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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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Summary

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SD/CP/02A

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INTRODUCTION

Since the beginning of the Industrial Revolution the scale of human impacts on their natural environment has become increasingly more important, altering the balance in the climate system and thereby triggering effects on temperature and precipitation, and consequently also on heat waves, drought, flooding as well as sea level rise. Climate change is currently regarded as one of the most important threats to the environment and human well-being. If the observed evolutions of our climate persist climate change will put an increasing burden on society and 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 gasses, 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 populations and ecosystems. In the framework of the ADAPT project the focus is on adaptation measures.

The ADAPT project consist of two working packages. The first working package (WP 1) is a synthesis report about the effects of climate change in Belgium, while the second working package (WP 2) is dedicated to the development of the practical methodology for guiding welfare maximising decisions about adaptation measures to increased river flood risk as a result of climate change.

Indeed, the project focuses on the particular problem of river flooding, which is expected to increase because of increasing frequency and intensity of heavy precipitation events. To develop the methodology, two case study areas are selected in the two main Belgian river basins (the Scheldt and the Meuse). One part of the project is devoted to the inventory and assessment of damages caused by floods, while another one concerns the analysis of the adaptation measures. Based on this information, the final task of the project consists in carrying out a cost-benefit analysis and/or a multi-criteria analysis in order to select the most appropriate adaptation measures in terms of integrated cost-effectiveness.

The evaluation of the primary impact of global change induced flooding on river basins is based on hydraulic modelling, which uses as input data either the results of hydrological modelling or directly hydrological data. The results of the hydraulic model are then used as input for the integrated risk assessment models for evaluating flood risk to economic, social and ecological systems.

The subject of climate change is vast and complex and so is the development of a comprehensive methodology for assisting policy makers in deciding about adaptation measures. Therefore, the project is approached in a multidisciplinary way, studying economic, social and environmental impacts as well as their interactions. The ADAPT team is composed of five partners of complementary scientific expertise, belonging to the three pillars of sustainable development, to meet the challenges the integrated analysis of complex problems impose. Besides, the ADAPT project works in close collaboration with the CCI-HYDR project. The output of the CCI-HYDR project, which studies climate change impacts on hydrological extremes along rivers and urban drainage systems in Belgium, serves as input for the ADAPT project.

EFFECTS OF CLIMATE CHANGE IN BELGIUM: GENERAL STUDY

The elaboration and application of a methodology for the selection of adaptation strategies (flood protection measures) in the context of climate change must obviously rely on a proper knowledge of climate change effects on flooding. The general study of the effects of climate change in Belgium serves therefore as a key starting point for WP 2, by exploring the existing knowledge and facts on the issue.

During the 20th century the global average surface temperature has increased by about 0.74°C. The warming has been neither steady nor the same in different seasons or in different locations. The IPCC recognises that as mean temperatures increases the probability of extreme warm days increases too. It is also indicated that standard deviation of temperature is likely to change (IPCCa, 2001).

Although the size of Belgium is relatively limited to enable irrefutable projections about Belgian Climate, the warming trend for Belgium is well established. In Belgium, the last two decades were marked by very high yearly average temperatures. Projections for Belgium, which are only illustrative of the general trend that can be expected, predict an increase in winter temperature between 1.7°C and 4.9°C and an increase in summer temperature between 2.4°C and 6.6°C by the end of the 21st century (Marbaix and van Ypersele, 2004). In addition, more pieces of evidence that climate change is already happening in Belgium can be mentioned: earlier migration of birds have been observed and several species of southern dragonflies become more frequent as a result of increasing temperatures (MIRA, 2005); Belgium has beaten temperature records year after year and heat waves have threatened many lives; in particular the heat wave during summer 2003 caused social, economic and environmental effects.

As regards annual precipitation, historical records in Europe demonstrate very different regional evolutions (increase in the north and decrease in the south). In Belgium, projections for the evolution of winter precipitation during the 21st century show a moderate increase (5 to 20%), while summer precipitation is likely to decrease but quantitative results diverge (from status quo to a decrease by 50%). An increase in the number of very rainy days has already been observed in the north and centre of Europe. In Belgium, the frequency of heavy rainfalls is also expected to rise.

Consequently, the hydrology of river basins will be strongly affected by the changes in temperature, precipitation and evapotranspiration, resulting from climate change. As a result, across much of Europe, flood hazard is considered as likely to increase, along with substantial rises in flood risk in coastal areas. In particular, climate change will lead to increased winter floods in much of Europe (EEA, 2005a).

In Belgium, changes in mean river discharges are found to be either positive or negative, according to diverse climate change scenarios. The result depends on the balance between increased precipitation and higher evapotranspiration and is strongly catchment dependent.

Regarding extreme events, the frequency of recorded floods in Belgium has already increased during the last decades. Major inundations took place in 1995, 1998, 2002, 2003 and 2005. Land use planning is obviously partly responsible for those floods, but variations in winter precipitation and increased frequency of heavy rainfalls will still amplify flood risk. Though it remains difficult to quantify the potential changes in flood frequency various analyses provide already an insight into the most probable evolutions (FLOODSITE, 2006). For instance, a specific study on the river Meuse upstream of Borgharen in Belgium and France predicts a small decrease of average discharge but a clear increase in extreme discharges and variability (5-10%) (Booij, 2003).

DEVELOPMENT OF A METHODOLOGY FOR GUIDING DECISIONS ABOUT ADAPTATION MEASURES TO CLIMATE CHANGE INDUCED FLOODING

As climate change is expected to influence rainfall and evapotranspiration, both impacting river flooding, flood risk management strategies need to account for those effects of climate change on hydrological extremes. Currently, this is not a common practice in Belgium and abroad. (Grinwis M. and Duyck M., 2001; Boukhris et al., 2006). The ADAPT project aims to meet 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 as well as ecological effects. 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 river Ourthe (Meuse basin) and (2) part of 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.

The evaluation of adaptation scenarios for reducing the effects of flooding critically depends on the ex-ante modelling of flood chances and characteristics. This is done by means of ***hydraulic models*** which take the discharge into the river as an input and provide flood maps as an output. The hydraulic modelling approach is different for the two case studies: for river Ourthe, hydraulic boundary conditions are set; while for the Dender, hydrological modelling is performed as an input for the hydraulic model.

The flow simulations for the case study of 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. For the floodplains along river Ourthe, topographic 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 Ministry for Facility and Transport - MET-SETHY). The hydraulic simulations are all performed on a regular grid of 2m by 2m. The model outputs are dense 2D distributions of water depth and flow velocity in the inundated areas, which are the main input data necessary for the subsequent damage evaluation.

Although the hydrodynamic model is perfectly suited for dealing with unsteady flow simulations, including highly transient flows, the steady-state approximation is exploited in the present case. This hypothesis has been demonstrated to be valid as a result of the relatively long duration of the floods, combined with a limited possible storage in the floodplains of the rather narrow valley of river Ourthe. The computation time has been further reduced thanks to an *automatic mesh refinement* technique.

The study is performed for two different return periods, namely 25 and 100 years, for which the best flood protection strategies will be complementary. At the present stage of the research project, simple assumptions have been considered regarding the expected perturbations affecting the peak discharges of the river Ourthe as a result of climate change. Those assumptions will eventually be confirmed and refined by comparison with the outcomes of the parallel project CCI-HYDR.

For each return period and each modelling scenario of river Ourthe, the following three maps have been generated: water depth, flow velocity and increase in water depth. The whole set of results is now available for the partners to evaluate the secondary impacts of flooding. As confirmed by these simulation results, the complexity of topography in the floodplains requires a two-dimensional flow model as the most credible approach to reliably represent the dynamics of inundation flows.

Flood risk modelling assesses the impact flooding has on society. In order to overcome the focus on the direct tangible effects of flooding to economic systems, as in conventional flood risk modelling practice, three complementary flood risk assessment modules are developed, respectively focussing on the effects of flooding to economic, social and ecological systems. The effects of flooding are best expressed in monetary terms, but only if doing so does not increase overall uncertainty. In case the monetisation of effects is not relevant, comprehensive quantitative indicators and/or indices are developed.

The central question when assessing flood risk is "What values derived from (well-functioning) economic, social and ecological systems will be lost as a result of flooding?" All relevant effects of flooding to economic, social and ecological systems have been identified, described, selected and attributed to one of the three risk assessment modules. The risk assessment methods for the three different effects covered greatly build on the same concept of flood risk, which is function of the probability that a flood event will occur and the consequence associated with that event. Practically, risk is made up of four major building blocks: the probability of flooding; the exposure of the elements-at-risk to a flood with certain characteristics; the value of these elements-at-risk and; the vulnerability of these elements-at-risk. The *probability* of flooding directly relates to the return period of foods. The *exposure* of the elements-at-risk is, to an important degree, obtained by hydraulic modelling. The assessment of the *value* of the elements-at-risk is generally less obvious. The elements-at-risk are not always of a direct tangible nature. Consequently, the value society holds for preventing elements-at-risk to be affected cannot always be easily determined. The *vulnerability* of the elements-at-risk is function of their susceptibility, adaptive capacity and resilience to the flood characteristics.

The objective of the flood risk assessment methodology is to come up with an estimate of the probable future flood risk on the one hand and to provide an insight in the distribution of flood risk and related causes on the other hand. This information is the crucial input for identifying adaptation measures.

The assessment of the ***economic impacts of flooding*** on the elements-at-risk, makes use of two methodologies: *(i)* the *market prices method*, based on the price of the losses in terms of market prices, and *(ii)* the *hedonic price method* (HPM), based on the analysis of existing markets. The later approach attempts to identify what price difference can be attributed to a particular environmental difference (inside/outside of the flood area) between properties.

The inventory of damages and their forecasting will be carried out with the help of damage functions. The vulnerability of the elements-at-risk (depending on their susceptibility, adaptive capacity and resilience) is introduced in the risk analysis by means of those damage functions. The object of the development of these damage functions is to represent direct damages caused by flooding on the individual habitat 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).

For the commune of Esneux (Ourthe case study), the analysis of the damage costs and the number of affected goods both indicate that the consequences were very different for each flood event and several trends were observed like the most importance of "housing" damages…

Social effects relate to the changes inundations have on the way people live, work, think and organise (Burdge, 1998). The vulnerability of people, and their social network, to flooding is many times more complex than the vulnerability of tangible assets. People's vulnerability can simply not be approximated via a simple depth-damage function. In the ADAPT project social vulnerability to flooding is being approximated by an index of a number of well-chosen personal characteristics. Based on an extensive literature review and expert judgement the seriousness, being a measure of the value potentially at risk, of various social effects has been determined and expressed by means of semi-quantitative scales. A limited number of

effects e.g. the health effects of flooding can however be monetised via the use of monetary factors borrowed from valuation studies.
The ***ecological effects*** of flooding relate to ecosystem service provision, the benefits people derive from ecosystems, being affected by flooding. Just as the social flood risk assessment methodology, the ecological flood risk assessment methodology is experimental.
For each ecosystem function at risk a specific knowledge table has been drawn up. As for the social vulnerability assessment methodology these knowledge tables serve as a complex, multi-dimensional damage functions. The main problem for including the ecological impacts of flooding in a CBA based decision framework is that the impacts to ecosystems often cannot be quantified very accurately, let alone monetised as the corresponding services are not valued in markets. Alternatively, the likely value of ecosystem service provision is scored by means of a quantitative scale.
Based on the predicted flood risk and a thorough investigation of the causes of the flood problem in the two case study areas, ***adaptation scenarios*** will be identified. The wider costs and benefits of adaptation scenarios also impact on welfare. In many instances stakeholder involvement is of particular importance for the identification as well as the assessment of these costs and benefits. The procedure consists of a checklist for facilitating the identification of the effects. The assessment of related costs and benefits will be carried out on the basis of the guidelines for carrying out socio cost benefits analysis.
For the case study of river Ourthe, the hydraulic effects of several local technical adaptation strategies have already been computed by hydrodynamic simulations, showing the change (reduction) in flood characteristics as a result of the implemented flood defence measures. Those 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. The considered adaptation measures involve either pumping, topography modifications for locally reducing flow resistance and the transformation of passive floodplains into active ones. The latter 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. 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 and leading to a better understanding of the flow paths, which directly influences the optimal design of adaptation measures.
Finally all effects assessed will be combined in an extended ***CBA*** to enable the evaluation of adaptation scenarios. This decision framework prioritises the use of monetised effects but offers a MCA based framework for presenting and dealing with non-monetary information in a balanced way as to make sure decisions – to the extent possible – are made on all information available. Only those adaptation scenarios that are expected to contribute to welfare are worth implementing. Benefits of adaptation scenarios therefore should outweigh associated costs. In order to allow for the optimisation of adaptation scenarios the spatial distribution of flood risk, which will be visualised by means of GIS, constitutes a crucial aid to the evaluation of adaptation measures in a CBA based decision framework.