CP/02

ADAPT - Results

Towards an integrated decision tool for adaptation measures - Case study: floods

DURATION OF THE PROJECT
01/01/2008 – 31/01/2010

BUDGET
1.180.117€

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

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.

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.
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.

a. 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..

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)..

b. 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.

c. 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.

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.

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.

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