Flooding in Esneux is expected to affect several valuable buildings. In some cases of flooding, an electric station will be flooded by 0,6 up to 2 m of water. This may result in a break-down of electricity supply. About two petrol stations may be affected, which increases the risk to environmental pollution in case of petrol leakage. Leisure facilities that may be affected are:

- 3 arts centres
- 8 sport facilities
- 1 camp site (about 2-4 meter)
- 1 recreational facility

Furthermore, a building of historical value, a castle, is projected to be flooded in cases of high discharge. Three supermarkets and three commercial facilities are at risk of flooding. Lastly, one old peoples home may be flooded (up to 2 meter), as well as two schools.

Social flood impact intensity

Regarding the social flood impact intensity, it is concluded that:

- The higher the discharge, the more intense the social flood impacts, which is explained by a higher number of affected people, more severe flood characteristics and/or vulnerability characteristics of the affected people.
- Social flood impact intensity is expected to slightly decrease in a low climate change scenario in comparison to a situation where there are no climate change effects. In case climate is changing towards a medium or a high scenario, social flood impact intensity is projected to increase.
- Total social flood intensity decreases when technical measures are implemented

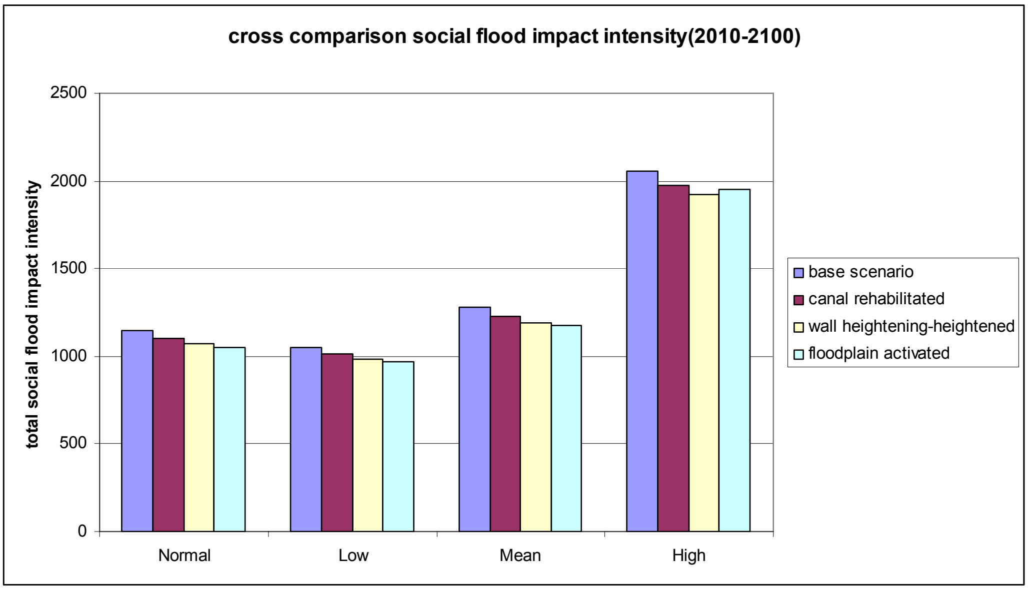

Figure 24: Cross comparison social flood impact intensity (2010-2100)

The highest proportion of susceptible people are located at Esneux, Rive Droite. The susceptibility is mainly explained by the high proportion lone parents and financially deprived people. The adaptive capacity towards floods of Esneux is medium to high. Aspects to increase adaptive capacity to a higher level are:

- Flood proofing of infrastructure, like the main road and sewerage system
- Flood proofing of buildings located near river banks
- Risk communication on the prevention of material damage to the house
- Reinforce collaboration with relevant actors in the affected municipalities and with the province
- Consider climate change effects in the implementation of flood measures

The figures illustrating this section dedicated to impacts evaluation are useful to carry out a comparative analysis of the three structural measures studied along river Ourthe. In the case of the protection wall heightening (Figure 25a.), it appears that expect effects of the measure in the vicinity of the 100-year flood turn into unfavourable influence on social impacts and exposure evaluation. The wall heightening induces socio-economic impacts more important as in the present situation for large flow rates. The reason is that for high discharges, it appears a water level raising upstream the wall. The additional protection becomes a larger obstacle to the flow that induces a larger spill over the protection wall in its upstream part. In this case, the interest of a risk analysis approach, accounting many exceedance probabilities, for flood protection design is obvious. If the design was carried out on a single return period between a 10-year and a 100-year flood, the evaluated impacts of the protection wall would be favourable. However, if numbers of exceedance probabilities are considered, the finding differs.

The rehabilitation of the ancient canal (Figure 25b) in direct economic damage to housing is found to reach 10 to 15% of initial damage for the whole range of discharges, except for return periods between 100-year and approximately 200-year, for which the relative reduction in damage becomes as high as 25% of the damage initial (Figure 4). This phenomenon is explained by the fact that an existing wall located downstream the town of Tilff, initially sized for a 100-year flood event, is now effective up to a return period slightly more than 200-year. Thanks to the river cross section increasing, the water level along the wall are lower for a given discharge.

Finally, the analysis on social vulnerability considering the activation of passive floodplain reveals another trend. Indeed, the protection level induced by this protection measure is directly proportional to discharge (Figure 25 c.). More the rate of flow increases, more the measure is effective. Once again, the interest of a risk analysis for designing protection against flooding is indisputable.

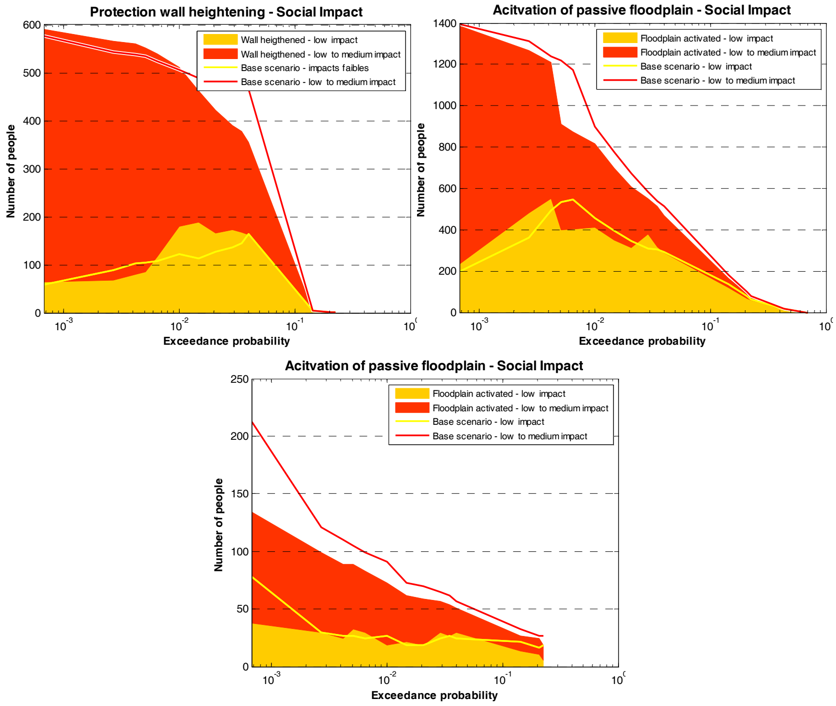

Figure 25: Social impacts for three structural protection measures, plotted by the number of persons affected by class of social vulnerability (scenario without climate change).

No flood fatalities are expected when we apply the methodology used by Flanders Hydraulics on the different types of flooding. This result is explained by the moderate water rise. Nevertheless, people may still die because of unreasonable behavior.

Sensitivity analysis on impacts evaluation

In addition to uncertainties associated with flood hazard modelling, another main factor influencing the overall impact assessment uncertainty lies in the evaluation of hydraulic parameters value for objects affected by the flooding and particularly water level inside house. The origin of this uncertainty comes from the lack of data available to determine accurately the level from which the object subject to the risk is affected by the flood

Several methods of hydraulic parameters assignment were tested following two main approach: either settings hydraulic are determined by a statistical analysis of the neighboring meshes of the object (Figure 26 a.); or, especially in the case of the water level, the altitude of the surface of the ground and the free surface are interpolated according to a plan inside the building (Figure 26 b.). The study shows that assignation according to plans fitting, either by a least squares method or a method based on detecting outliers such as RANSAC, may prove promising. In the absence of additional data, other methods of neighborhood analysis have been implemented (averaging all neighboring meshes and assigning maximum value in the vicinity of the object) in order to provide respectively a lower and an upper bound of water depth affecting element-at-risk. Therefore, these two values have to be considered in the risk analysis in order to account for the uncertainty on the determination of the level from which the object is actually affected by the inundation.

For illustrating this point, Figure 26 c. presents the economic impact curve for rehabilitation of the old canal case study. The solid line represents the case for which the water level is assigned by averaging the water depth in the vicinity of the element-at-risk (lower bound) whereas the dashed line refers to the maximum value of water depth around the building (upper bound). The direct tangible economic impact is expressed in the form of the ratio between the damage (D) and a reference value corresponding to the damage induced by the 100-year flood in the base scenario with average water depths (D_0).

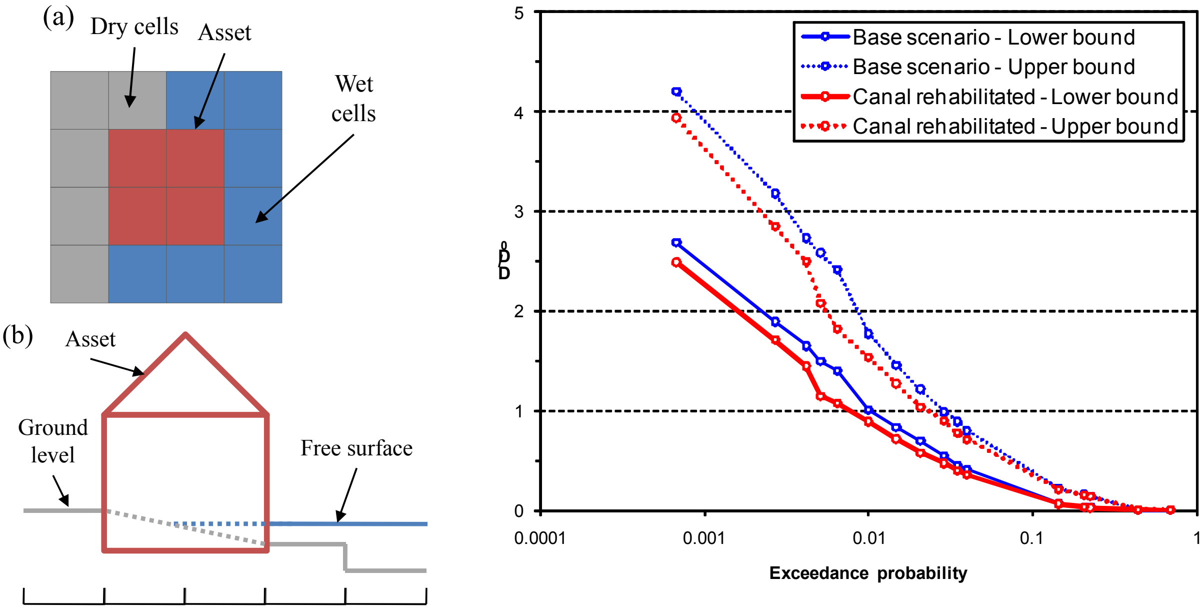

Figure 26: Sensitivity analysis on impacts evaluation. a., b. Approach for evaluating the hydraulic parameters affecting element-at-risk. c. uncertainty on flood exposure carried over direct tangible damage curves for the canal rehabilitation measure (scenario without climate change).

3.3.1.6 Flood risk evaluation for climate change scenarios (including base scenario)

The economic and social flood risk are key criteria for evaluating adaptation scenarios for attenuating the effects of flooding. These evaluation criteria are calculated on the basis of the expected economic damage and social impact respectively. The procedure for calculating flood risk is described in the methodology section of this report. The evaluation of the adaptation scenarios requires a consistent framework. In order to arrive at a correct ranking, assessment of the ENPV and assessment of the cost-effectiveness of the scenarios a

number of additional parameters has to be defined: the project horizon and the discount factor. In addition it is also important to know how the impacts (costs and benefits) evolve over time as the economy grows and the population changes.
The key assumptions underlying the calculation of the flood risk are presented first. Next, the influence of climate change on flood risk is evaluated. Finally the effectiveness of the scenarios concerning the reduction of the economic and social flood risk is evaluated.

Assumptions

Project horizon

The project horizon applied in project analysis of investments in environmental infrastructure is usually around 30 years. For natural risk projects, like adaptation to flooding, the project horizon used often exceeds 50 years. The horizon for the analysis is mostly geared to the planned useful life of the investment. The difficulty is that investments in flood protection, which may consist of a range of very different technical and non-technical measures, often do not have a fixed life span. Provided that the necessary maintenance is carried out the benefits of the project may be considered eternal. In the framework of this study we the period 2010-2099. (Florio et al., 2008 and Bulckaen et al., 2005)

Discount factor

A discount rate is used to discount future cash flows to their present values in order to allow comparing the value of a Euro today to the value of that same Euro in the future. The social discount rate reflects the social view on how future benefits and costs should be valued against present ones. There, however, is no real consensus among economists about what discount rate would be appropriate. In the framework of this study a real (inflation free) discount rate of 4% will be used. This rate has been put forward by the Flemish standard method for the execution of CBA (Bulckaen et al., 2005). The Services of the European Commission informally advice the use of a discount rate of 4%. The Dutch guidelines for the evaluation of wet infrastructure proposes the use of a real risk free discount rate of 2,5%. This rate can be increased to 5,5%, depending on the risk of the investment and the risk profile of the investor. The influence of the discount rate on the results will be assessed. For this a rate of 2,5% and 5% will be used as a lower and upper bound respectively. (Wooning A. et al., 2007)

Economic growth

The value in the study area will evolve over time. A better flood protection to floods may provide people the incentive to invest in the area. According to the local authorities no new buildings are raised in the flood risk area. This means the economic growth in this area is probably relatively limited. Because of this a conservative yearly economic growth rate of 1% assumed over the entire project horizon. In order to test the robustness of the evaluation of the project alternatives the effect of a 0% and 2% increase in economic growth will be considered as well.

Population dynamics

The population in the study area is expected to grow. The same holds for the number of households. This means the number of people per house decreases. Assuming no new houses are being raised the number of people in the area-at-risk decreases over time. This evaluation is taken into account. The projections for both parameters are were taken from the preparatory work done by the Federal Planning Bureau in the framework of State of the Environment Report on the expected environmental development.

3.3.1.7 Impact of climate change on flood risk

The current level of flood protection is probably not optimal as we consider the current climate. Climate, however, is changing and is expected to change flood risk. Figure 27 and

Figure 28 show what effect climate change may have on social and economic flood risk. The trend is very similar for both types of risk. Flood risk decreases in a low climate change scenario. If the mean climate change scenario would become reality flood risks are expected to increase slightly. In case we find ourselves in a high climate change scenario flood risk is expected to (at least) double. From a flood management point of view the problem, however, is one does not know what climate scenario is the most likely.

Assumptions concerning the economic growth and population dynamics do not change the fact that flood risk will get worse if climate change hits hard. The same holds for the project horizon and the discount rate. It is, however, true that both the absolute and relative importance of the difference in flood risk between the no climate change scenario and the various climate change scenarios will change as the assumptions are changed.

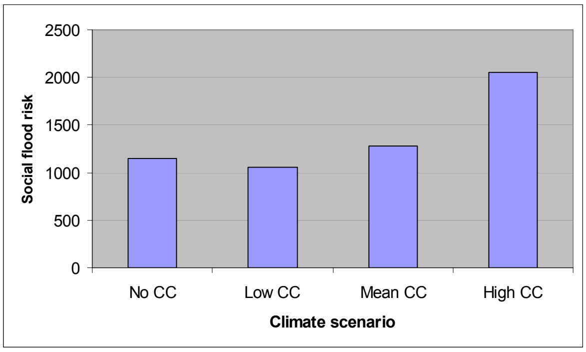

Figure 27: Social flood risk for the baseline scenario given different climate change scenarios

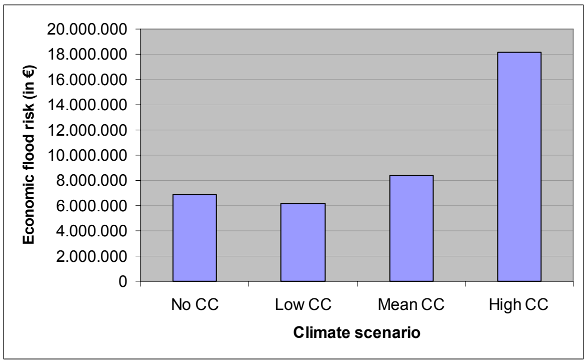

Figure 28: Economic flood risk for the baseline scenario given different climate change scenarios

3.3.1.8 Effectiveness of the scenarios

All adaptation scenarios considered reduce the economic and social flood risk irrespective of the climate scenario, see Figure 29 and Figure 30. The higher the flood risk in the baseline scenario the higher the risk reduction. The activation of an ancient flood plain is expected to be the most effective measure for the reduction of the social flood risk, except for the high climate change scenario. The heightening of walls, either permanently or by means of mobile aluminium beams, is the most effective measure for the reduction of the economic flood risk.

Assumptions concerning the economic growth, population dynamics, project horizon and discount rate do influence the results, but the conclusions remain valid. All measures are expected to reduce flood risk. The heightening of walls is expected to yield the highest reduction of the economic flood risk. Both the wall heightening and the flood plain activation perform well for the reduction of the social flood risk.

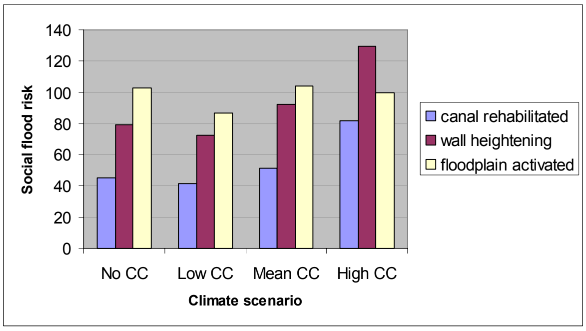

Figure 29: Avoided social flood risk for the scenarios given different climate change scenarios

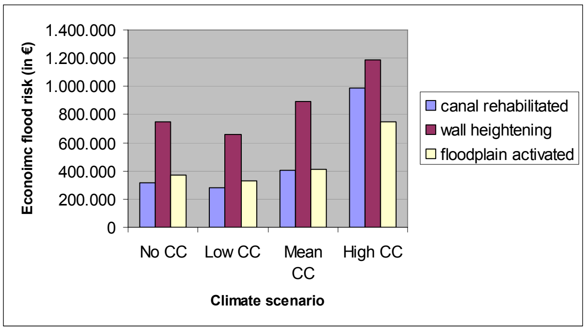

Figure 30: Avoided economic flood risk for the scenarios given different climate change scenarios

3.3.1.9 Direct costs of the adaptation measures of the Ourthe case study

In order to proceed with the extended CBA, it was necessary to evaluate the direct costs of the selected measures. As explained in the section dedicated to the methodology, the evaluation of the direct costs mainly focused on the investment, maintenance and operation costs of the adaptation measures described here above.

Rehabilitation of an old canal

This measure implies the rehabilitation of two sections of an old canal. The first section is 1,400m long and the second is 1,000m long. The total length to be considered for the evaluation of the direct costs is thus 2,400m by 8m high and 12m wide (figures provided by ULg).

The costs involved are mostly **investment costs** under the form of civil works to excavate the earth and build the canal. It is foreseen that the works are carried out during the first year. The works involve: excavating 230,000 m^3 earth and building concrete walls and base plate. In the calculation, the concrete walls and base plate are 0.4m wide.

The necessity to dredge the canal was also investigated, which constitutes a **maintenance cost**. Regarding the necessary frequency for the dredging, the following was considered: the canal belongs to the category of non navigable water ways, for which there is only limited data available regarding dredging. Besides, between 1995 en 2003 almost no dredging activity has been carried out in the Walloon Region (see the Report from IRGT on sludge management, 2005). Taking those elements into consideration, the assumption was made that during the period of 90 years considered for the ADAPT project, dredging would be carried out every 20 years (year 20, 40, 60 and 80). The number of m^3 to be taken into account for the dredging was also difficult to estimate, considering the fact that it depends of the sedimentation in the canal. The assumption was made that the two parts of the canal would be dredged (total length 2.400 m, width of 12 m) on a height of 0.5 m.
Regarding the costs of dredging, they are influenced by many factors, among which the sedimentation. Since those parameters are unknown (the canal is currently filled with earth and not water), it was decided to use average values for the costs of dredging. The average value for dredging costs, according to expert judgement, lies between 15-20 €/m^3. When the extra costs for treatment, transportation and storage are taken into account, the costs are estimated around 50 €/m^3 (Expert estimation provided by J.M. Hiver, Directeur du Laboratoire de recherche hydraulique DPW-DIR GEN opérationnelle des voies hydrauliques et de la mobilité) which is the value used in table 12. However, if the sludge is contaminated, extra costs are necessary for the treatment.

The resulting costs are given in Table 12.

Adapt project: direct costs of adaptation measure 1

		Unit	Quantity	Cost/unit	Total Costs
Old Canal Rehabilitation					
Investment costs: civil works					
Excavating + transporting off-site		m^3	230,000.00	15.00 €	3,450,000.00 €
Building of structure	Concrete base plate	m^3	11,520.00	350.00 €	4,032,000.00 €
	Concrete walls	m^3	15,360.00	450.00 €	6,912,000.00 €
TOTAL investment costs					**14,394,000.00 €**
Maintenance costs					
Dredging (every 20 year)		m^3	14,400.00	50.00 €	720,000.00 €
TOTAL maintenance costs			4	720,000.00 €	**2,880,000.00 €**

Table 12: Evaluation of the direct costs of old canal rehabilitation (base year prices)

Source: expert estimation for average costs provided by François-David JONARD (Projektleider), Jan de Nul Group, www.jandenul.com.

As mentioned above, these costs are indicative average costs and are subject to variations. Indeed, the costs for the civil works may vary from one entrepreneur to the other. Besides, the nature of the material to be removed has a major influence on the excavating costs: For instance, if it is rock instead of earth that has to be removed a supplement of 40 € / m^3 should be added to those costs. Conversely, the fact that the earth could be re-used in another site would lower the price.

Permanent heightening of walls

This adaptation measure consists in the permanent heightening of existing protection walls by 1 m on a total length of 1,800m (two sections of 1,000m and 800m).

The fact that this measure concerns the heightening of existing walls posed a problem for the evaluation of the costs. Indeed, it would have been necessary to test the resistance of the existing walls in order to provide an accurate view of the extra costs for reinforcing the structure. Since it is beyond the scope of this study to carry out such an engineering resistance study, it was decided to consider the price of the walls as if they had been build on the ground as a basis for the evaluation of the costs of this adaptation measures. The same assumption was made for the mobile walls scenario.

For the permanent heightening of the walls, we have considered a construction in concrete. The costs involved are mainly **investment costs** under the form of civil works to be carried out during the first year of the project.

The **maintenance costs** foreseen include repairs and cleaning (tag removal) and have been evaluated on the basis of expert judgement. The frequency of this task is once every three years (thus 30 times over the 90 years period considered). Provided those maintenance work are carried out, the walls should still stand at the end of the period considered for the ADAPT project.

The details of the costs for the permanent walls are shown in Table 13.

		Unit	Quantity	Cost/unit	Total Costs
Heightening of walls (permanent)					
Investmentl costs: civil works					
Building of walls	Preparation work	m'	1,800.00	200.00 €	360,000.00 €
	Groundwork	m^3	540.00	350.00 €	189,000.00 €
	Concrete Walls	m^3	540.00	450.00 €	243,000.00 €
TOTAL investment costs					**792,000.00 €**
Maintenance costs					
Repair and cleaning (every 3 years)		m2	600.00	15.00 €	9,000.00 €
TOTAL maintenance costs			30	9,000.00 €	**270,000.00 €**

Table 13: Evaluation of the direct costs of permanent heightening of walls (base year prices)

Source: expert estimation for average costs provided by François-David JONARD (Projektleider), Jan de Nul Group, www.jandenul.com.

Heightening of walls with mobile aluminium beams

This measure offers an alternative to the permanent heightening of the protection wall. We have considered a system with inox poles and aluminium beams (technology developed by Steinhardt Wassertechnik, HydroBeam® mHWS, expert judgement given by Mr. C. Burssens from HydroConcept®). The costs involve mostly **investment costs**, under the form of equipment costs. Other investment costs involve: drilling holes for the supports (300 mm deep, with a diameter of 50 mm) every 6.5 meter, a cost for temporary plugs that have to be put in those holes, making the connection with the existing dike at both ends (x2, because there are 2 sections), and training (1 day) to get familiar with installing the beams and working out the procedure.

Regarding storage costs, we have assumed that they are supported by the local authorities. However, if this is not the case, additional costs should be computed (which comprise 120,000 € for the containers, expert estimation).

The operating costs have been calculated taking the weight of the beams into consideration and are identical for the setting up and dismantling of the mobile walls (average prices). They will apply as many times as it is necessary to set up and dismantle the mobile walls.

The assumption was made that the mobile walls would be set up by the local authorities (fire brigade), and therefore, no extra labour cost has been included.

The expert judgement from Mr. Burssens (Hydroconcept) regarding maintenance costs is to foresee around 500 € for the repair every time the material has been set up and used against flooding. The labour costs would be supported by the local authorities.

From what has been explained above, the operating and maintenance costs for the mobile walls are incurred every time they are used. To estimate the flow of costs, it was thus necessary to estimate the number of times the mobile dikes would have to be set up and dismantle. In order to do so, we have used the return period provided by the IRM for different scenarios regarding the intensity of climate change. Climate change effects are accounted for by assuming changes in the expected peak discharge for fourteen different river discharges. For each climate scenario (the current climate as well as the three climate change scenarios) a return period has been attached to each peak discharge by the RMI in the framework of the cooperation between the CCI-HYDR and ADAPT project, making use of the SCHEME model. (see table 14).

Discharge	Return periods (in years)			
	No CC	Climate change		
		High CC	Mean CC	Low CC
	RMI			
508	3	1	3	6
520	4	1	3	7
570	6	2	4	11
726	40	5	20	59
742	50	5	24	73
762	65	6	30	98
798	106	8	46	165
834	177	10	66	240
876	328	14	109	438
919	627	19	171	708
943	909	23	210	629
963	1244	27	271	851
1007	2512	38	477	1675
1138	22399	113	2840	13865

Table 14: Return periods attached to each peak discharge by the RMI in the framework of the cooperation between the CCI-HYDR and ADAPT project, making use of the SCHEME model

The following assumption was made: the mobile walls would be set up every time there is an alert for an inundation. Therefore, the return period for the lowest discharge value (508m^3/s) was selected for the 4 scenarios (no cc, high cc, mean cc and low cc). The maintenance and operating costs were then divided by the return period, in order to estimate an average cost per year. This is of course an approximation that does not fit exactly the flow of costs, but it allows for the integration of the return period into the stream of cash flows.

		Unit	Quantity	Cost/unit	Total Costs
Heightening of walls (mobile aluminium beams)					
Investment costs: civil works, equipement & training					
Mobile walls	Beams	m	1,800.00	671.00 €	1,207,800.00 €
	Temporary stops				11,000.00 €
	Drilling				45,000.00 €
	Adaptators on the 4 sites				25,000.00 €
	Training				2,500.00 €
TOTAL investment costs					**1,291,300.00 €**
Maintenance costs					
Reparation after use					500.00 €
TOTAL maintenance costs no CC (every year)			90	166.67 €	**15,000.00 €**
TOTAL maintenance costs high CC (every year)			90	500.00 €	**45,000.00 €**
TOTAL maintenance costs mean CC (every year)			90	166.67 €	**15,000.00 €**
TOTAL maintenance costs low CC (every year)			90	83.33 €	**7,500.00 €**
Operation costs					
Setting up	Loading	t	150.00	3.80 €	570.00
	Transport	t	150.00	1.90 €	285.00
	Unloading	t	150.00	3.80 €	570.00
Dismantling	idem				1,425.00
Setting up and dismantling					2,850.00
TOTAL operation costs no CC (every year)			90.00	950.00	**85,500.00 €**
TOTAL operation costs high CC (every year)			90.00	2,850.00	**256,500.00 €**
TOTAL operation costs mean CC (every year)			90.00	950.00	**85,500.00 €**
TOTAL operation costs low CC (every year)			90.00	475.00	**42,750.00 €**

Table 15: Evaluation of the direct costs of permanent heightening of walls (mobile aluminium beams) (base year prices)

Source: expert estimation for average costs provided by Carl Burssens, Zaakvoerder, HydroConcept (hydroconcept@pandora.be)

The floodplain activation

The costs involved for this measure are **investment costs**, and more specifically the costs associated to the civil works to be carried out during the first year of the project: excavating 95,000.00m3 of earth, of which 14,000.00m3 have to be transported off-site, and 81,000.00m3 can be re-used on the site (figures provided by ULg).

Another type of investment costs was also investigated: the costs related to the **purchase of land** (expropriation and compensation costs). However, it appeared from the cadastral data that the piece of land considered for the floodplain is a property of the local district.

The assumption was made to consider the public authorities as a single actor, not differentiating therefore between the different local, regional or federal levels of decision power. Besides, it is stated in the Walloon "Code de l'eau[2]", that the costs of works against inundation (that can be submitted to environmental permit or declaration) are supported by those who took initiative" (Ch II, Sec. 3, Art. D.41). Taking those elements into consideration, no expropriation and compensation costs were taken into account.

Regarding the maintenance costs, the following assumption was made: 1% of the initial civil works would have to be carried out every 5 years to maintain the floodplain (thus 18 times over the lifetime considered for the project).

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[2] The « Code de l'eau » contains the set of rules concerning water management in the Walloon Region

	Unit	Quantity	Cost/unit	Total Costs
Floodplain activation				
Investment Costs: civil works				
Excavating	m³	95,000.00	2 €	190,000.00 €
Transporting off-site	m³	14,000.00	13.00 €	182,000.00 €
Transporting on the site	m³	81,000.00	5.00 €	405,000.00 €
Reusing on the site	m³	81,000.00	3.00 €	243,000.00 €
TOTAL investment costs				**1,020,000.00 €**
Maintenance costs				
Excavating	m³	950.00	2 €	1,900 €
Transporting off-site	m³	950.00	13.00 €	12,350.00 €
TOTAL maintenance costs		18	14,250.00 €	**256,500.00 €**

Table 16: Evaluation of the direct costs of floodplain activation

Source: expert estimation for average costs provided by François-David JONARD (Projektleider), Jan de Nul Group, www.jandenul.com.

3.3.1.10 Damages function and benefits (avoided costs)

Table 17 illustrates the results of the damage function for some houses ("Function1" and "Function 2"). The real values of damages for which compensation is asked by the owner following the flood event ("asked") and the damages accepted by the "Disaster Funds" to be compensated ("accept to compensate"). The house value (HV) was studied and determined to inject it in the damage function and such one was developed on the basis of some cadastral and experts data. The two functions tested to evaluate the house value, just with the use of a data base, are the following:

- HV1 = Surface (m²)*38, 76 (€/m²)*30
- HV2= 125.000+112*cadastral income (CI)

The final function: $D = (2x^2+2x)*HV/100$.

Wd	HV1	HV2	Rel Function	Function 1	Function 2	Asked	Accept to compensate
0,337	93024		0,902	839,48		18077,44	333,01
0,549	106978		1,702	1820,86		17476,04	463,59
0,549	106978		1,702	1820,86		5690,00	552,70
0,400	218606	267128	1,122	2452,07	2996,33	16495,00	1735,25
0,318	79070	170472	0,839	663,23	1429,90	15,66	689,10
0,171	40698	168792	0,399	162,45	673,76	2914,25	340,08
0,190	84884	206536	0,454	384,97	936,68	1561,32	795,03
0,025	59303	172152	0,052	31,00	89,98	1767,00	329,74
0,251	100001	226248	0,629	629,43	1424,07	6000,00	979,59
0,354	169769	291208	0,957	1625,08	2787,54	5536,90	1125,15
0,199	174420	263768	0,478	833,14	1259,92	5389,83	1730,12
0,149	123257	216280	0,342	421,35	739,35	1162,23	0,00

Table 17: Comparison between real values and the damage function

Wd" represents the water depth registered during the flood event in the house (m).
The "Rel function" gives results of the function in damage's degree (%).
The "HV" is the House Value (€) determined by the function "HV=38,76 (€/m²)*surface area (m²)*30" for the HV1 and by the function "HV=125000+112*CI (cadastral income)" for the HV2 (see the methodological note to evaluate the house value).
The "function" represents results of the function multiplied by the House Value (with the HV1 for the "function1" and HV2 for the "function 2") and divided by 100 to obtain absolute results in €. And the two last column represent real value of damages estimated and asked by the owner of the house ("asked") and accepted by the "Disaster Funds" ("accept to compensate") in €.

The result of the damage function is more or less close to the amount accepted by the "Disaster Funds" considering that damage depends on various parameters besides the water depth. Data concerning damage for which compensation is asked by the owner of the house do not need to be taken into account for comparison with our results because these data are subjective. Data from damages accepted by the "Disaster Funds" will be more objective because they are more homogenous and based on common criteria. We can see that results obtained by this damage function give a more or less value scale of the housing damages, because if the owner trades to ask a big amount and the "Disaster Funds" agree to give too small a sum, our result is in the same scale of value as the damage amount "Provided"; and inversely if the inhabitant asks for a really small amount to cover all the damages occurring in his house and the "Disaster Funds" gives twice as much, our result is closer to the "Provided" amount. By taking the first three data of comparison in Table 17 into account, the result of our damage function is not really close to the real value accepted by the "Disaster Funds", but it is closer to this amount compared to the amount asked by the owner.

There are a lot of uncertainties linked to the economic flood damage estimation and a further task will be focused on the analyse of those uncertainties.

Cost avoided

Costs listed in Table 18 refer to damages expected to the houses in the Ourthe Case study. Damages (in €) are considered for different rates of flow (508 to 1138 m³/s) and the damage to houses and household goods can be seen with or without implementation of the adaptation measure. Damage to houses for the flood velocity of 943m³/s are currently estimated at 2,968,453 € if the canal has not been restored and damages are reduced to 2,271,553 € for houses if this adaptation measure has been taken into account.

Scenarios		Type of damage	Damage (€)							
			m³/s							
			508	570	742	798	876	943	1007	1138
Structural	canal base scenario	Damage to houses	39191,74	112847,9	742394,7	1134334	1772809	2968453	4176575	7210274
		Damage to household goods	11757,52	33854,38	222718,4	340300,2	531842,8	890535,8	1252973	2163082
	canal rehabilitated	Damage to houses	37989,48	106161,7	660355,2	996362,3	1607574	2271553	3555970	6486152
		Damage to household goods	11396,84	31848,5	198106,5	298908,7	482272,1	681466	1066791	1945846
	wall heigthening base scenario	Damage to houses	0	1915,96	1209181	1461691	1804579	2204202	2571478	3654225
		Damage to household goods	0	574,7881	362754,2	438507,3	541373,6	661260,6	771443,4	1096268
	wall heightening-heightened	Damage to houses	0	1917,725	823460,7	1088887	1520054	2551212	3125518	4147257
		Damage to household goods	0	575,3175	247038,2	326666,1	456016,1	765363,5	937655,5	1244177
	floodplain base scenario	Damage to houses	25701,81	45817,27	162706,3	214502,7	362767,7	479418,4	630731,9	1198177
		Damage to household goods	7710,543	13745,18	48811,9	64350,82	108830,3	143825,5	189219,6	359453
	floodplain activated	Damage to houses	13280,08	26756,83	104180,3	138303,4	258587,4	328924,8	451970,9	791920
		Damage to household goods	3984,024	8027,049	31254,1	41491,03	77576,23	98677,44	135591,3	237576

Table 18: Damage expected to houses and household goods for the Ourthe Case study for different scenario (with or without adaptation measures)

3.3.1.11 Application of MCA/CBA for ranking adaptation measures

Ranking

The ranking of the scenarios on the basis of multiple evaluation criteria, see Figure 31, learns the rehabilitation of the old canal (scenario 1) is by far not the preferred option if only one measure has to be selected. The investment costs of this canal are simply much too high and the resulting reduction in flood risk is much too limited. The performance of the other scenarios seems to be quite similar. This is, however, is a bit misleading since the rehabilitation of the old canal is an outlier which tends to camouflage the differences between the other scenarios in a multi-criteria analysis. Having a closer look to the results we see the wall heightening (scenarios 2 and 3) outperforms the reactivation of the ancient flood plain (scenario 4). As the net present value of the investment, operating and maintenance costs of a permanent wall (scenario 2) are expected to be only two third of the costs of a mobile wall made up of aluminium beams (scenario 3) the permanent wall heightening is the best option to reduce the impacts from flooding along the Ourthe in our study area. Only if our current estimate underestimates the visual disamenity of a permanent wall investing in a mobile wall will become relatively more attractive. This is not only the case when studying the current climate. All the above conclusions are equally valid for the three climate change scenarios.

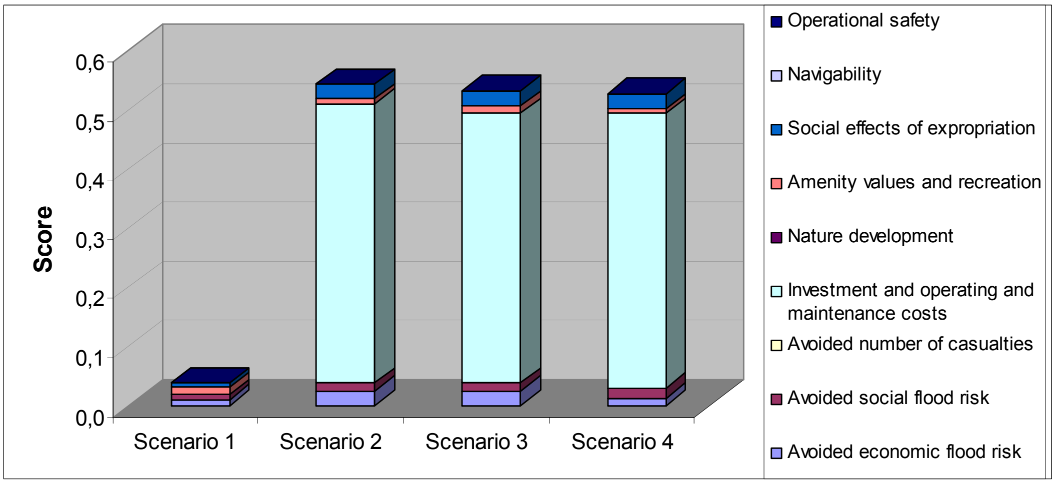

Figure 31: Ranking of the scenarios given the current climate.

Sensitivity analysis

Changes in the assumptions concerning the economic growth, population dynamics, project horizon and/or discount rate would not change the hierarchy of the scenarios. Such changes do, however, influence the economic performance or expected contribution to welfare of the scenarios, but this can not be analysed by means of a multi-criteria analysis.

Figure 32 illustrates the ranking of the scenarios is not altered when the weights attributed to the different evaluation criteria vary. The exception is a change in the amenity and recreational values (weighting option 7 in Figure 32) as the permanent wall (e.g. visual disturbance) and the activation of an ancient flood plain (e.g. possibly giving up sport and recreational facilities) are probably less favourable in this respect than a mobile wall.

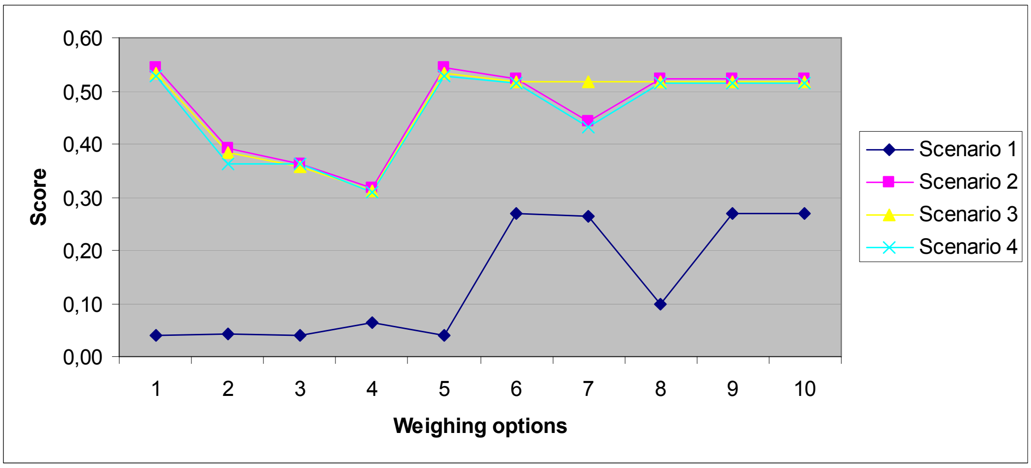

Figure 32 Sensitivity of the scores and ranking of the scenarios to changes in the weights given the current climate

Taking a closer look at some major transitions we see the wall heightening by means of a mobile wall would outperform the construction of a fixed wall if its investment, operating and maintenance costs decrease by 25% or more. Alternatively the same is true if the investment, operating and maintenance costs of a permanent wall would be underestimated by 39% or more. A similar analysis can be carried out for the activation of an ancient flood plain. The investment, operating and maintenance costs of this measure would need to decrease by 44% or more before the activation of the ancient flood plain becomes the most attractive scenario. Alternatively the same is true if the investment, operating and maintenance costs of a permanent wall and a mobile would be underestimated by 56% or more and 12% or more respectively.

Uncertainty analysis

Both the scores attributed to the scenarios for the different criteria as well as the weights attributed to the criteria are somewhat uncertain. In order to analyse how sure we can be about the ranking of the scenarios we have defined the uncertainty margins of the scores, see Table 19. The upper and lower boundaries of the uncertainty margin of the weights was assumed to be 25% for all criteria. Given these uncertainty margins, and all other assumptions kept constant, the permanent heightening of walls is expected to be the preferred adaptation option in about 98% of the cases. The scenario with the mobile walls only has a small chance of ranking first. The chance of the activation of an ancient flood plain ranking first is around 0,1%. The uncertainty over what scenario is likely to rank second is much bigger. The scenario with the heightening of the walls by means of a mobile structure is likely to outperform the activation of the ancient flood plain in 77% of the cases, see for an insight in the dynamics of the ranking of the scenarios given the uncertainty margins specified above.

Evaluation criteria	Low	High
Avoided economic flood risk	20%	20%
Avoided social flood risk	30%	30%
Avoided number of casualties	30%	30%
Investment and operating and maintenance costs	10%	10%
Nature development	20%	20%
Amenity values and recreation	20%	20%
Social effects of expropriation	20%	20%
Navigability	20%	20%
Operational safety	20%	20%

Table 19: Score uncertainty

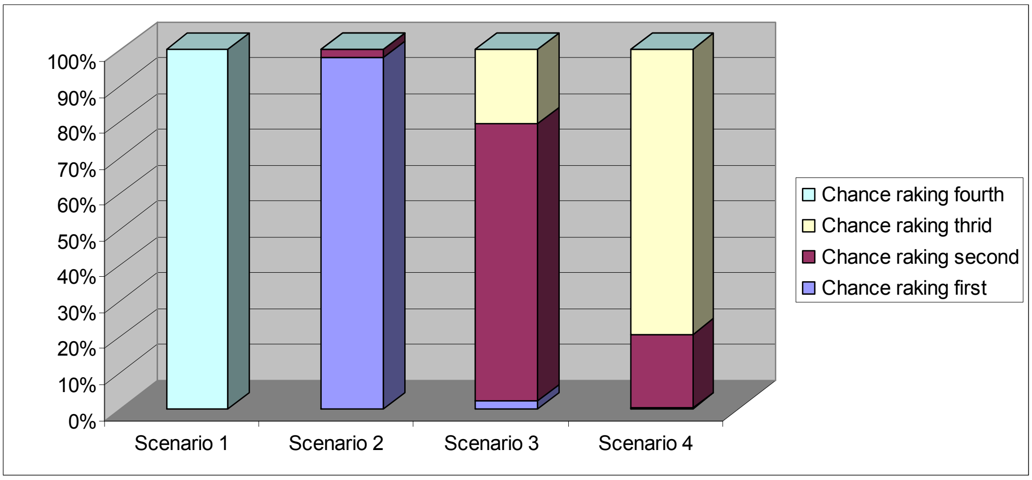

Figure 33: Expected ranking of the scenarios given the current climate

If the economy in the flood risk area is likely to grow at a higher rate (e.g. 2% instead of 1%) then the chance the scenario with the mobile walls ranks first increases to about 7%. This is because the likely avoided flood risk increases as the economy grows and the other parameters such as investment, operating and maintenance costs remain unchanged. The performance of the ancient flood plain decreases when the economy grows as the expected avoided flood risk of this measure is inferior to the expected avoided flood risk of the heightening of the walls. Since the expected avoided flood risk increases in the mean and high climate scenarios, similar conclusions can be drawn for an increase in the growth of the economy. In the high climate change scenario the chance of the scenario with the mobile walls ranking first increases to about 15%.

Economic net present value

The evaluation of the ENPV confirms the ranking of the adaptation scenarios in all climate scenarios. The ranking, however, does not tell whether the scenarios studied create or destroy welfare. A scenario that is expected to have a positive ENPV can be accepted. A scenario with a negative ENPV should be rejected. From Table 20 we conclude that the permanent heightening of walls creates welfare in each climate scenario. The scenario with the mobile walls will only contribute positively to welfare in the high and mean climate change scenarios. The activation of the ancient flood plain should only be carried out if the high climate change scenario is expected to arise.

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
No CC	-14.950.124	161.208	-168.829	-320.093
Low CC	-14.984.358	32.585	-289.351	-442.517
Mean CC	-14.855.810	402.417	85.212	-270.897
High CC	-14.263.992	1.076.908	784.477	190.870

Table 20: ENPV of the adaptation scenarios given the basic assumptions

If the economy is expected to grow at a pace of 2% a year in the flood area the ENPV of the scenarios looks even better. No matter what climate scenario is considered the heightening of the walls does always create extra welfare. The reactivation of an old flood plain yields a positive ENPV in the mean and high climate change scenarios. The higher the economic growth, the better is the performance of the adaptation scenarios. This conclusion should, however, not be misinterpreted. This insight should not lead the decision makers to promote new economic activities or the construction of new houses in the area-at-risk. Economic growth in the flood risk area increases the overall flood risk. The avoided flood risk, however, is only a fraction of the additional flood risk.

The discount rate applied to compare the costs and benefits arising at different time has an important influence on the desirability of the results. A higher discount rate reduces the potential benefits while a lower discount rate has the opposite effect. If a discount factor of 5,5% is used, leaving all other assumptions unchanged, all scenarios should be reject with the exception of the permanent walls in the mean and high climate scenarios and the mobile walls in a high climate change scenario. In case a discount factor of 2,5% is used, leaving all other assumptions unchanged, the picture looks much better, see Table 31.

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
No CC	-15.174.495	737.723	463.033	112.481
Low CC	-15.243.526	478.301	211.941	-133.774
Mean CC	-14.983.960	1.225.362	976.564	207.650
High CC	-13.789.692	2.576.542	2.409.790	1.084.784

Table 21 ENPV of the adaptation scenarios given the basic assumptions, using a discount rate of 2,5%

The above results are all based on the assumption that the social flood risk more or less equals a total of 85% of the economic flood risk. Reducing this percentage reduces the performance of the scenarios from a welfare point of view. Table 22 provides the ENPV of the scenarios given a reduction of the importance of the social flood risk to e.g. about one fourth of the economic flood risk.

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
No CC	-15.038.382	-104.371	-452.937	-669.217
Low CC	-15.062.296	-203.332	-541.854	-729.303
Mean CC	-14.968.061	61.065	-278.831	-632.192
High CC	-14.501.714	439.570	98.132	-288.007

Table 22 ENPV of the adaptation scenarios given the basic assumptions, reducing the value of the social flood risk to one fourth of the economic flood risk

Cost-effectiveness

The costs-effectiveness analysis shows how much benefits are generated by each euro invested. Like the ENPV this ratio has to be positive. Scenarios with a negative cost-effectiveness should be rejected. The higher the value of the ratio is the better. There are two factors that determine the height of this ratio: the investment, operating and maintenance costs on the one hand and the ENPV on the other hand. Again the scenario with the permanent heightening of the flood protection walls is the most preferred. It yields the highest benefits at the lowest costs, see Table 23.

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
No CC	-1,00	0,19	-0,13	-0,29
Low CC	-1,00	0,04	-0,22	-0,41
Mean CC	-0,99	0,47	0,06	-0,25
High CC	-0,95	1,25	0,57	0,18

Table 23 Cost-effectiveness of the adaptation scenarios given the basic assumptions

3.3.2 Case study Dender

The case study Dender has been considered in this project as an opportunity to evaluate both structural as well as non-structural measures like spatial planning or flood warnings and the integration of the environmental impacts.

3.3.2.1 Hydrological analysis study site

The Dender is a tributary of the Scheldt and has a total length of 70 km. The river originates in the Walloon village of Ath (elevation 40 m TAW) and flows about 18 km in the Walloon region. At Dendermonde (elevation 3 m TAW), the Dender reaches the Scheldt. Whereas the Dender itself is a navigable river, its tributaries are not. The most important tributaries of the Dender in terms of influence on the water level are the Marke, the Molenbeek (Zandbergen), the Bellebeek and the Molenbeek (Erpe-Mere). (HIC, 2003).

The Dender is a typical spate river; rainfall strongly influences the water level and the discharge. While in winter the discharge is generally high, low flows occur in summer. The average discharge of the Dender is about 10 m³/s in Dendermonde. In winter the average is around 25m³/s and the average maximal discharge is 60 m³/s. During dry periods in summer the water level is very low in most water courses in the Dender basin and the average discharge in Dendermonde is then in the order of 2,5 m³/s. During wet summers peak discharges up to 25 and even 30 m³/s have been observed. (VMM, 2009)

In the course of time, the Dender has gone through intense human influences. As the Dender connects the Walloon region with the Antwerp harbour by way of the Scheldt Estuary, the Dender is used for navigation. 13 level-regulating structures guarantee navigation and convey water fast and safely at times of high discharges in between Ath and Dendermonde. The Dender has also been straightened, canalized and embanked for facilitating navigation.

In addition, to protect the basin from flooding, several artificial modifications have been made, like the construction of dikes and storage reservoirs. (VMM, 2009)
Inundations are a natural phenomenon in the Dender basin. Peak discharges in winter cause water courses to leave their banks and to use their winter beds. The valley of the Dender between Geraardsbergen and Ninove is marked by wide flooding areas most of which can be considered as natural flooding areas. Elsewhere in the basin of the Dender (the valleys of the Marke, Bellebeek, Molenbeek (Erpe-Mere), etc.) the valleys are regularly flooded too. Most inundations only last for a limited period of time and do not cause much damage.
Over the last decades severe floods have caused important material damage in the Dender basin: winter 1993-1994, January 1995, December 1999, 2001, January 2002 and winter 2002-2003. While Geraardsbergen was flooded in 1995, 1999, 2001 and 2002, Ninove was flooded in December 2002 for the first time. (VMM, 2009)

Because the conceptual flood modeling approaches were unsuitable to provide the needed output for ecological impact assessment, an existing time series from the quasi 2D Mike 11-model was used for the application of the methodology. The analysis of the time series is used to demonstrate the practical implementation of the ecological impact assessment tool on a floodplain site. The selected floodplain study site is located upstream from Ninove and a large part is flooded frequently (almost annually for the period 1987-2001). The site location is illustrated in Figure 34. Unfortunately, there are no time series available for climate change scenarios or adaptation measures. What we can deduct from the flood return maps generated by the conceptual model, is that the projected flood events for the 5 year return maps are more severe than the observed flood events in the period 1987-2001, even for the base scenario (no adaptation and no climate change). The reason is to be sought in the use of the composite-hydrograms that are statistically derived from the flow time series and used as input for the conceptual model.

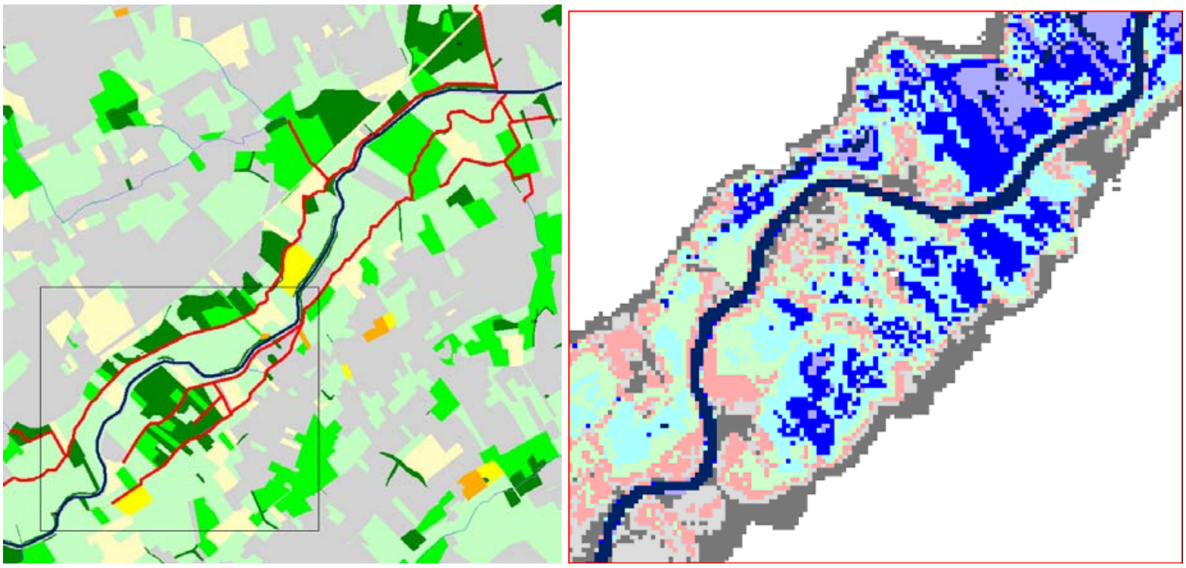

Figure 34: A) Study site location (rectangle), Drainage infrastructure (red) and ecological values (green) B) Flood depth and extent in intervals of 20 cm.

Figure 35 shows all 30 flood events that have occurred between 1987 and 2001 (14 years). From the graphs we can see that there is a very fast rise time of the flood and a more gradual decrease. The Mike 11 hydrological model is unfortunately not calibrated for flood duration. The model therefore assumes a certain fixed infiltration rate, which is realized by artificial pumping stations. This is visible in the graphs since the flood decrease follows very similar patterns. When the flood level reaches 10 cm, a sudden drop in the water levels is forced upon by the model. There is no dataset available to effectively calibrate flood duration.

In reality this artificial pumping may be close to reality since there is an actual presence of drainage facilities, flood hatches and pumping stations. As soon as the Dender water levels drop, this infrastructure will ensure a maximal drainage of the floodplains. The artificial nature of the hydraulic infrastructure and the management objectives (agriculture, shipping safety), make it hard to draw any conclusions on ecological functioning of the floodplains.

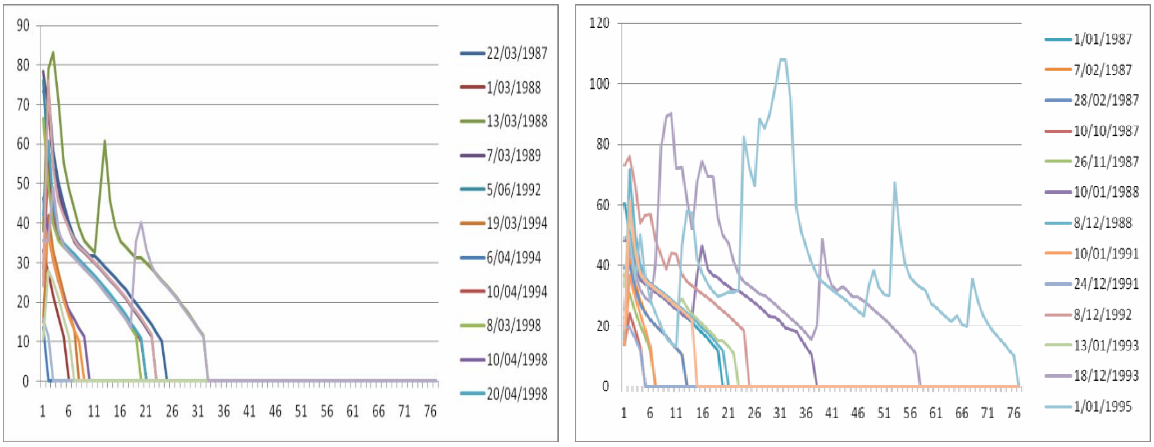

Figure 35: Summer and Winter flood events.

Figure 35 shows that 6 floods occurred with a duration of + 14 days. Short flooding episodes occurred 10 times within the period 1987-2001 (13 years). In the years 1990, 1991, 1993, 1995, and 1996 no summer flooding occurred. Severe floods occur mainly in March-April. It also shows that since 1996, there were no flood events during winter. As the vegetation is inactive during winter, there is almost no damage to vegetation. The duration of the floods is however much longer and multiple flood peaks can be observed within one flooding episode.

The study site flood branch was selected from the dataset and a detailed spatial explicit analysis of flood type occurrences was made. Flood branches are created for the hydrological modeling to expand the 1-dimensional Mike 11 river model (river) to a quasi 2D model by connecting flood branches. Because of the technical issues described in the previous paragraphs, it was chosen to select only one flood branch. The time series is classified in occurrences of different flood types and for elevation intervals of 20 cm. In practice, elevated areas are usually flooded less deep (20 cm intervals), less frequent and less long. Certain parts within the floodplain are flooded with short re-aeration intervals. The different flood events have been classified into flood types (Table 24). This has been done for different flood levels (20 cm intervals), relative to the flood branch elevation. The numbers indicate the total number of days that this flood type occurred in the period 1987-2001. The elevation differences of the columns in Table 24 apply to the flood depth/extent intervals of Figure 34B.

ID	Season	regularity	Duration	Depth	0 cm	20 Cm	40 Cm	60 cm	80 cm	100 cm	120 cm	140 cm
5	W	> 5 years	> 14 days	> 50	19	9	0	0	0	0	0	0
6	W	2-5 years	< 14 days	< 20	25	147	39	17	8	2	0	0
8	W	2-5 years	< 14 days	> 50	22	9	6	0	0	0	0	0
9	W	2-5 years	> 14 days	< 20	36	23	1	0	0	0	0	0
10	W	2-5 years	> 14 days	20-50	85	11	0	0	0	0	0	0
13	W	1-2 years	< 14 days	20-50	98	32	20	10	2	0	0	0
30	Z	2-5 years	< 14 days	< 20	27	149	29	11	1	0	0	0
34	Z	2-5 years	> 14 days	20-50	38	0	0	0	0	0	0	0
38	Z	1-2 years	< 14 days	> 50	19	8	0	0	0	0	0	0
43	Z	yearly	< 14 days	20-50	129	28	10	1	0	0	0	0
45	Z	yearly	> 14 days	< 20	64	12	0	0	0	0	0	0

Table 24: Flood type classification of flood events between 1987 and 2001

3.3.2.2 Socio-economic characteristics

Although the Flemish case study area is larger than the Walloon case study area in terms of absolute population number, the age distribution is equal in the three cities and is comparable to the national level. About 22% of the population is younger than 20 years, while about 60% is between 20 and 64 years and about 18% is older than 65 years. Population density in these areas differs. The Dender case study cities are more densely populated than Belgium density. Besides the elderly, other population groups susceptible to floods are foreign born people and single parents. The proportion of foreigners is below the national average in both case study areas. The proportion of single parents is below the national average.

Population	**Geraardsbergen 2006**	**Ninove 2006**	**Belgium 2006**
Total population	**31,380**	**35,651**	
Population < 20 years	**21.4%**	**21.4%**	**23.1%**
Population ≥ 20 and ≤ 64 years	**60%**	**61%**	**59.7%**
Population > 65 years	**18.6%**	**17.6%**	**17.2%**
Population density	**393.7 inhabitants/km²**	**491.3 inhabitants/km²**	**342 inhabitants/km²**
Non-Belgian nationality	**2.3%**	**2.1%**	**8.6%**
Single parents (2005)	**20.2%**	**20.2%**	**22.2%**

Table 25: Organisation of the population

Source: FPS Economy, http://statbel.fgov.be/pub/d2/p204y2005_nl.pdf (consulted in 2009)

Housing

In 2001, Geraardsbergen and Ninove had respectively 12,376 and 13,805 private dwellings. The majority of these private buildings was built before 1980. Most of these private dwellings are owned. The proportion of rented houses in Geraardsbergen is about 19% and in Ninove about 24.3%. The price of most of the houses is increasing. The figures in the table below illustrate that the prices of villas, bungalows and country houses are below national average in the case study areas. However, a large diversity in prices of these properties in the case study areas should be emphasized. The price of houses is below the national average in Geraardsbergen and Ninove. Apartments, flats and studies are most expensive in Ninove.

Property market (€)	**Geraardsbergen 2005**	**Ninove 2005**	**Belgium 2005**
Villas, bungalows and country houses	232,941	219,174	257,967
Houses	96,362	116,078	133,768
Apartments, flats, studios	87,558	149,403	145,948
Plot of land	57.6 €/m²	73.1	106

Table 26: Property market

Source: FPS Economy, http://statbel.fgov.be/verkiezingen2006/downloads/com_gem_41018_nl.doc.pdf (consulted in 2009)

Income

Population wealth determines the susceptibility of the population. Figures in table below illustrate that the average income of Geraarsbergen and Ninove is around the national average

Average income (€)	**2003**	**Evolution 93-03 (%)**
Geraardsbergen	23,532	+10.6
Ninove	24,826	+14.7
Esneux	28377	+23
Belgium	24,455	+14.5

Table 27: Average Income

Source: FPS Economy (consulted in 2007)

3.3.2.3 Environmental characteristics

The dynamics of natural river systems strongly influence floodplain habitats, resulting in specific complexes of ecosystems and habitats. The biodiversity of any given area depends upon the diversity of the physical and chemical environment and is thus enhanced by the presence of gradients and processes. The physical characteristics of a catchment play a crucial role in the hydrological dynamics of its rivers and associated floodplains. Flooding characteristics are variables that affect the development of ecological communities. For certain there are other natural mechanisms and processes that affect species composition in floodplains and it is clear that many of these mechanisms and processes are severely disturbed in the Dender Catchment.

Like many European rivers the Dender River has been subjected to major antrophogenic impacts. The term "flooding" is often associated with negative aspects and since centuries mankind has tried to reduce flooding as much as possible through River normalisation, embankments etc... Not the recognition of social and economic impacts of flood events, we also need to recognise that flood events are an essential part of the water system and that flooding events are necessary for healthy water systems.

The Dender catchment has a significant topographic variation and is characterized by loamy soils. This implicates a slow infiltration and consequently a high run-off/infiltration ratio. These loamy soils are also very fertile and often in agricultural use. The combination of high slope, loamy soils and crofts promote run-off and erosion which leads to on-site and downstream problems. A climate change induced increase of summer storms (either in frequency or by intensity) could lead to aggravation of this phenomenon. Alternatively, the Dender floodplains also suffer from droughts during summer. Increased droughts can lead to aggravation of run-off, since soil sealing and hydrophobic behavior increase. This combination of features makes the Dender highly vulnerable to climate change, both for episodes of flooding as well as for episodes of low-flow. If the Dender had not been normalised to enable water transport, it would be a fast running and dynamic stream. The Dender has a very quick response to precipitation and has extensive floodplains. The floodplains were formerly used as moist haylands in summer and were flooded regularly. Because of the quick response of the Dender to rainfall episodes, the Dender carries a high sediment load during these episodes. The formerly slightly elevated natural river banks have been replaced by artificial embankments to reduce flood frequency and allow water transport and more intensive agriculture in the valleys. After the embankments, the Dender valley still floods regularly, but merely as emergency flood water storage. The permanent haylands have suffered from the more intensive use for agriculture (pastures and cropland), losing much of their ecological values. The water transport function of the Dender has significant impact on the river hydrology and morphology. To enable water transport, the water level is kept artificially high by sluices. This causes many parts of the valley to be permanently wet, even during summer. At many sites drainage networks and pumping stations have been installed to enable agriculture (figure 34A). The floodplain water table is mainly dependent on stagnating rain – or floodwater, since seepage is almost non-existent in the clay-subsoil of the floodplains. Only at the edges of the floodplain, very vulnerable seepage exists from horizontal groundwater flows.

For a land-use distribution analysis, we chose the extent of the 25-year flood return map. Because the valley edge is steep, the 10 and 5 year flood return maps comprise respectively 96 % and 90 % of the 25 year maximal extent. If we look at land-use in these floodplains (table 28), we see that (permanent) grasslands cover 53 %, followed by poplar plantations 13 %, alluvial forests – alder – ashen - willow (4.8 %) and non-forest wetland types (5.2 %). For the selected study area, we see a similar pattern.

25-year flood return extent	%	Study site extent	%
Grassland	53,00%	Grassland	39,37%
Poplar	13,23%	Poplar	27,04%
Built-up	11,79%	Alluvial forest	12,31%
Wetland	5,18%	Water	6,27%
Alluvial forest	4,82%	Forest	6,24%
Water	4,46%	Built-up	3,42%
Forest	3,28%	Wetland	2,66%
Shrubs	2,23%	Cropland	1,06%
Cropland	1,38%	Dike	0,85%
Dike	0,64%	Shrubs	0,79%
Various	0,01%	Various	0,00%
Grand Total	**100,00%**	**Grand Total**	**100,00%**

Table 28: Land-use distribution in the 25-year flood map extent and selected study site

It is evident that the ecological mechanisms and processes related to floodplain ecology could apply to the Dender floodplains, if the Dender hydrology were not that severely impacted. The ecological values of the Dender floodplains are only to a minor extent determined by flooding. The impact of climate change will not only affect hydrological regimes, but will also affect other ecological impact mechanisms. The major impact on ecological values has occurred in the past through river normalization, drainage and intensification of land-use. Seemingly more extreme and frequent floods could even benefit the nature values. Not because extreme flooding is beneficial in se, but rather because it does not allow other land-uses and re-instates natural development and reduced management. In addition, flooding is then beneficial to the structural abiotic diversity of the floodplain (erosion, sedimentation, denitrification, carbon pools) and hence increases biodiversity.

3.3.2.4 Considered adaptation measures

For the river Dender two sets of adaptation scenarios will be evaluated. A first set consists of three technical flood protection measures that are combined to three scenarios. A second set of three scenarios focuses on complimentary measures like spatial planning, risk communication and flood warning and forecasting.

Flood protection scenarios

Three adaptation scenarios, being the combination of one or more measures, that are ought to increase the protection against flooding have been modelled. These scenarios are to be compared to the baseline scenario (including a strict building stop), which is the state of the river Dender at the time of the floods in the winter of 2002-2003.

- Baseline scenario + strict building stop + dike heightening
- Baseline scenario + strict building stop + dike heightening + replacement of the weirs
- Baseline scenario + strict building stop + dike heightening + replacement of the weirs + construction of retention basins

In all scenarios, the baseline scenario included, we assume there is a strict building stop, communication about flood risk is quasi non-existing and the level of flood warning and forecasting is average.

Baseline scenario + dike heightening

In the aftermath of the foods in the winter of 2002-2003 the following measures have been taken:

- construction, heightening and reparation of dikes along the river,
- installation of New Jerseys along the river,
- construction of new transversal dikes;
- installation of outlets for evacuating the water from the flood plains.

With the exception of the construction of some smaller retention basins along the side branches of the Dender, this scenario corresponds quite well to the current state of the Dender.

Investment costs of these works amounted to 250.000 € (Callebaut, 2009). Every five years 10.000 € is spend on the maintenance of these structures.

Baseline scenario + dike heightening + replacement of the weirs

The weirs on the Flemish part of the Dender are to be replaced by larger ones in order to ensure the drainage of the flood water. During the floods of 2002-2003 these weirs on the Flemish part of the Dender acted as a major bottleneck, causing flooding upstream (Secretariaat Denderbekken, 2003). This is, at least partly, due to the increased drainage from the Walloon region as a result of the broadening of the weirs on the Walloon part of the Dender. In addition, the existing ones are old and both hard as unsafe to operate. Replacing them would increase their reliability and the safety of the workers. (Secretariaat Denderbekken,2009)

For our study area only the weirs of Geraardsbergen, Idergem and Pollare are important. The cost of their replacement is estimated at 10.800.000 € (Secretariaat Denderbekken,2009). Currently about 9 people operate these three weirs. In future this number can be reduced to 2 or 3 people, resulting in a yearly saving of about 250.000 €.[3] The maintenance cost of the weirs is assumed equal to the current situation. The costs of the dike heightening need to be added to the costs of the replacement of the weirs.

Baseline scenario + dike heightening + replacement of the weirs + construction of retention basins

In the '90s the idea of space for water gained ground little by little. At the turn of the century, supported by the evidence of a series of exceptional events ('94, '95, '98 and '99), the principle of promoting space for water started to be widely recognised among water managers. At the moment, several tens of retention basins have been developed along the side branches of the Dender. Most of this storage capacity has been created to solve local problems, also reducing / enabling to master the discharge of the side branches into the Dender.

Today, plans are made to create additional storage capacity along the Marke and the Molenbeek Zandbergen, two important side branches discharging in the Dender inside the study area. The extra storage capacity reckoned within this scenario is set at 500.000 m³ for the Marke and 820.000 m³ for the Molenbeek Zandbergen. 80% of this volume can effectively be used.

On the basis of an analysis of the investment costs of retention basins, already constructed in the Dender basin, the cost per m³ storage capacity corresponds to about 2 - 2,5 € per m³. The cost of a flood control area is, however, largely dependent on location specific factors. Reckoning with a cost of about 2,25 € per m³, the cost for an extra 1.320.000 m³ storage capacity along the Molenbeek Zandbergen and the Marke is estimated at 3.000.000 €. (Rigo, 2008) Yearly 7.500 € is spent on the maintenance of the flood retention basins. The costs of the dike heightening and the replacement of the weirs have to be added to the cost of the construction of the retention basins.

Alternative adaptation scenarios

Protection against flooding is getting ever more expensive. Taking additional technical measures is not straightforward as, especially (in the Dender basin) in Flanders, much has been done to limit both the occurrence and impacts from flooding. In addition it is ever more difficult to get the necessary permits for raising a measure that has a clear spatial impact. In response to these observations one should deliberately look at complementary, non-technical, measures focussing on prevention, awareness raising, disaster management and the creation of the necessary coping capacity. In order to leave the conceptual discussion about such complimentary measures we evaluate the possible benefits of a building stop, risk communication and flood forecasting and warning.

The current situation, the baseline scenario + dikes (without a strict building stop), is taken as the baseline for the evaluation of the complementary measures. The water test currently prevents the erection of new unadapted constructions in flood risk area. We, however, assume there is no strict building stop in our baseline. We assume that in the absence of a strict building stop the available building lots will be built progressively within the next 20 years.

A strict building stop implies no new constructions are raised in flood risk area. In the absence of such a regulation the values-at-risk would certainly increase. For assessing the effect on flood risk of a strict building stop we have inventoried both the available building lots and the residential expansion areas located in flood risk area in Geraardsbergen and Ninove. Using the data from the land register 42 building lots have been identified in flood risk area.

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[3] 6,5 full time equivalents could be saved. Reckoning with a 220 workings days a year, 7,6 working hours a day and 23,73 € per hour we arrive at a saving of 257.898€ a year. The 23,73 € per hour is the cost for a worker in the public sector in 2008. The estimate of the hourly rate of a worker in the public sector has been derived on the basis of the methodology used by the 'Dienst Wetsmatiging of the Flemish administration' for calculating standard hourly rates for the calculation of administrative burdens. (Dienst Wetsmatiging of the Femish administration, 2009 en NSSO, 2009

From the region plan of Flanders we find more than 21 hectares of residential expansion area is located in flood risk area. Assuming an average parcel size of 750 m² about 281 houses could potentially be raised in these areas.

The scenarios for assessing the effect of complementary measures against flooding are listed below:

- Baseline scenario + dike heightening + strict building stop
- Baseline scenario + dike heightening + strict building stop + risk communication
- Baseline scenario + dike heightening + strict building stop + risk communication + improved flood forecasting and warning

The net costs of these scenarios (compared to the baseline scenario + dike heightening but without strict building stop) has been set at 7.500 €, 12.500 € and 17.500 € a year respectively.

	Baseline	Dikes	Wears	Flood areas	Building stop	Risk communication	Flood forecasting and warning	Private protection and evacuation of valuable items
Scenario 1	Yes	No	No	No	Yes	No	Moderate application	Low application
Scenario 2	Yes	Yes	No	No	Yes	No	Moderate application	Low application
Scenario 3	Yes	Yes	Yes	No	Yes	No	Moderate application	Low application
Scenario 4	Yes	Yes	Yes	Yes	Yes	No	Moderate application	Low application
Scenario 5a	Yes	Yes	No	No	No (+buildings lots	No	Moderate application	Low application
Scenario 5b	Yes	Yes	No	No	No (+buildings lots and potential buildings lots)	No	Moderate application	Low application
Scenario 6	Yes	Yes	No	No	Yes	Yes	Moderate application	Low application
Scenario 7a	Yes	Yes	No	No	No (+buildings lots	No	Full application	Moderate application
Scenario 7b	Yes	Yes	No	No	No (+buildings lots and potential buildings lots)	No	Full application	Moderate application
Scenario 8	Yes	Yes	No	No	Yes	Yes	Full application	Full application

Table 29: 8 scenarios tested

3.3.2.5 Evaluation of social flood impacts

Flood fatalities

By means of the methodology of Flanders Hydraulics, flood fatalities due to the flooding itself are not expected. This is mainly due to the moderate water rise. Nevertheless, people may still die because of irrational behavior.

The number of affected people:

It is demonstrated that:

- The higher the return period, the more people are affected by the flood, which is explained by the larger flood surface of higher return period floods (see annexes 3). It is to be noted that, only considering the building stop, the highest number of people to be affected by flooding is 67. Although the number of 67 seems to be insignificant in relation to the high investment costs of technical protection measures, we would like to emphasize that the results of the Dender case study includes only two municipalities of the Dender catchment and only one of the rivers, the Dender. The total number of affected people by flooding in the Dender catchment (including all municipalities and all Dender tributaries) is expected to be higher.

- Flooding in the low climate change scenario is expected to affect less people compared to a situation where no climate change effects occur. In some scenarios the medium climate change situation results in less flood victims (scenarios 3, 5a, 5b, 7a, 7b) compared to no climate change situation and in other measure scenarios, the medium climate change situation results in more affected people (scenarios 1, 2, 4, 6, 8). In case climate change will evolve towards the high scenario, the number of affected people will increase significantly compared to a no-climate change effects situation.

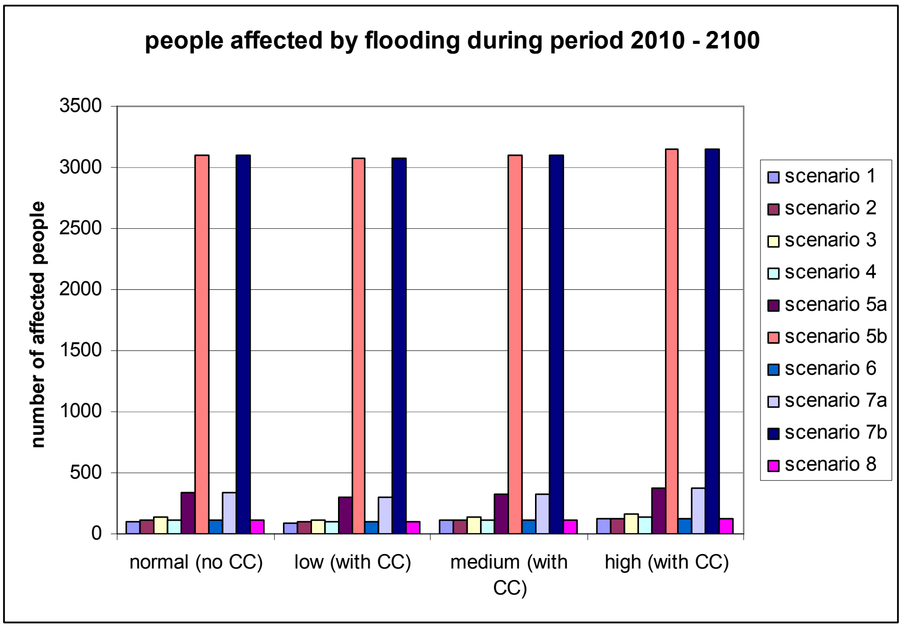

Figure 36: Number of people affected by flooding (2010-2100)

- According to the results of the case study, the implementation of extra technical flood measures does not automatically result in less affected people in the municipalities Geraardsbergen and Ninove. In addition, the construction of flood plains seems to be necessary to reduce the number of affected people caused by the development of wears. However, it should be repeated that only a limited part of the Dender catchment is considered. In order to make statements on the efficacy of technical measures, the whole catchment should be considered.

- The implementation of non-technical measures does not automatically result in less affected people. Their houses, which are immobile, will still be located in the flood area. However, the material damage is expected to decrease, resulting in reduced social flood impact experience.

The research results emphasize the importance to obey the Flemish water test, which is a non-technical measure that prevents the construction of new buildings in flood risk areas. In case people can keep on building on building lots currently located in flood risk areas, the number of affected people will increase with 227 in a no-climate change effects situation, and with 248 in a high climate change effects scenario (during 2010 – 2100). Construction in areas that may be indicated as building lots in the future (hereafter named potential building lots), will result in about 2999 extra flood victims in a no-CC effects scenario and 3019 in a high-CC effects scenario (during the period 2010 – 2100). Respect to the water test is crucial to avoid extra flood victims in the future.

Number and type of affected valuable buildings

Depending on the scenarios, one or two electricity cabines will be flooded, which may result in a short-cut in electricity provision. About three or four sport facilities will be flooded, as well as a swimming pool, depending on the flood scenario. This may result in more costs to the municipality to repair the damage. Lastly, a building for well-being and care will face inundation of high return period floods.

Social flood impact intensity

Regarding flood impact intensity, it is concluded that:

- The higher the return period, the more intense the social flood impacts, which is explained by a higher number of affected people, more severe flood characteristics and/or vulnerability characteristics of the affected people.
- Social flood impact intensity is expected to decrease in a low climate change scenario in comparison to a situation where there are no climate change effects. In case climate is changing towards a medium or a high scenario, social flood impact intensity is estimated to increase.

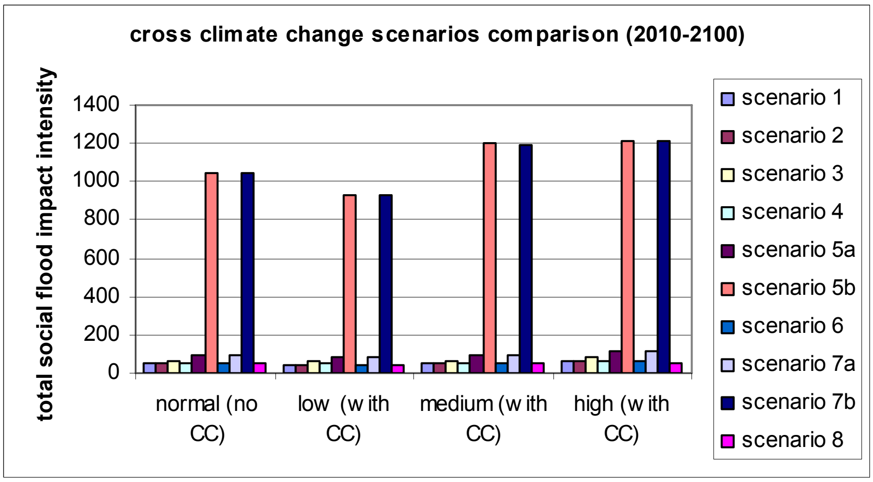

Figure 37: Cross climate change scenario comparison (2010-2100)

- The implementation of technical protection measures does not automatically result in less severe social flood impacts. Non-technical measures positively contribute to the reduction of social flood impact intensity per capita. The social flood impact severity is smallest in scenarios 8, 6 and 2.

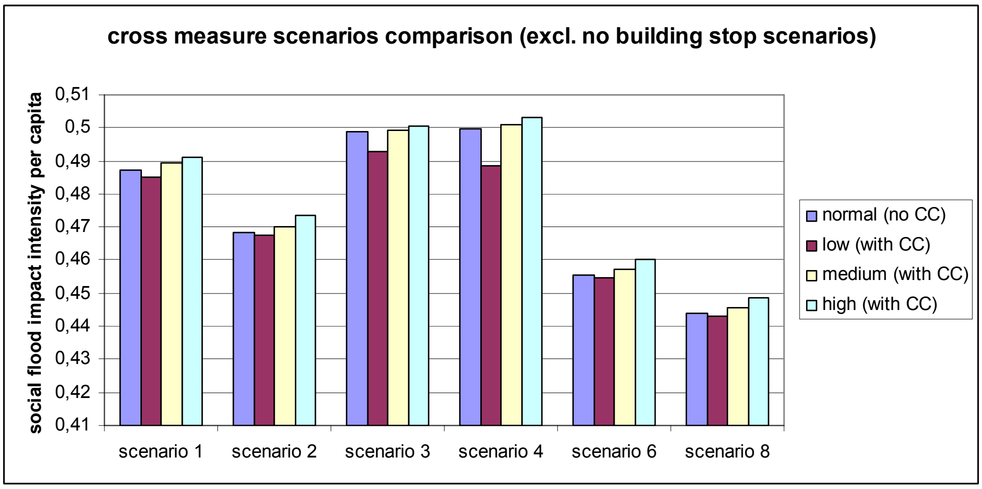

Figure 38: Cross measure scenario comparison

3.3.2.6 Economic impacts

For the communes of Ninove and Geraardsbergen located in the Dender basin, a similar analysis has been carried out for different flood events. Several trends have been highlighted:

For the commune of Ninove:
- The highest damage was recorded in the business category
- No damages are recorded for the farm category

For the commune of Geraardsbergen:
The distribution of damage between the various categories of goods is similar to that found in the case study of Esneux (i.e. that themain damagesare recorded in the housing category)
- The majority of the damages is located in the town of Geraardsbergen
- The damage costs recorded for the agriculture are relatively small
- A big difference in total damages costs is observed between the different flood events

3.3.2.7 Ecological impacts

The floodplain site has some natural values, but does not demonstrate well developed natural values due to fragmentation and drainage. The dominant vegetation types at the site are permanent grassland and poplar plantations, which is representative for the all floodplain within the 25-year flood extent (table 28). These two vegetation types can cover many different species, which are only to a limited extent represented in the secondary mapping units of the Biological Valuation Map. The flood vulnerability maps integrate this secondary mapping layer.

A large part of the floodplain thus has vegetation communities that are to some extent resilient to flooding, but are probably situated in non-optimal conditions (recovering from flood events). Poplar is a tree species that is well adapted to grow at moist locations and it is also capable to deal with flooding. Flooding does not exclude poplar cultivation, although it may limit the productivity. For ecological values this is no problem, since the ecological values are created by the undergrowth, rather than the actual poplar stand. The BVM-grassland vegetation classification is to general to make conclusions. Many of these poorly drained floodplains are actively drained to allow use of the grasslands. This is necessary because most of the time, the river water level is above the floodplain ground level. Presence of flood tolerant vegetation communities can be ascribed rather to the presence of non-flood related water logged conditions. These conditions can in theory be present at many more sites that are now artificially drained.

The flood types 5, 6, 8, 9, 10, 13, 30, 34, 38, 43 and 45 occur at the lowest parts of the floodplain and are flooded when water levels rise above 20 cm (table 24 and figure 34B). This annually flooded area is selected from the flood vulnerability maps and the different flood vulnerability maps are cumulated by the number of days that the flood type occurs. Flood-type 43 occurs 129 days, over a 14 year period at the lowest parts of the floodplain. These inundations occur in early summer and do create problems for non adapted species. The most severe impact is to be observed at sites with lower ecological values (grassland with ecological values). Grasslands will be severely impacted, but their recovery is rather quick. The sites with high ecological value are not that severely impacted by these inundations. The flood vulnerability is also relatively high because the poplar-plantations are impacted by these flood types. The secondary and tertiary vegetation mapping units for these sites are Grey Alder, Willow and Queen of the Meadow, which are rather flood tolerant.

The cumulative flood impact is visualised in Figure 39C. The cumulative flood impact should be normalised for interpretation and comparison to the ecological impact of the different climate change scenarios. The ecological impact as seen in Figure 39-C is the reference situation without climate change. At some locations vegetation will be already adapted and at other locations vegetation is able to recover from the flood impact. In some cases the high flood impact is caused by indeterminacy in interpretation of the BVM classification. Based on the flood impact of the base scenario, one can exclude vegetation types that are not-adapted at sites with a high flood impact. By doing this, a better and more credible comparison of flood impact can be realized.

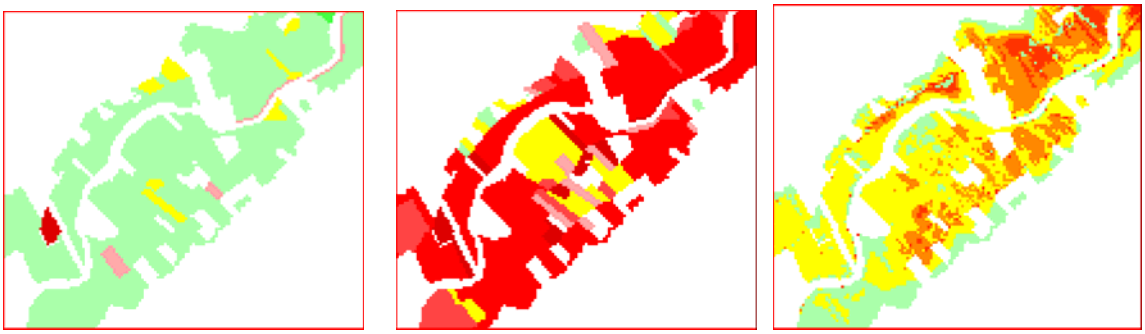

Figure 39: Examples of flood vulnerability maps: a) FT 5: winter, > 5 years, > 14 days, > 50 cm; b) FT 43: summer, yearly, < 14 days, 20-50 cm. c) Cumulative (relative) flood impact on current vegetation for the given period between 1987 and 2001 (10 equal interval classification).

3.3.2.8 Flood risk evaluation

The economic and social flood risks are key criteria for evaluating adaptation scenarios for attenuating the effects of flooding. These evaluation criteria are calculated on the basis of the expected economic damage and social impact respectively. The procedure for calculating flood risk is described in section 2.1 of this report. The evaluation of the adaptation scenarios requires a consistent framework. In order to arrive at a correct ranking, assessment of the ENPV and assessment of the cost-effectiveness of the scenarios a number of additional parameters has to be defined: the project horizon and the discount factor. In addition it is also important to know how the impacts (costs and benefits) evolve over time as the economy grows and the population changes.

The key assumptions underlying the calculation of the flood risk are the same as those for the Ourthe case study. First the influence of climate change on flood risk is evaluated.

Second the effectiveness of the scenarios concerning the reduction of the economic and social flood risk is analysed.

Impact of climate change on flood risk

The current level of flood protection is probably not optimal as we consider the current climate. Climate, however, is changing and is expected to change flood risk. Figure 40 and Figure 41 show what effect climate change may have on social and economic flood risk. The trend is very similar for both types of risk. Flood risk decreases in a low climate change scenario. If the mean climate change scenario would become reality flood risks are expected to increase slightly. In case we find ourselves in a high climate change scenario flood risk is expected to increase by about one fifth. From a flood management point of view the problem, however, is one does not know what climate scenario is the most likely.

Assumptions concerning the economic growth and population dynamics do not change the fact that flood risk will get worse if climate change hits hard. The same holds for the project horizon and the discount rate. It is, however, true that both the absolute and relative importance of the difference in flood risk between the no climate change scenario and the various climate change scenarios will change as the assumptions are changed.

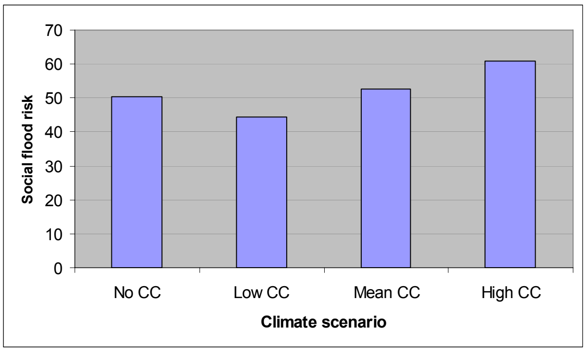

Figure 40: Social flood risk for the baseline scenario given different climate change scenarios

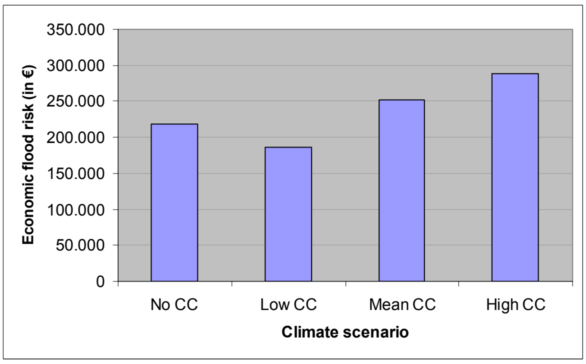

Figure 41: Economic flood risk for the baseline scenario given different climate change scenarios

Effectiveness of the scenarios

Flood protection scenarios

The current situation, the baselines scenario + dikes, reduces both the social and economic flood risk, see Figure 42 and Figure 43. This reduction, however, is very limited. In a low climate change scenario the expected social flood risk even slightly increases. The other two adaptation scenarios are expected to increase both the social and economic flood risk, at least on the basis of the flood data that have been used for calculating flood risks. One should, however, not overlook that the retention basins undue some of the negative effects on flood risk the weirs are expected to generate. The construction of the weirs seems, at least from these results, not a good option for reducing flood risk along the Dender in the communities of Geraardsbergen and Ninove. One should be very careful with this conclusion as this is not in line with what can be logically expected. The replacement / adaptation of the old weirs should normally create a higher drainage capacity, at least partly removing the bottleneck the old ones were. Nevertheless replacing / adapting them will be very beneficial for their operational safety (reducing both the risk for the workers operating them and the risk of failure). Besides, this investment would also be beneficial for the navigability of the Dender. A similar picture can be drawn for the planned retention basins. Although these basins are expected to reduce flood risk along the Dender they are primarily constructed for solving flood problems locally, along the side branches of the Dender.

Assumptions concerning the economic growth, population dynamics, project horizon and discount rate do influence the results, but all the conclusions made above remain valid. Changes in the assumptions would both change flood risk in the baseline scenario and the adaptation scenarios considered.

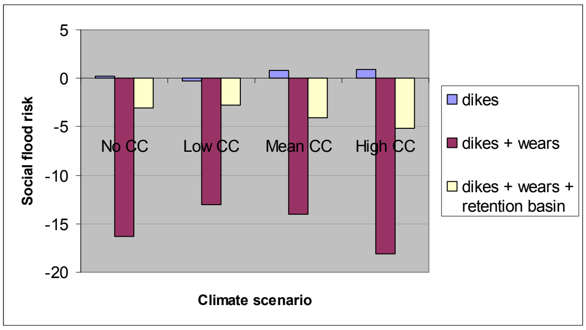

Figure 42: Avoided social flood risk for the scenarios given different climate change scenarios

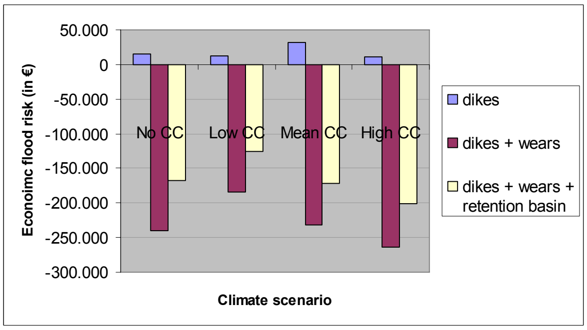

Figure 43: Avoided economic flood risk for the scenarios given different climate change scenarios

Alternative adaptation scenarios

Figure 44 and Figure 45 show that a strict building stop, risk communication and flood forecasting and warning do reduce flood risk. It is very clear that a strict building stop, preventing new constructions are raised in flood risk is the most effective measure. Risk communication and improved flood forecasting and warning are much less effective. This picture is, however, a bit too simple. Risk communication is e.g. important in creating the necessary support for a strict building stop. The same is true for ensuring flood warning, which effectively results in a general deployment of private protection measures and the evacuation of valuable items.

The majority of the avoided social and economic flood risk is realised by preventing the increase of values in the flood plain. These figures depict the avoided flood risk if the 42 available building lots located in flood risk area are left untouched. The avoided flood risk can even increase tenfold in the event of developing the residential expansion areas in the study area located in flood risk area. By this we wish to illustrate that the importance of a policy that either prevents the construction in risk areas or requires buildings to be adapted can hardly be overestimated.

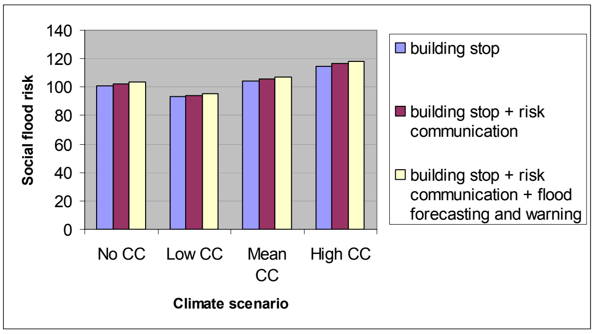

Figure 44: Avoided social flood risk for the scenarios given different climate change scenarios

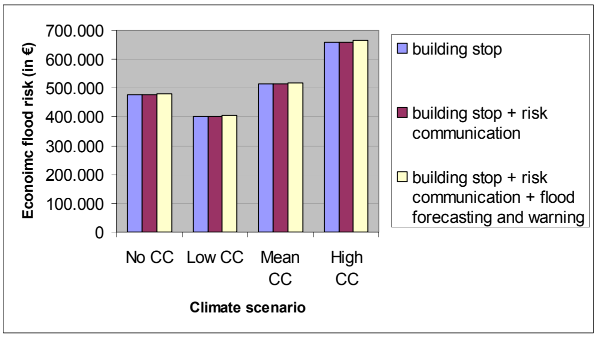

Figure 45: Avoided economic flood risk for the scenarios given different climate change scenarios

3.3.2.9 Scenario evaluation

Flood protection scenarios

Ranking

The ranking of the scenarios on the basis of multiple evaluation criteria, see Figure 46, shows that the current situation, the baseline scenario + dikes, (scenario 1), is by far the most attractive scenario. The scenario dikes + weirs + retention basins (scenario 3) is the least preferred scenario. The most dominant factor influencing the ranking of the scenarios are the investment and operating and maintenance costs. The avoided social and economic flood risk do not play a determinative roll in the ranking of the scenarios. All the above conclusions are equally valid for the three climate change scenarios.

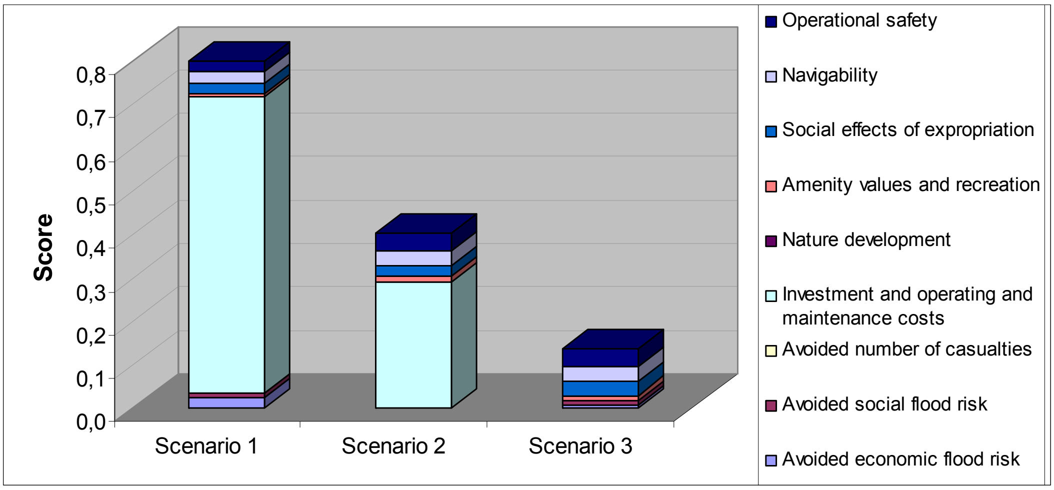

Figure 46: Ranking of the scenarios given the current climate.

Sensitivity analysis

Changes in the assumptions concerning the economic growth, population dynamics, project horizon and/or discount rate would not change the hierarchy of the scenarios. Such changes do influence the economic performance or expected contribution to welfare of the scenarios, but this cannot be analysed by means of a multi-criteria analysis.

Figure 47 illustrates the ranking of the scenarios is not altered when the weights attributed to the different evaluation criteria vary. A big increase in the weight attached to the evaluation criterion 'operational safety' would bring the scenarios that consist of the replacement /

adaptation of the old weirs more in line with the current situation, the baseline scenario + dikes, in terms of desirability.

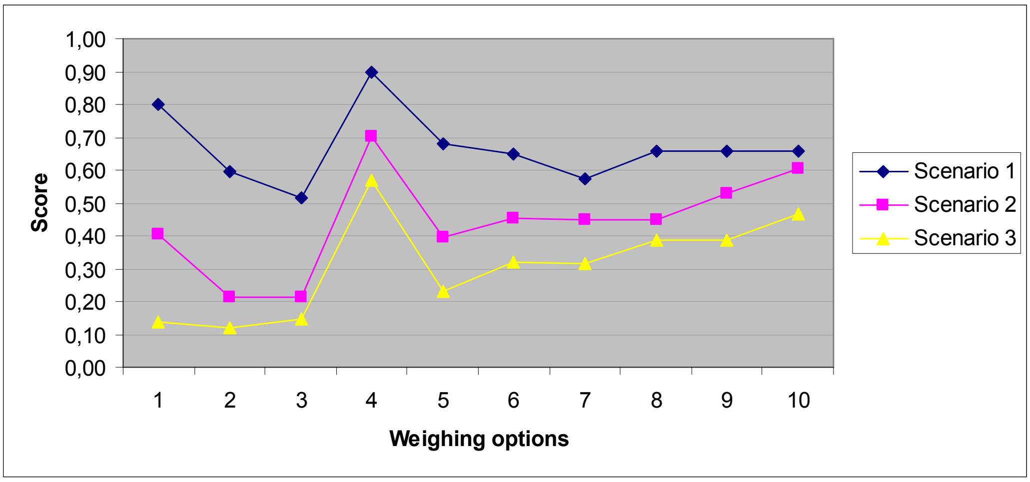

Figure 47: Sensitivity of the scores and ranking of the scenarios to changes in the weights given the current climate

Uncertainty analysis

Both the scores attributed to the scenarios for the different criteria as well as the weights attributed to the criteria are somewhat uncertain. In order to analyse how sure we can be about the ranking of the scenarios we have defined the uncertainty margins of the scores, see Table 30. The upper and lower bound uncertainty margin of the weights has assumed to be 25% for all criteria. Given these uncertainty margins, and all other assumptions kept constant, the ranking of the scenarios will stay unchanged. Changes in the assumptions like the project horizon, economic growth and population dynamics will not influence this. Only a sharp decrease in the discount rate, considerably lower than the 2,5% we take as a minimum, would make the scenario dikes + weirs to become more preferable to the scenario dikes.

Evaluation criteria	Low	High
Avoided economic flood risk	20%	20%
Avoided social flood risk	30%	30%
Avoided number of casualties	30%	30%
Investment and operating and maintenance costs	10%	10%
Nature development	20%	20%
Amenity values and recreation	20%	20%
Social effects of expropriation	20%	20%
Navigability	20%	20%
Operational safety	20%	20%

Table 30: Score uncertainty

Economic net present value

The evaluation of the ENPV confirms the ranking of the adaptation scenarios in all climate scenarios. The ranking, however, does not tell whether the scenarios studied create or destroy welfare. A scenario that is expected to have a positive ENPV can be accepted a scenario with a negative ENPV should be rejected. From Table 31 we conclude that all scenarios should be rejected, given the basic assumptions concerning the project horizon, discount rate, economic growth and population dynamics.

	Scenario 1	Scenario 2	Scenario 3
No CC	-324.797	-4.670.260	-7.599.492
Low CC	-331.296	-4.592.870	-7.743.211
Mean CC	-304.240	-4.649.008	-7.795.569
High CC	-326.303	-4.699.494	-7.827.399

Table 31: ENPV of the adaptation scenarios given the basic assumptions

Keeping all other parameters unchanged, a change in the project horizon, the economic growth or population dynamics would not alter the economic performance of the scenarios considered. Changes in the discount rate, to the contrary, do have an important influence on the scenarios that consist of the renewal / adaptation of the weirs. At a discount rate of 1,5%, which is really low, the scenario dikes + weirs is expected to be have a positive ENPV in all climate change scenarios, see Table 32. The economic performance of the current scenario remains nearly unchanged. The economic performance of the scenario dikes + weirs + retention basins becomes much less negative.

	Scenario 1	Scenario 2	Scenario 3
No CC	-339.085	1.116.443	-1.813.243
Low CC	-360.805	1.382.794	-1.803.945
Mean CC	-267.245	1.192.042	-1.985.587
High CC	-343.834	1.016.266	-2.094.499

Table 32: ENPV of the adaptation scenarios given the basic assumptions, using a discount rate of 1,5%

Alternative adaptation scenarios

The scenario where only a strict building stop is foreseen (in addition to the baseline scenario + dikes) ranks first. This is because the costs of risk communication and an improvement of the current flood forecasting and warning system are relatively high compared to the expected marginal increase in the avoided flood risk. As has been argued already this does not mean one should use this as an argument for not investing in risk communication and an improved flood forecasting and warning system. Awareness of the flood risk is necessary to create acceptance for a strict building stop, to encourage people to be prepared to do the right things before, during and after a flood etc. A flood forecasting and warning system does not only reduce flood risk in the sense that people are more likely to (try to) save part of their properties. The extra information of the forecasting system can help water managers, rescue workers, etc. to make the right decisions at the right time.

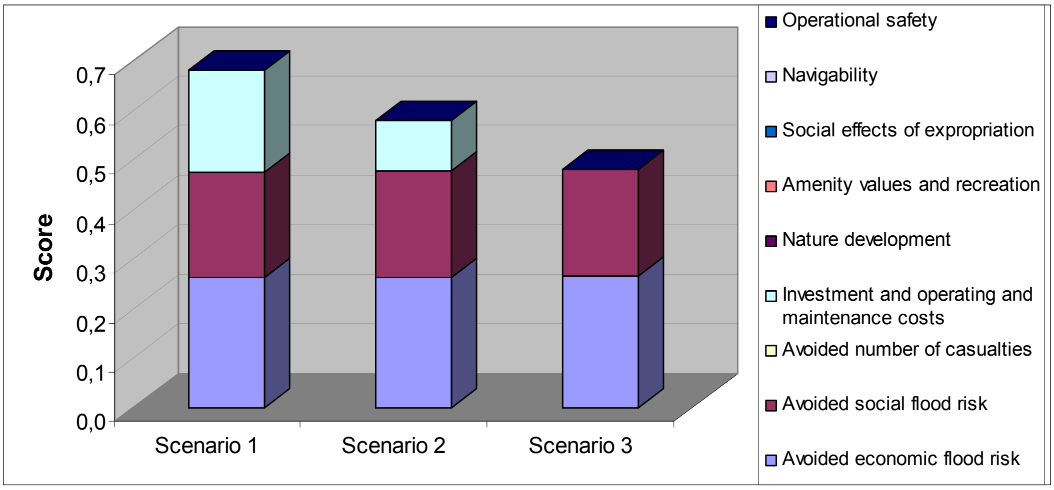

Figure 48: Ranking of the scenarios given the current climate.

From the information in Table 33, we can conclude all scenarios have a highly positive effect on welfare in all climate scenarios. A strict building stop is expected to yield the highest net benefits. We, however, need to account for the fact that the benefits of risk communication and an improved flood warning and forecasting system are underestimated. To the extent the awareness of the actual flood risk is limited a strict building stop may be harder to enforce. In case one would also develop the residential extension areas located in flood risk area in a scenario without strict building stop the ENPV of the alternative adaptation scenarios would be around 15.000.000 € for all scenarios, given the basic assumptions and the current climate.

	Scenario 1	Scenario 2	Scenario 3
No CC	674.140	553.644	436.922
Low CC	542.779	421.322	303.150
Mean CC	740.751	620.717	504.801
High CC	992.485	874.435	761.497

Table 33: ENPV of the adaptation scenarios given the basic assumptions

Because of the relatively limited costs the alternative adaptation scenarios considered have a high cost effectiveness, see Table 34. This ratio increases more than tenfold if also the residential extension areas located in flood risk area would be developed in a situation without a strict building stop.

	Scenario 1	Scenario 2	Scenario 3
No CC	3,56	1,75	0,99
Low CC	2,87	1,34	0,69
Mean CC	3,91	1,97	1,14
High CC	5,24	2,77	1,72

Table 34: Cost effectiveness of the adaptation scenarios given the basic assumptions

3.3.2.10 Conclusion / comparative analysis of both case studies

In both case study areas climate change will effectively change flood risks. In a low climate change scenario flood risks are expected to decrease while in a high climate change scenario risks are expected to increase. Given the current climate and assuming a strict building stop in both case studies the absolute flood risk is more than a factor 20 higher in the Ourthe case study. In addition, the expected increase in flood risk when climate change would hit hard is relatively much more important along the Ourthe than along the Dender.

In both case study areas three flood protection scenarios have been studied. Where the scenarios studied along the Ourthe are expected to be all effective in terms of risk reduction this is not the case for the scenarios studied in the Dender case study.

For the Ourthe case study the permanent heightening of flood protection walls would yield a positive ENPV in all climate change scenarios considered, given the basic assumptions. The highest benefits are to be expected in the high climate change scenario. The scenario with the mobile walls will only contribute positively to welfare in the high and mean climate change scenario. The activation of the ancient flood plain should only be carried out if the high climate change scenario is expected to arise. The rehabilitation of an old canal is not an interesting option. It would definitely destroy welfare as it is a very expensive measure and it is not expected to reduce flood risk more than the other measures considered are expected to do, even to the contrary. Changing certain parameters does influence the results. A drop in the discount rate increases the ENPV of all scenarios, while an increase has the opposite effect. The opposite is true for the economic and population growth, the higher the growth the higher the expected ENPV of the scenarios. A drop in the importance of the social flood risk relative to the economic flood risk will decrease the overall benefits and thus the ENPV of the scenarios. The ranking of the scenarios is not altered, given the changes in the assumptions just described. Changes in the values of the scenarios on certain decision criteria or in the weights attached to the decision criteria can possibly influence the ranking of the scenarios. The uncertainty analysis and sensitivity analysis learned the chance is relatively limited any other scenario will be more attractive than the permanent heightening of walls.

With the exception of the baseline scenario + dikes the scenarios considered for the Dender consist of multiple measures. This makes it harder to evaluate the contribution of individual measures. The current situation, the baselines scenario + dikes, reduces both the social and economic flood risk. This reduction, however, is very limited. In a low climate change scenario the expected social flood risk even slightly increases. The other two adaptation scenarios are expected to increase both the social and economic flood risk, at least on the basis of the flood data used. The flood retention basins are expected to undo some of the negative effects the renewal/adaptation of the wears is expected to generate. The scenario representing the current situation ranks first, but still its ENPV is negative. The ENPV of the scenario with dikes + weirs and the scenario with dikes + weirs + retention basins is even much lower.

The construction of the weirs seems, at least from these results, not a good option for reducing flood risk along the Dender in the communities of Geraardsbergen and Ninove. One should be very careful with this conclusion as this is not in line with what can be logically expected. The replacement / adaptation of the old weirs should normally create a higher drainage capacity, at least party removing the bottleneck the old ones were. Nevertheless replacing / adapting them will be very beneficial for their operational safety (reducing both the risk for the workers operating them and the risk of failure).. Besides, this investment would also be beneficial for the navigability of the Dender. A similar picture can be drawn for the planned retention basins. Although these basins are expected to reduce flood risk along the Dender they are primarily constructed for solving flood problems locally, along the side branches of the Dender.

Protection against flooding is getting ever more expensive. Taking additional technical measures is not straightforward as flood risks are generally relatively limited in Belgium. Quite often much has been done already to limit both the occurrence and impacts from flooding. In addition it is ever more difficult to get the necessary permits for raising a measure that has a clear spatial impact. In response to these observations one should deliberately look at complementary, non-technical, measures focussing on prevention, awareness raising, disaster management and the creation of the necessary coping capacity. In order to leave the conceptual discussion about such complimentary measures we evaluate the possible benefits of a building stop, risk communication and flood forecasting and warning.

Preventing the increase of the values located in flood risk area has shown to be a very interesting measure both in terms of its likely effect on welfare as its cost-effectiveness. Limiting the values-at-risk should be the corners stone of any flood management strategy. One however, should, make sure both the common people as well as the administrations are well aware of the actual flood risk in order to ensure the acceptance of a strict building stop.

4 POLICY SUPPORT

4.1 Introduction

Climate change is expected to influence river flooding and consequently also socio-economic and ecological systems. Even with swift and firm global action on the reduction of greenhouse gas emissions a certain degree of climate change is inevitable. Therefore, mitigation measures must be complemented by adaptation efforts. As authorities are ought to maximise welfare they should try to strive for a cost-effective allocation of the available resources.

Initially an overview is presented of the added value of the project for promoting decision making about adaptation to flooding in a climate change context. The methods and tools that have been developed and/or improved, however, are an aid to (political) decision making not a substitute for it. Thereafter a number of recommendations are formulated, touching policy making in various ways.

4.2 Added value of the project

During the past four years the project has contributed to a solution for a number of important pitfalls in current flood risk assessment and management practices:

- the integration of climate change effects in flood modelling;
- the development of assessment methods of the flood risk to social and ecological systems;
- the development of a practical tool for evaluating adaptation scenarios that are characterised by multiple not readily comparable evaluation criteria.

4.2.1 Progress concerning the quality and the number of impacts assessed in a climate change context

Climate change is expected to alter flood probabilities and risks. However the impact of climate change is uncertain not considering the likely effects of climate change is definitely not a good option. The effect of climate change on flood probabilities has been accounted for in two ways. Discharges into the river Dender have been derived for a low, mean and high climate change scenario, reliably representing the overall range, on the basis of hydrological modelling. Historical time series of evapotranspiration and rainfall have been altered, using the perturbation tool produced in the framework of the CCI-HYDR project. Discharges into the river Ourthe have been derived for a low, mean and high climate change scenario by applying direct assumptions on the perturbation of historical hydraulic data.

The hydraulic models developed and used for simulating flood characteristics for both case studies are fundamentally different. The fully dynamic quasi-3D flow model for the Ourthe and the 1D conceptual hydraulic model for the Dender both have their (relative) advantages and disadvantages. In the framework of the ADAPT project the model for the quasi-3D flow model has been exploited for the Ourthe case study. It offers a very valuable tool for the in-depth (ex-ante) analysis of structural adaptation measures on the dynamics of the river system and thus the optimal design of adaptation measures. The model that has been set up for the Dender, on the other hand, illustrates the possibilities of a conceptual model. Such a model offers opportunities for creating an integrated model that encompasses the different detailed models, potentially promoting integrated decision making.

Indirect and intangible effects of flooding to social and ecological systems are largely disregarded. To the extent that not all important effects are accounted for decisions are at risk of being suboptimal. Methods have been developed to assess the effects of flooding on social and ecological values, making use of a robust flood risk assessment framework.

The social flood impact tool provides a comprehensive, quantitative method that covers people's exposure, vulnerability and adaptive capacity in a standard way. Because of its relative simplicity and comprehensiveness water managers are offered a very valuable instrument for assessing the impact of one of the most important effects of flooding.

For what concerns the assessment of the ecological effects, the merit of the project is particularly the understanding of the ecological impact mechanisms in flood management. It is demonstrated that the methodology for ecological impact assessment is applicable, although data was not available to compare climate change scenarios. The cumulative ecological impact is calculated and visualised for a study site. The methodology and particularly the flood vulnerability maps (based on the Biological Valuation Map), can be applied at any site in the Flemish Region where advanced flood modelling is able to produce the necessary variables.

However, economic flood risk modelling is relatively well established. Currently there is no accurate methodology for assessing flood losses from damage to housing and household goods geared to the Belgian situation. The use of an object oriented approach in combination with a validated damage function and an object specific valuation permits a more accurate appraisal of the damage to housing and household goods.

4.2.2 Progress concerning the deliberation of adaptation measures

The quantification of social and ecological flood risk on the basis of state-of-the-art methods does not guarantee that adaptation scenarios are deliberately assessed on all available information. As long as scenarios are characterised by multiple evaluation criteria that are not readily comparable, certain criteria risk being overlooked and/or over- or undervalued by the decision makers. Reducing the arbitrary aspect of the evaluation of several flood management options requires finding out from the public where their preferences lie; how the value the different impacts. Below guidance is provided for deriving sensible weights or, even better, the value of a standard unit of social impact. The model that has been developed goes beyond the execution of an extended CBA, bus also offers various options for carrying out a comprehensive Monte Carlo based risk and sensitivity analysis as analysing, channelling and accounting for uncertainties is an important part of the decision making process. The decision support model is currently also being used in the framework of a study for the Flemish Environmental Agency and the CLIMAR project which is financed by the Belgian Science Policy.

4.3 Specific recommandations

4.3.1 Impact assessment methods

The ecological and social impact assessment methodologies ideally require the spatially explicit prediction of additional flood characteristics like the rise rate, flow velocity, duration, season of occurrence and water quality. The WOLF-2D hydraulic model is more suitable to generate spatially distributed event classification than the conceptual model. Where the prediction of flood risk to socioeconomic values requires predicting flooding for low probability events, the ecological impact assessment rather requires predicting flooding for high to very high probability events. Hydrological models still need to be improved to provide insight in the effects of climate change on the occurrence, timing and duration of frequent inundations and are to be validated for such high probability events.

The BELSPO SUDEM-CLI project will address the issues on predicting changes in high probability events and related parameters for ecological impact assessment.

Economic, social and ecological impact assessment techniques depend on good quality and detailed input data for both validating the methods as well as running them. The assessment methods could be much more accurate if information from private as well as public institutions had been made more accessible; possibly under strict conditions of use and confidentiality. Besides, it would be interesting to have flood damages recorded in a way that directly meets research needs. To this end a protocol has to be set up. The German HOWAS database could serve as an example in this respect.

Limited understanding of the complexity of socioeconomic systems complements the data limitations. It is hard to fix the relative importance of different flood characteristics, vulnerability characteristics and parameters describing people's and communities' adaptive capacity. This has been overcome on the basis of a Delphi study. However, it is advisable to take track of new insights, if possible asking people directly about these issues, and adapt the assessment methodology correspondingly.

In recent years flood management has undergone a paradigm shift towards giving rivers more space, potentially creating chances for nature development. Adaptation should therefore not only focus on limiting the negative effects of flooding, but also on maximising possible opportunities. Flooding is a crucial and fundamental aspect of water system functioning. It is a regulating service, affecting the timing and quality of water flows (Tockner, Malard et al. 2000; Jungwirth, Muhar et al. 2002; Junk 2003). Naturalised floodplains and associated ecosystems develop themselves in such a way that they retain water after flooding, allowing functions such as denitrification, carbon sequestration, water retention, nursery functions etc… The concept of ecosystem goods and services is ideal for assessing the benefits of restoring natural floodplains, and CBA-tools have already been developed to include regulating ecosystem services (Liekens, Staes et al. 2010). The assessment of ecosystem goods and services will become common practice in the assessment of the effects of climate change in general and the design of adaptation measures in particular. In the case of the Dender, naturalisation of downstream floodplains would increase the flood risk, because they now primarily serve as emergency flood storage and agricultural land. Opportunities to increase both flood storage and ecological values are to be sought in the upstream parts of the catchment. Furthermore, these upstream wetland ecosystems could function as water retention systems and mitigate the severity of low flow periods. A truly source oriented measure would be reforestation on the most erosion/run-off sensitive slopes, infiltration ponds, the implementation of buffer strips and the distributed implementation of small in-stream water retention structures in the upstream rivers.

4.3.2 Mapping and channelling uncertainties

Uncertainty in the assessment of the effects of adaptation scenarios in a climate change context is important and has many sources. The various sources of uncertainty are identified. Interactions between the various sources of uncertainty are generally well understood, but the problem is to really quantify uncertainty. More efforts should be directed to the quantification of uncertainties. Priority should be given to those uncertainties that are either easy to eliminate or are most important in the overall result.

When studying adaptation measures to flooding, much of the uncertainty is related to the effect of climate change. In the context of adaptation measures to flooding the assessment of the (perturbated) discharge into the river is particularly problematic. 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 events.

4.3.3 Involvement of people and stakeholders in the assessment and optimisation of adaptation scenarios

The assessment and optimisation of adaptation scenarios requires specific deliberations and value judgements. Different stakeholders in and around the flood risk area each have their specific ideas regarding the way how the impacts from flooding should be tackled. It is a fact that very often the realisation of flood protection measures is complicated and delayed by stakeholders using all possible means to defend their proper interests.

The decision support tool developed builds to an important extent on the foundations of an MCA. An MCA framework can be used perfectly for organising stakeholder involvement. In this way, it is possible to deal with the values, perceptions and objections of the relevant actors.

All relevant stakeholders have to be involved. The process should be open, equal and fair. Stakeholders should be able to present their own values and perceptions. Information is equally distributed and available to the participants. In the beginning of the process, goals should be clearly communicated in order to streamline expectations. Processes that are too slow or go to fast are likely to result in disappointed participants. A moderate speed of subsequent meetings is necessary to retain the broad involvement of the stakeholders. There are various methods to enhance participation, such as brainstorming, citizens' panel, focus groups, group model building, public hearings, reframing workshop, review sessions, role playing game, round table conference and scenario building.

A participatory MCA brings about a new role for both governments and experts. Experts need to provide the necessary information and to assemble the necessary knowledge for assessing the problem and defining the solutions. Governments are both stakeholders as well as the facilitator of the participatory process.

4.3.4 Use of the tools and methods by water managers

The methodologies developed or optimised in the framework of the ADAPT project can be used ad hoc. The research team, however, advises water managers to formalise the assessment of measures that may impact flood probabilities. The economic and social flood risk methodology should be programmed and assessed in a standard way. The same holds for the evaluation of measures by means of a decision support tool. If this is not done the assessment of adaptation measures risks staying without obligation on the one hand and the ad hoc assessment of adaptation measures risks being very expensive and lacking in quality on the other hand.

With a view to the popularisation of the use of the social impact of flooding in the assessment of measures it is advisable to monetise the value of a unit of social impact. It is better to fix a good, representative value once and for all, which can be used in any evaluation in Belgium. There is a risk that *ad hoc* case studies of specific assessments will be too arbitrary. Another real risk is that the lack of a well-founded and accepted value for a unit of social impact will constitute a serious barrier to effectively account for the social impact of flooding.

The value of a unit of social impact can be determined by a valuation study. There are several valuation methods that can be useful in this respect. Each method, however, has its specific advantages and disadvantages. The quality of the study has to be sufficiently high to ensure the results are accepted by both policy and decision makers. This means the valuation study should be a primary valuation study with a carefully designed questionnaire. The answers to this questionnaire should allow an original value for a unit of social impact to be determined by means of statistical processing,. Because people may find it hard to state their willingness to pay directly we advise using the contingent ranking method.

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A similar analysis can be conducted for a standard unit of ecological impact. The valuation of ecological effects can, however, to a certain extent also be based on existing values which can e.g. be taken from the Environmental Costing Model for Flanders.[4]

4.3.5 Set up of a knowledge network

The methodology developed and optimised in the framework of the project can and should be further improved. In order to take track of the latest insights and developments, discuss and disseminate the latest advancements and organise coordinated research, the set up of a knowledge network could prove very valuable. The research team believes this is a cost-effective way of pushing forward both the integral assessment of measures and the quality of the assessment methodologies.

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[4] See http://www.emis.vito.be/index.cfm?PageID=371 for more information on the Environmental Costing Model for Flanders.

4.3.6 Looking beyond the impact of climate change

Climate change is expected to increase flood risk to both socioeconomic and ecological systems. There are, however, other evolutions that one should not lose sight of. A false feeling of safety may increase the value of socioeconomic systems in a flood risk area. Concerning ecological values and biodiversity one could point at anthropogenic evaluations that manipulate and disturb natural gradients and processes. Climate change robustness is determined by the spatial extent of nature areas, their connectivity to other nature areas and the existence of gradients and heterogeneity within sites. This is especially a problem in the highly fragmented Flemish region. Climate change will aggravate and accelerate the decrease in biodiversity, but climate change is not the primary driver. It will only accelerate ongoing decline. Adaptation measures can, however, compensate for climate change induced biodiversity losses if one opts for robust and spatially interconnected nature structures.

4.3.7 Search for robust, no regret measures and strategies

Achieving an optimal level of adaptation to flooding is not straightforward. Uncertainties about e.g. the preferences of the public, climate change etc. remain high and much effort has to be put into identifying, developing and evaluating measures. Climate change, however, is expected to generate many other impacts. In order to address climate change in an optimal manner one should find the right balance between doing nothing, adaptation and mitigation. To be able to take decisions on how best to adapt, it is essential to have access to reliable data on the likely socioeconomic and ecological impacts of climate change and the costs and benefits of the available mitigation and adaptation options. Where adaptation is very much local, mitigation requires a global coordination.

As this picture is overly complex and as uncertainty is endemic to the problem of climate change it is hard to establish an optimum strategy. It therefore is essential to seek:

- Robust adaptation strategies. These are strategies that perform reasonably well compared to the alternatives across a wide range of plausible scenarios and that can evolve over time in response to new information.
- No regret options. These are adaptation measures whose socio-economic benefits exceed their costs whatever the extent of future climate change.
- Win-win options. This are adaptation measures that have the desired result in terms of minimizing the climate risks or exploiting potential opportunities but also have other social, environmental and economic benefits.

Adaptation has to be mainstreamed into sectoral policies. In each policy area there should be a review of how policies could be re-focused or amended to facilitate adaptation.

5 DISSEMINATION AND VALORISATION

The valorisation and dissemination of the research results is developed along three essential lines:

5.1 Communication tools: website and summary sheets

As far as communication tools are concerned, the website developed for the ADAPT project allows for a permanent dissemination of the project results. Another aim of the project is to develop a series of summary sheets ("fiches") that provide the essential information on the different adaptation measures in a concise and reader-friendly manner. Those "fiches", will be available on the ADAPT website.

5.2 Communicating the results to officials, scientists and stakeholders

In order to do so, the partners in the project have participated in conferences at national and international level, and have organised follow-up committee meetings on a regular basis.

5.2.1 Conferences and workshops

Regarding conferences and workshops, the means to communicate the results of the project include presentations, poster presentations, and publications in the proceedings of conferences.

At national level:

- Poster presentation - *Belgian Biodiversity Forum. Biodiversity and Climate Change*. 21-22 May 2007. Brussels. (ECOBE – UA & HIVA – KULeuven).
- Poster presentation - *Congres Watersysteemkennis*. 6-7 December 2007. Antwerp. (ECOBE – UA & HIVA – KULeuven).
- Presentation by Hussain Saleh and publication in the proceedings: H. Saleh, G. Allaert & R. De Sutter. W. Kellens, Ph. De Maeyer, W. Vanneuville "Intelligent Decision Support System Based Geo-Information Technology and Spatial Planning For Sustainable Water Management in Flanders, Belgium.", - *International Urban Water Conference*. 15-19 September 2008. Heverlee. (ARCADIS).
- Presentation by Renaat De Sutter, invited speaker, R. De Sutter, I. Coninx, L. De Smet & A. Courtecuisse: "Can we measure social effects of climate change? Case floods – adapt", and poster presentation J. Ernst, B.J. Dewals, S. Detrembleur, P. Archambea, S. Erpicum & M. Pirotton: Detailed 2D hydrodynamic modeling as an onset for evaluating socio-economic impacts of floods - *Conference "Water and Climate change"*, organised jointly by the Embassy of France & the "Leerstoel Integraal Waterbeheer Vlaanderen". 14-15 October 2008. Antwerp. (ARCADIS & HIVA – KULeuven & HACH – ULg).

At international level:

- Paper presentation, I. Coninx and K. Bachus (2007), "Integrating social vulnerability to floods in a climate change context." - *International Conference on Adaptive and Integrated Water Management, Coping with Complexity and Uncertainty*. 13 November 2007, Basel, Switzerland. (HIVA-KULeuven)

- Presentation by Wim Kellens, "full A1 – paper" and publication in the proceedings: W. Kellens, P. Deckers, H. Saleh, W. Vanneuville, Ph. De Maeyer, G. Allaert & R. De Sutter. "A Gis Tool for Flood Risk Analysis in Flanders (Belgium)" - *Risk Analysis 2008. Sixth International Conference in Computer Simulation Risk Analysis and Hazard Mitigation*. 5 - 7 May 2008. Cephalonia, Greece. (ARCADIS).:
- Presentation and publication in the proceedings: J. Ernst, B.J. Dewals, W. Hecq & M. Pirotton. "Integrating Hydraulic and Economic Analysis for Selecting Flood Protection Measures in the Context of Climate Change"– *4th International Symposium on Flood Defence.* 6-8 May 2008. Toronto, Canada. (HACH – ULg & CEESE – ULB).
- Participation and publication in the proceedings: B.J. Dewals; E. Giron, J. Ernst, W. Hecq & M. Pirotton. "Integrated Assessment of Flood Protection Measures in The Context of Climate Change: Hydraulic Modelling And Economic Approach" – *International Conference "Environmental Economics*. 28-30 May 2008. Cadiz, Spain (HACH – ULg & CEESE – ULB).
- Paper presentation Coninx I. (2008). "Tackling Climate Change Risks. Stakeholder Participation in Flood Risk Management." - *ECPR Summer School on Environmental Politics and Policy.* 7th – 18th July 2008. Keele, United Kingdom. (HIVA-KULeuven)
- Presentation and publication in the proceedings: S. Erpicum, B.J. Dewals, P. Archambeau, S. Detrembleur & M. Pirotton. "Detailed 2D numerical modeling for flood extension forecasting" - *River Flow 2008*. 3-5 September 2008. Izmir, Turkey. (HACH – ULg).
- Presentation by Renaat De Sutter and publication in the proceedings: L. De Smet, & De Sutter. "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" - *IWA-conference "Watershed and river basin management"*. 4-5 September 2008. Budapest, Hungary. (ARCADIS).
- Presentations, poster presentations and publications in the proceedings :, S. Detrembleur, P. Archambeau, S. Erpicum & M. Pirotton. "Detailed 2D Flow Simulations as an Onset for Evaluating Socio-Economic Impacts of Floods" and J. Ernst, B.J. Dewals, S. Detrembleur, P. Archambeau, S. Erpicum & M. Pirotton. "Integration of Accurate 2D Inundation Modeling, Vector Land Use Database and Economic Damage Evaluation"- *European Conference on Flood Risk Management – Flood Risk 2008.* 30 September – 2 October 2008. Oxford, United Kingdom. (HACH – ULg).
- Presentations and publications in the proceedings: J. Ernst, B.J. Dewals, S. Detrembleur, P. Archambeau, S. Erpicum & M. Pirotton. "Une modélisation hydrodynamique 2D et un SIG à haute resolution pour évaluer des mesures de protection contre les inondations en milieu urbain" - *3èmes Journées doctorales en Hydrologie Urbaine*. 14-15 October 2008. Nancy, France. (HACH – ULg).
- Paper presentation: J. Ernst , I. Coninx, B.J. Dewals, S. Detrembleur, S. Erpicum, K. Bachus and M. Pirotton. "Planning flood risk reducing measures based on combined hydraulic and socio-economic impact modelling at a micro-scale." - *7th International Conference on water resources conservancy and risk reduction under climatic instability*. 25 – 27 June 2009, Limassol. Cyprus. (HACH-ULg and HIVA-KULeuven)

- Paper presentation I. Coninx and K. Bachus. "Social vulnerability assessment of flood prone areas in Flanders". *15th Annual International Sustainable Development Research Conference*. 5-8 July 2009. Utrecht. The Netherlands. (HIVA-KULeuven)
- Presentation by Walter Hecq " ADAPT Project (2006-2010) Towards an integrated decision support tool for adaptation measures. Case study: Floods . Overview and a few late developments" – *ERA-net CIRCLE Climate Impact Research Coordination for a Larger Europe, Workshop Design and Use of Decision Support Systems*. 16 July 2009. Bonn, Germany. (CEESE).
- Paper presentation B. Dewals, I. Coninx, J. Ernst, K. Bachus, M. Pirotton, S. Erpicum, S. Detrembleur. "Social Flood Impacts in Urban Areas: Integration of Detailed Flow Modeling and Social Analysis of Flood Consequences." - *33rd IAHR 2009 Congress – Water Engineering for a sustainable environment*. 9 – 14 August 2009. Vancouver, British Columbia. (HACH-ULg and HIVA-KULeuven)

Participations in Workshop

- Participation in *LNV Klimaat Adaptatiedag*. 14 September 2006. Rotterdam, Nederland. (HIVA-KULeuven)
- Participation in IWA conference. *Innovations in coping with water and climate related risks*. 25-27 September. Amsterdam. (Arcadis Belgium nv)
- Participation in Workshop for professionals: *Vlaamse innovaties in watersysteemkennis: thema oppervlaktewaterkwantiteit*. 12 October 2006. Katholieke Universiteit Leuven. (HIVA-KULeuven and Arcadis Belgium nv)
- Participation in Workshop *Millenium Ecosystem Assessment: implications for Belgium.* 27 October 2006. Brussels (HIVA-KULeuven)
- Participation in Workshop *Improving assessment of the environment in impact assessment.* 15 January 2007. Ecologic. Brussels. (HIVA-KULeuven)
- Participation in Workshop for professionals: *Mensen en watersystemen: duurzaam te combineren?* 31 May 2007. University of Antwerp. (HIVA-KULeuven and Arcadis Belgium nv)
- Participation in Workshop *Limiting global climate change to 2°C: the way ahead for 2020 and beyond.* 28 June 2007. Institute for European Environmental Policy. Brussels. (HIVA-KULeuven)
- Participation in IWA conference *Risks of climate change to water management and utilities - from impact analysis to adaptation.* 5 October 2007. Amsterdam. (ARCADIS Belgium nv)
- Participation in EWA congress. Water Management and Climate Change. 5 November 2007. Brussels. (Arcadis Belgium nv)
- Participation in *Congres Watersysteemkennis*. 6-7 December 2007. Antwerpen. (HIVA-KULeuven and Arcadis Belgium nv)
- Participation in *Workshop Worldbank: Climate change and development*. 27 May 2008. Brussels (HIVA-KULeuven)
- Participation in *"Green Week": Only One Earth* organised by the European Commission. 3-6 June 2008. Brussels (CEESE – ULB and Arcadis Belgium nv).

- Participation in Workshop on Water and Adaptation to Climate Change, United Nations – Economic commission for Europe*, Meeting of the parties to the convention on the protection and use of transboundary watercourses and international lakes.* 1-2 July 2008. Amsterdam, The Netherlands. (CEESE – ULB).
- Participation in *Freude Am Fluss*, 22 – 24 October 2008. Nijmegen, Nederland (HIVA-KULeuven)
- Participation in SUDEM-CL workshop *Impact of climate change on river hydrology and ecology*. 29 January 2009. Wilrijk. (Arcadis Belgium nv – organization ECOBE - UA)
- Participation in the Conference *Climate Change Adaptation and Water – the need for stronger cooperation in Europe*. 12-13 March 2009, Baden-Württemberg (CEESE – ULB).
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- Participation in - *"Green Week" Climate Change: act and adapt,* organised by the European Commission. 23-26 June 2009. Brussels (CEESE – ULB and Arcadis Belgium nv).

5.2.2 Follow-up committees

Follow-up committees, beyond providing input and feedback also offer the opportunity to communicate the project results to different actors, among whom are, officials, decision-makers and stakeholders. These actors belonged to the following categories:

National and regional administration

- Région wallonne – MET, Direction générale des Voies hydrauliques (DGVH), Direction des Etudes hydrologiques et des Statistiques (D.212), Service d'études hydrologiques (SETHY)
- Région wallonne – Direction générale des Ressources Naturelles et de l'Environnement (DGRNE)
- Vlaamse Overheid – Departement Mobiliteit en Openbare Werken
- Vlaamse MilieuMaatschappij, afdeling water (IVA-VMM)
- Vlaamse Overheid – Vlaamse Leefmilieuadministratie, afdeling water (AMINAL), nu Afdeling Milieu-, Natuur- en Energiebeleid.
- Vlaamse Overheid – Waterbouwkundig Laboratorium (WLH)
- Région de Bruxelles-Capitale, Ministère, Direction de l'eau (AED)
- Institut Bruxellois pour la gestion de l'environnement, «Recherche, données et prospectives » (IBGE –BIM)
- Service Public Fédéral Santé, Sécurité de la chaîne alimentaire et environnement – Direction générale Environnement

European Institutions

- European Environment Agency – Climate Change and Energy
- Participation in events organised by European Institutions (see above)

Private Sector

- Aquafin nv – Wastewater treatment (sole shareholder Flemish Environmental Holding)
- Assuralia – Union professionnelle des entreprises d'assurances / Beroepsvereniging van verzekeringsondernemingen
- HydroScan nv – Onhafhankelijk bureau gespecialiseerd in waterbeheer
- Probabilitas – Consultancy on statistics and quantitative risk analysis

Environmental NGOs and non-profit organisations

- Regionaal Landschap Zenne, Zuun en Zoniën vzw – Coordinator Interreg IIIb ESPACE project.

5.3 Creating a network

Regarding contacts with other research groups and the development of synergies and clustering, a close cooperation was developed with the project CCI-HYDR.
The project has also benefited from the networking activities of the different partners.

5.4 Dissemination of the final results

Regarding the dissemination of the **final results**, several journals are targeted, amongst others:

- **Risk Analysis** ("Published on behalf of the Society for Risk Analysis, *Risk Analysis* is ranked among the top 10 journals in the ISI Journal Citation Reports under the social sciences, mathematical methods category - and is designed to meet the need for organization, integration, and communication and provide a focal point for new developments in the field." www.wiley.com).

- **Natural Hazards** ("Journal of the International Society for the Prevention and Mitigation of Natural Hazards" "Natural Hazards is devoted to original research work on all aspects of natural hazards, including the forecasting of catastrophic events, risk management, and the nature of precursors of natural and technological hazards." www.springer.com).
- **Disasters** ("*Disasters* is a major, peer-reviewed quarterly journal reporting on all aspects of disaster studies, policy and management. It aims to provide a forum for academics, policy-makers and practitioners for high-quality research and practice related to natural disasters and complex political emergencies around the world". www.wiley.com)

- **Journal of flood risk management** ("*Journal of Flood Risk Management* provides an international platform for knowledge sharing in all areas related to flood risk. Its explicit aim is to disseminate ideas across the range of disciplines where flood related research is carried out and it provides content ranging from leading edge academic papers to applied content with the practitioner in mind". www.blackwellpublishing.com)

- **Engineering Applications of Computational Fluid Dynamics** ("The journal is a truly interdisciplinary forum, and publishes original contributions on the latest advances in numerical methods in fluid mechanics and their applications to various engineering fields including aeronautic, civil, environmental, hydraulic and mechanical. The journal has a distinctive and balanced international contribution, with emphasis on papers addressing practical problem-solving by means of robust numerical techniques to generate precise flow prediction and optimum design, and those fostering the thorough understanding of the physics of fluid motion." http://www.cse.polyu.edu.hk).

- **The Journal of Multi-Criteria Decision Analysis** ("The Journal of Multi-Criteria Decision Analysis was launched in 1992, and from the outset has aimed to be the repository of choice for papers covering all aspects of MCDA/MCDM. The journal provides an international forum for the presentation and discussion of all aspects of research, application and evaluation of multi-criteria decision analysis, and publishes material from a variety of disciplines and all schools of thought. Papers addressing mathematical, theoretical, and behavioural aspects are welcome, as are case studies, applications and evaluation of techniques and methodologies" http://www3.interscience.wiley.com

- **Ecological Economics** ("The journal is concerned with extending and integrating the study and management of "nature's household" (ecology) and "humankind's household" (economics). This integration is necessary because conceptual and professional isolation have led to economic and environmental policies which are mutually destructive rather than reinforcing in the long term. The journal is transdisciplinary in spirit and methodologically open". "Specific research areas covered include: (…) methods of implementing efficient environmental policies" www.elsevier.com)

- **Climate Policy** ("Climate Policy presents the highest quality refereed research and analysis on the policy issues raised by climate change, and provides a forum for commentary and debate. It addresses both the mitigation of, and adaptation to, climate change, within and between the different regions of the world. It encourages a trans-disciplinary approach to these issues at international, regional, national and sectoral levels". Amongst the topics covered : "Analysis of mitigation or adaptation policies and strategies (at macro-, meso- and/or micro- scales)" www.earthscan.co.uk)

- **Global Change Biology** ("*Global Change Biology* exists to promote understanding of the interface between all aspects of current environmental change and biological systems, including rising tropospheric O3 and CO2 concentrations, climate change, loss of biodiversity, and eutrophication". www.wiley.com)

- **Journal of Hydrology** ("The Journal of Hydrology publishes original research papers and comprehensive reviews in all the subfields of the hydrological sciences including water based management and policy issues that impact on economics and society". www.elsevier.com)

6 PUBLICATIONS

Books

Dewals, BJ, Giron E, Ernst J, Hecq W, Pirotton M. 2008. Integrated assessment of flood protection measures in the context of climate change: hydraulic modelling and economic approach", 10p in the book "Environmental Economics and Investment Assessment II", Aravossis, K., Brebbia, C.A. and Gomez, N. Ed., 2008. WIT Press Southampton, Boston, 316 pp.

Journal article

Coninx I., De Smet L. and De Sutter R. (2007) Naar een evenwaardige beoordeling van ecologische, economische en sociale effecten van de toename aan overstromingen door de klimaatverandering: het ADAPT-verhaal. In Water. Jaargang 2007. nr. 33. pp. 30-36.

Conference papers

The conference papers are listed at section IV (Dissemination and Valorisation), under point 2.

Research reports

De Groof A., Hecq W., Coninx I., Bachus K., Dewals B., Pirotton M., El Kahloun M. Meire P., De Smet L. and De Sutter R. (2006) General study and evaluation of potential impacts of climate change in Belgium. Belspo. 75p.

Coninx I. and El Kahloun M. (2007) Case study of the Dender basin. Focus on Geraardsbergen and Ninove. Belspo. 36p.

Giron E., Joachain H., Hecq W., Coninx I., Bachus K., Dewals B.J., Ernst J., Pirotton M., Staes J., Meire P., De Smet L and De Sutter R. (2009), ADAPT - towards an integrated decision tool for adaptation measures - case study: floods, ex-post report. Belspo, 100p.

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9 APPENDICES

9.1 APPENDIX 1: COPY OF THE PUBLICATIONS

Will be available on the website of the ADAPT project

9.2 APPENDIX 2: MINUTES OF THE FOLLOW-UP COMMITTEE MEETINGS

Will be available on the website of the ADAPT project

9.3 APPENDIX 3: DETAILED RESULTS

Results I Ourthe: number of affected people

Scenarios						affected people													Risk people exposed			
						m^3/s													CC scenarios and return periods			
	building stop	risk communcication	flood forecasting and warning	private protection + evacuation of valuable items	508	520	570	726	742	762	798	834	876	919	943	963	1007	1138	Normal	Low	Mean	High
base scenario	yes	no	average	low	90,09	108,57	187,11	965,58	1000,23	1053,36	1168,86	1270,5	1425,27	1674,75	1718,64	1753,29	1838,76	2039,73	2399,557	1250,504	1722,087	3299,321
canal rehabilitated	yes	no	average	low	85,47	99,33	173,25	921,69	974,82	1018,71	1099,56	1191,96	1344,42	1422,96	1469,16	1727,88	1797,18	2032,8	2261,815	1195,248	1638,321	3134,802
wall heightening-heightened	yes	no	average	low	90,09	108,57	187,11	863,94	914,76	974,82	1104,18	1245,09	1429,89	1690,92	1739,43	1776,39	1859,55	2053,59	2297,845	1175,007	1621,851	3172,093
floodplain activated	yes	no	average	low	83,16	106,26	180,18	960,96	995,61	1046,43	1159,62	1261,26	1409,1	1660,89	1709,4	1734,81	1820,28	1972,74	2340,371	1162,353	1632,135	3187,852

Results II Ourthe: social flood impact intensity

Scenarios					social flood impact intensity														social flood impact intensity			
					m^3/s														CC scenarios and return periods			
	building stop	risk communcication	flood forecasting and warning	private protection + evacuation of valuable items	508	520	570	726	742	762	798	834	876	919	943	963	1007	1138	Normal	Low	Mean	High
base scenario	yes	no	average	low	43,69	51,27	85,87	467,12	490,42	520,67	573,70	622,76	697,90	790,18	821,08	876,47	929,79	1080,99	1149,745	1053,122	1279,794	2055,506
canal rehabilitated	yes	no	average	low	42,55	48,27	81,96	450,84	477,59	496,88	549,61	596,84	669,77	717,86	745,14	860,46	906,96	1072,76	1104,359	1011,858	1228,217	1973,556
wall heightening-heightened	yes	no	average	low	43,69	51,27	85,87	396,09	425,06	453,59	513,56	578,63	669,92	770,55	811,86	870,65	924,83	1071,70	1070,332	980,909	1187,308	1925,832
floodplain activated	yes	no	average	low	34,08	42,67	73,44	447,01	591,95	497,61	548,17	596,13	662,41	751,01	782,28	832,98	882,74	984,23	1046,980	966,361	1175,673	1955,771

Results I Dender: number of affected people

										number of affected people																				affected number of people (2010 - 2100)			
										CC scenarios and return periods																				CC scenarios and return periods			
										Normal					Low					Mean					High								
	Baseline	Dikes	Wears	Flood areas	building stop	risk communcication	flood forecasting and warning	private protection + evacuation of valuable items	Type of imact / risk	250	100	25	10	5	250	100	25	10	5	250	100	25	10	5	250	100	25	10	5	Normal	Low	Mean	High
1	yes	no	no	no	yes	no	average	0,2367	SFI	40,5	38,1	23,8	16,7	11,9	26,2	19	14,3	7,14	7,14	50	40,5	28,6	19	14,3	57,1	47,6	40,5	38,1	21,4	103,2700	91,7300	107,5700	124,1200
current situation 2	yes	yes	no	no	yes	no	average	0,2367	SFI	38,1	30,9	26,2	19	11,9	26,2	23,8	14,3	9,52	7,14	45,2	33,3	26,2	21,4	14,3	64,3	61,9	35,7	28,6	26,2	106,9200	95,8400	110,1200	126,8900
3	yes	yes	yes	no	yes	no	average	0,2367	SFI	40,5	38,1	35,7	23,8	14,3	35,7	23,8	16,7	9,52	7,14	47,6	38,1	26,2	23,8	16,7	66,6	57,1	40,5	35,7	35,7	133,6100	116,8200	133,4000	157,8700
4	yes	yes	yes	yes	yes	no	average	0,2367	SFI	38,1	35,7	28,6	16,7	11,9	35,7	23,8	16,7	9,52	7,14	45,2	38,1	33,3	23,8	14,3	61,9	54,7	38,1	35,7	28,6	106,8200	96,7300	113,0800	131,5200
5a	yes	yes	no	no	no	no	average	0,2367	SFI	133	121	100	88,1	64,3	107	95,2	64,3	54,7	47,6	136	119	107	80,9	61,9	164	159	126	109	100	333,8300	300,0300	330,9700	374,9400
5b									SFI (+ pot building lots)	802	790	768	756	733	775	764	733	723	716	804	787	775	749	730	833	828	794	778	768	3105,1400	3071,4300	3101,8900	3146,2200
6	yes	yes	no	no	yes	yes	average	0,2367	SFI	38,1	30,9	26,2	19	11,9	26,2	23,8	14,3	9,52	7,14	45,2	33,3	26,2	21,4	14,3	64,3	61,9	35,7	28,6	26,2	106,9200	95,8400	110,1200	126,8900
7a	yes	yes	no	no	no	no	yes	0,4733	SFI	133	121	100	88,1	64,3	107	95,2	64,3	54,7	47,6	136	119	107	80,9	61,9	164	159	126	109	100	333,8300	300,0300	330,9700	374,9400
7b									SFI (+ pot building lots)	802	790	768	756	733	775	764	733	723	716	804	787	775	749	730	833	828	794	778	768	3105,1400	3071,4300	3101,8900	3146,2200
8	yes	yes	no	no	yes	yes	yes	0,71	SFI	38,1	30,9	26,2	19	11,9	26,2	23,8	14,3	9,52	7,14	45,2	33,3	26,2	21,4	14,3	64,3	61,9	35,7	28,6	26,2	106,9200	95,8400	110,1200	126,8900

Results II Dender: social flood impact intensity

										social flood impact intensity																				social flood impact intensity (2010 - 2100)			
										CC scenarios and return periods																				CC scenarios and return periods			
										Normal					Low					Mean					High								
	Baseline	Dikes	Wears	Flood areas	building stop	risk communcication	flood forecasting and warning	private protection + evacuation of valuable items	Type of imact / risk	250	100	25	10	5	250	100	25	10	5	250	100	25	10	5	250	100	25	10	5	Normal	Low	Mean	High
1	yes	no	no	no	yes	no	average	0,2367	SFI	20,8	19,1	11,8	8,2	5,62	12,8	9,29	7,11	3,25	3,25	24,8	20,2	14,1	9,29	7,11	29	24,8	20,4	18,9	10,5	50,3245	44,5037	52,6280	60,9793
current situation 2	yes	yes	no	no	yes	no	average	0,2367	SFI	19,4	15,3	12,5	8,78	5,43	12,7	11,2	6,71	4,34	3,25	23,1	16,6	12,7	9,87	6,71	32,8	31,5	16,7	14	12,5	50,0821	44,7907	51,7614	60,0733
3	yes	yes	yes	no	yes	no	average	0,2367	SFI	21,1	19,7	17,8	11,8	7,11	16,6	11	7,85	4,02	3,25	24	20,1	12,7	11,8	8,41	34	29,1	21,1	18,2	17,6	66,6756	57,5744	66,6194	79,0428
4	yes	yes	yes	yes	yes	no	average	0,2367	SFI	20,1	18,2	14,3	8,41	5,83	15,6	11,8	7,85	3,25	3,25	23	20,1	16,7	11,8	7,32	31,7	28	20,1	18,2	14,3	53,3920	47,2608	56,6707	66,1707
5a	yes	yes	no	no	no	no	average	0,2367	SFI	51	40,5	29,9	19,4	12	32,4	23,8	14,4	10,9	9,82	55,9	45	31,2	23,6	15,4	75,7	68,6	46,1	35,7	27,6	94,4575	84,4405	99,1958	118,0370
5b									SFI (+ pot building lots)	383	372	362	351	146	364	356	148	144	143	388	377	363	356	347	406	401	378	368	360	1043,764	930,244	1196,589	1215,934
6	yes	yes	no	no	yes	yes	average	0,2367	SFI	18,9	14,8	12,1	8,54	5,29	12,3	10,9	6,53	4,23	3,17	22,5	16,2	12,3	9,6	6,53	31,9	30,6	16,3	13,6	12,1	48,6982	43,5632	50,3302	58,4121
7a	yes	yes	no	no	no	no	yes	0,4733	SFI	50,9	40,4	29,8	19,4	12	32,3	23,8	14,4	10,9	9,8	55,8	44,9	31,1	23,5	15,4	75,5	68,4	46	35,7	27,5	94,3636	84,3605	99,0654	117,8647
7b									SFI (+ pot building lots)	382	372	361	351	145	364	355	148	144	143	387	376	363	355	347	406	400	377	367	359	1040,923	928,273	1194,221	1212,696
8	yes	yes	no	no	yes	yes	yes	0,71	SFI	18,4	14,5	11,8	8,32	5,15	12	10,6	6,36	4,12	3,08	21,9	15,8	12	9,36	6,36	31,1	29,8	15,9	13,2	11,8	47,4646	42,4489	49,0555	56,9167

Appendix D: Flood vulnerability matrix for vegetation types of Flanders