SSD

SCIENCE FOR A SUSTAINABLE DEVELOPMENT

FINAL REPORT PHASE I

TOWARDS AN INTEGRATED DECISION TOOL FOR ADAPTATION MEASURES - CASE STUDY : FLOODS

«ADAPT»

SD/CP/02A

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SCIENCE FOR A SUSTAINABLE DEVELOPMENT

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FINAL REPORT (Phase I)

TOWARDS AN INTEGRATED DECISION TOOL FOR ADAPTATION MEASURES - CASE STUDY : FLOODS «ADAPT»

SD/CP/02A

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I. ACRONYMS, ABBREVIATIONS AND UNITS

AMR	Automatic Mesh Refinement
BWK	Biological Value Maps
CBA	Cost-benefit analysis
CC	Climate Change
CCI-HYDR	Climate Change Impact on hydrological extremes along rivers and urban drainage systems (BELSPO Project)
CEESE	Centre for Economic and Social Studies on the Environment
COD	Chemical Oxygen Demand: measures the amount of organic and anorganic pollution of water
DPSIR	Driving force, Pressures, State, Impact and Response
DWA	Diffusive Wave Approximation
ECOBE	Ecosystem Management Research Group
EGS	Ecological Goods and Services
FHRC	Flood Hazard Research Centre
FI	Fish Index
GCM	Global Circulation Models
GEV	Global score for Ecological Values
GHG	Greenhouse Gas
GIS	Geographic Information System
HACH	Applied Hydrodynamics and Hydraulic Constructions
HIVA	Higher Institute for Labour Studies
HPM	Hedonic Price Method
KUL	Katholieke Universiteit Leuven
MCA	Multi-criteria analysis
MEA	Millennium Ecosystem Assessment
MOG	Modeled Flooded Areas
NOG	Natural Flooded Areas
POG	Potential Flooded AreasRCM: Regional Climate Model
RCM	Regional Climate Model
ROG	Recently Flooded Areas
SIA	Social Impact Assessment
SWE	Shallow-Water Equations
UA	University of Antwerp
ULB	Université Libre de Bruxelles
ULg	University of Liège
WP	Working Package

II. EXECUTIVE SUMMARY

A. 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.

B. 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).

C. 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.

III. INTRODUCTION

A. Context

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, February 2007). It is very likely that we will be confronted with an increase in temperature, changes in the quantity, intensity and patterns of rainfall, heat waves, incidences of drought, flooding and a rising sea level. If we do nothing to limit the threats, these phenomena will generate multiple damages that will put an increasing burden on our societies, as is demonstrated by the Stern Review (2006) and IPCC (April 2007).

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 development of adaptation policies is not an easy task due to the uncertainty about the extent, timing and the localisation of climate change impacts. In addition, it is difficult to select the most cost-effective adaptation measures as it is on the one hand difficult to identify and assess all effects and on the other hand it is hard to balance social, economic and ecological effects. The ADAPT project aims to meet the need to support decision-making in developing and selecting adaptation measures by the development of an integrated decision methodology for adaptation measures. In particular, the project focuses on the 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 a second one concerns the analysis of the adaptation measures. Based on this information, the third task of the project is to carry out a cost-benefit analysis or a multi-criteria analysis in order to limit the choices and to select the most appropriate adaptation measures. The ADAPT project lasts four years (15/12/2005 -31/01/2010). This report concerns the work carried out during the half of the project and is therefore limited to the description of the intermediary results. This report consists of three major parts. The first part introduces the objectives and the scientific methodology of the project. In a second part, the research is described in greater dept; highlighting methodologies used and developed and presenting intermediary results. In the final part conclusions and recommendations are made.

B. Objectives

The objective of the ADAPT project is twofold. First, a first aim is to provide a synthesis of the knowledge and facts concerning the effects of climate change in Belgium. This synthesis provides information on the intensity, probable progression in time and uncertainty limit concerning the effects discussed. This synthesis sketches out the context and expectations of climate change impacts in Belgium. Secondly, the core of the ADAPT project is to develop a practical methodology for assisting policy makers in deciding about adaptation measures to climate change induced flooding. For this, the study is based on two case studies located in the two major Belgian river basins.

The synthesis report about the effects of climate change in Belgium is the subject of a first working package (WP 1), while the second working package (WP 2) is dedicated to the development of the practical methodology for guiding decisions about adaptation measures.

WP 1 has been executed during the first year of study and will be upgraded during the next years of the project when new insights arise. WP 1 focuses on the discussion of the primary impacts (temperature, rainfall, etc.) of climate change and how these translate into the impacts on human and natural systems as well as the interaction between the effects on human and natural systems.

The execution of WP 2 started in the middle of 2006 and will continue until the end of the project. The present report only covers the first two years, hereafter referred to as the first phase of the project.

The development of a practical methodology for assisting policy makers in deciding about adaptation measures to climate change induced flooding involves the integration of a number of distinct models and methodologies. The development and integration of these models and methodologies gives rise to a considerable number of intermediate objectives. These objectives have been combined into a number of working packages.

WP 2.1 is about the evaluation of the primary impact of global change induced flooding on river basins. Any evaluation of adaptation measures for reducing the effects of flooding, informing water managers about what measures or combination of measures to adopt, critically depends on flood or hydraulic modelling. As the ADAPT project is dedicated to guiding decisions about adaptation measures in a climate change context flow modelling has to account for the effects climate change may have on flooding. For the case study located in the Meuse basin (river Ourthe, see section V.C on page 41), the flow simulations are conducted by HACH-ULg (by means of the two-dimensional flow model WOLF 2D) at a very detailed resolution, providing thus the most valuable inputs for the evaluation of the secondary impacts. Nevertheless, such high-resolution flow simulations may require significant computational resources; therefore techniques for reducing the computation time have also been investigated.

WP 2.2 concerns the development of three complementary flood risk assessment modules, respectively focusing on the effects to economic, social and ecological systems. The integrated flood risk assessment methodology should, using results of flow simulations as an input, 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. It is imperative that the outputs of each module (= partial flood risk assessments) can be combined and integrated as to be able to calculate the overall flood risk. To this end the relevant effects of flooding on economic, social and ecological systems have to identified and selected. The assessment methodologies of all effects covered by the three risk assessment modules need to be built on a general risk assessment framework. Special attention has to be paid to the assessment of vulnerability of the elements-at-risk.

Based on historical data, local knowledge, simulated flood maps, 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, selected and developed under WP 2.3.

WP 2.4 aims to develop a methodology for evaluating costs of adaptation measures. The costs of the realisation and management of the adaptation scenarios are in the first place the financial costs faced by the project initiator and manager. Besides, the realisation of adaptation scenarios is quasi always accompanied by a number of additional costs and benefits.

Every adaptation scenario has to be evaluated in terms of its costs and benefits in order to support decision making. The primary benefit of adaptation is the flood risk avoided. The methodology for the integration of costs and benefits is to be developed under WP 2.5. On the basis of the input from evaluation of costs and benefits proposed adaptation scenarios may require further fine-tuning.

Finally, recommendations will be drawn up in WP2.6.

C. Scientific methodology

The subject is vast and complex. 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. The project is coordinated by the CEESE-ULB, which coordinates and has coordinated several integrated research projects both on a national and a European level.

The synthesis report about the effects of climate change in Belgium has predominantly been based on a thorough literature review. Besides, a number of interviews were carried out. Finally, information has been completed with expert judgement.

The development of the methodology for assisting policy makers in deciding about adaptation measures to climate change induced flooding requires the use, development, optimisation and integration of distinct models and methodologies. The project is organised along two case-studies which serve as the basis for adapting, extending and/or refining existing as well as developing new methodologies.

In brief the evaluation of the primary impact of global change induced flooding on river basins is based on hydraulic modelling which is fed by the results of climate change modelling and hydrological modelling or data.

The results of the hydraulic model are then fed into risk assessment models for evaluating flood risk to economic, social and ecological systems. In addition, each of these assessment methodologies is made up of modelling systems' vulnerabilities and values.

On the basis of flood risk modelling results and expert knowledge procedures are drawn up for the identification, selection and development of adaptation measures. Likewise assessment procedures are drawn up for the determination of the financial costs of adaptation scenarios as well as their wider costs and benefits to society. Costs and benefits then are integrated in a cost-benefit or multi-criteria framework.

The hydrodynamic model WOLF 2D applied for the case study located in the Meuse basin (river Ourthe, see section V.C on page 410) had been developed previously by the team HACH-ULg, while the development of the various other models and methodologies are based on extensive literature review, discussions with key experts, focus group discussion, expert judgement, consultation of stakeholders, collection of information from authorities, international collaborations and synergies with other international projects (e.g. the German projects REISE and MEDIS, conducted in the framework of the federal research program RIMAX), etc.

During the process, scientific support for the authorities was sought out and contacts were established with the leaders of other BELSPO research projects.

The integrated tool will be built on the basis of criteria such as efficiency feasibility and acceptability framework and their limitations, for which uncertainty analysis will be a permanent preoccupation.

Another issue has been the need to inform the public and to reinforce the joint links between partners, and so a website on the project was created during the first part of the year 2006. This site was conceived both to present the project to interested persons and organisations and as platform for exchanging and sharing information between the different members of the project.

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, constitute a very valuable input for the ADAPT project. The outputs of the CCI-HYDR-project constitute an input into the ADAPT project. The projects have the case study in the Dender basin in common. Cooperation between both projects is facilitated via a core synergy team which discusses advancements and information exchange on a regular basis. The results obtained by the two teams are therefore always being transmitted between the two projects. In the same view, the follow-up committee meetings are held together with the two project partners.

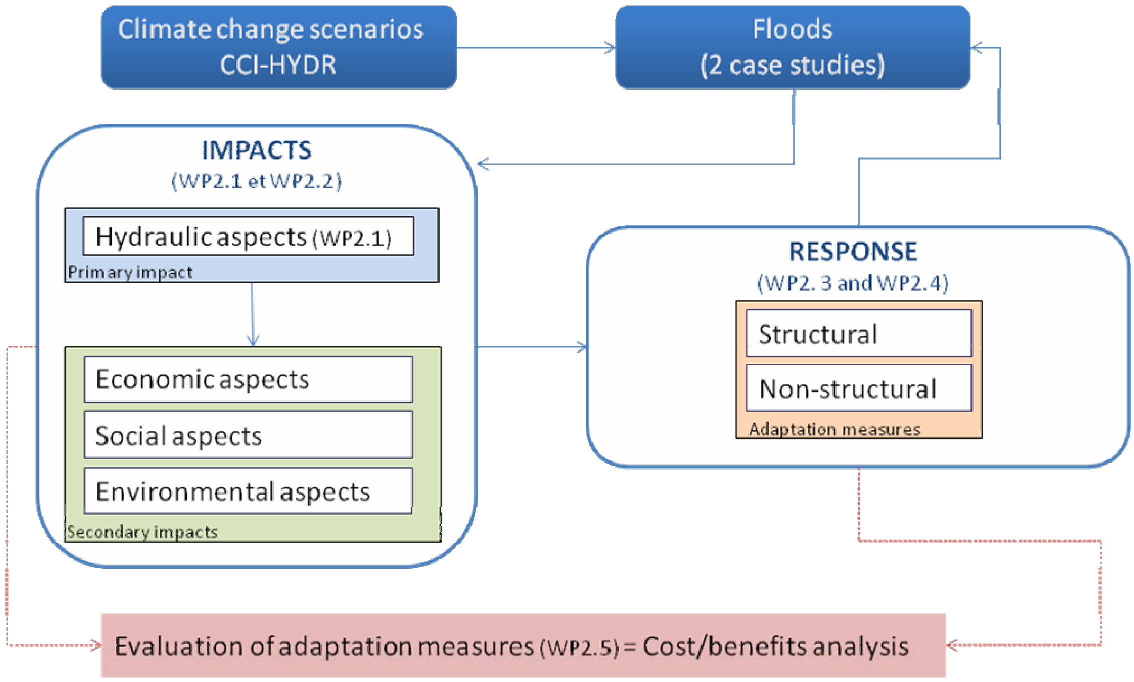

Figure 1: Overview of the whole process

IV. EFFECTS OF CLIMATE CHANGE IN BELGIUM: GENERAL STUDY

A. Introduction

To develop a methodology to select adaptation measures against climate change effects, one has to start exploring the existing knowledge and knowledge gaps on climate change effects in Belgium. Therefore, the main objective of WP 1 is to synthesize the knowledge and facts of climate change effects in Belgium. This will be a valuable input for the work under WP 2 as it provides readily useful data and methodological insights as well as it allows putting things in perspective.

Research and knowledge on climate change impacts in Belgium is rather fragmented. While some issues are thoroughly studied, knowledge on other aspects is limited up till now. The synthesis is mainly based on literature review. This information was completed by a number of interviews and expert judgments. In cases knowledge on Belgian effects was absent, we relied on findings in neighboring countries to estimate potential consequences within the borders.

The final outcome of this WP 1 is the report 'General study and evaluation of potential impacts of climate change in Belgium'. This report is already finished and uploaded on the project website, but might be updated when new insights arise (http://dev.ulb.ac.be/ceese/ADAPT/public_section/Doc/WP1_climate%20change%20in%20Belgium.pdf).

In the following paragraphs, the context of climate change is described. Next, we focuses on the primary impacts of climate change (temperature, rainfall etc…), while the subsequent section explores how these primary impacts are translated into impacts on the human and natural systems as well as the interaction between the effects on human and natural systems.

B. Climate change in an international context

Climate change is mainly due to the emissions of greenhouse gasses which are spread all over the world. A global response, supported by the majority of the world population, is needed to prevent dangerous anthropogenic interference with the climate system. This view was recognised by the international community through the signature of the UN Framework Convention on Climate Change in 1992. The Convention entered into force in 1994. During the third session of the Conference of the Parties (COP), which is the supreme body of the Convention, the Kyoto protocol was adopted. The developed countries are to reduce their emissions of six key greenhouse gasses by at least 5%.

In order to establish a sound understanding of the mechanisms driving the earth's climate and the impacts of the predicted change and to explore response strategies, the Intergovernmental Panel on Climate Change (IPCC) was founded in 1988 by the United Nations Environmental Programme and the World Meteorological Organisation. Today, this panel is the most influential body on climate issues as it groups thousands of specialists worldwide, cooperating to get a better understanding of the climate system and the influence of human-induced climate variations.

C. Evidence of climate change in Belgium

The size of Belgium is too limited to enable irrefutable statements about Belgian Climate. Unlike, for example the KNMI in the Netherlands, we do not have a body making national predictions. Therefore, we need to broaden our focus first to the observations, evolutions and projections for Europe. Regional climate predictions are relatively difficult since small changes in spatial climate patterns can make a substantial difference on the regional scale. Moreover, year to year fluctuations in specific regions are generally more important than changes in the world average. On a larger scale, variations in one region are compensated, levelled out, by opposite variations elsewhere (Beersma, 2004; IPPC, 2001a).

Some evidences that climate change is already happening in Belgium are mentioned hereafter. First, Leysen and Herremans have observed earlier migration of birds (MIRA, 2005). De Bruyn has found that several species of southern dragonflies were more frequent in Flanders because of increasing temperatures (MIRA, 2005). Furthermore, Belgium has beaten mean temperature records year after year (RMI, 2006). And heat waves have threatened many lives; in particular the heat wave during the summer of 2003 caused several social, economic and environmental effects (UNEP, 2004; Sartor, 2004).

D. Primary impacts of climate change

a) Temperature

During the 20th century the global average surface temperature has increased by about 0.74°C (+/- 0,18°C) (IPCC, February 2007). However, the warming has been neither steady nor the same in different season or in different locations. During the 20th century the average for Europe was higher than the global average with a calculated increase of 0.95°C. In Europe, the 1990's has been the warmest decade in the instrumental record. In the northern hemisphere, warming during the past century was the highest of the last 1000 years (EEA, 2004, IPCCa and b, 2001; IPCCa, 2007, Marbaix and van Ypersele, 2004).

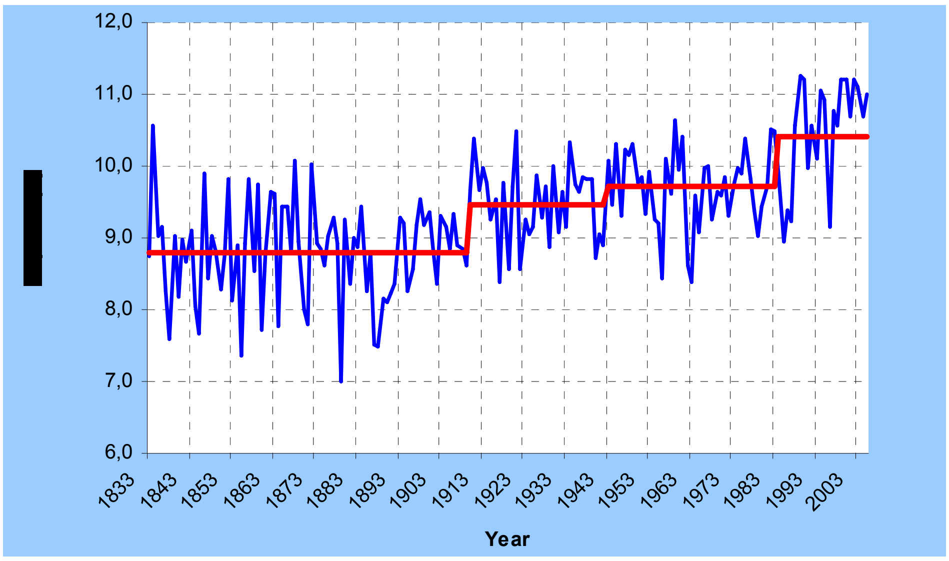

Figure 2 Evolution of the mean annual temperature in Uccle over the period 1833-2005 (RMI, 2006)

The warming trend for Belgium is also well established. In Belgium last two decades were marked by very high yearly average temperatures. Statistical analysis of the records on the average in Uccle since instrumental record allows distinguishing four periods as illustrate in Figure 2. Between 1833 and 1909 the yearly average temperature was 8,8 °C. Between 1910 and 1942 and between 1943 and 1983 the yearly average temperature amounted to respectively 9,5°C and 9,7°C. From 1984 onwards, the yearly average is about 10.4 °C. (RMI, 2006)

Based on different models and for different scenario's, which serve as an input for impact studies, a global average temperature rise from 1,4 to 5,8 C° is put forward for the period 1990-2100 by the Third Assessment Report. Annual mean temperatures in Europe are likely to increase more than the global mean. (IPCCa, 2001; IPCCa, 2007)

A limited simulation, making use of five Global Climate Models and two scenarios (A2, B2), by De Marbaix and van Ypersele predicts an increase in winter temperature between 1,7°C and 4,9°C the end of the 21st century for Belgium. The model results for the evolution in summer temperature vary between 2,4°C and 6,6°C. These projections are, however, only illustrative of the general trend that can be expected. (Marbaix and van Ypersele, 2004)

Predicted temperature increase for Europe, however, will be weakened in case the Gulf Stream, which transports heat from the tropics to higher latitudes, would slow or stop as a result of global warming. Especially in Northern and Western Europe this may lead to considerable cooling (Marbaix and van Ypersele, 2004).

b) Precipitation

Historical records in Europe demonstrate very different regional evolutions in annual precipitation (increase in the north of Europe 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 precipitations in summer are 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, although the frequency of heavy rainfalls is also expected to rise, additional studies are needed to quantify this evolution.

The parallel project CCI-HYDR will provide some more insight into the expected trends for future precipitation in Belgium.

c) Climate variability and extreme weather phenomena

(1) Heat waves and drought

The assessment reports of the IPCC recognise that the warmer mean temperatures increase the probability of extreme warm days. It is also indicated that standard deviation of temperature is likely to change. This means that increased temperature variance raises the probability of higher extreme temperatures as it adds to the already higher mean temperatures. The Third Assessment Report concludes that higher maximum temperatures and more hot days are likely to occur over all land areas (IPCC, 2001b).

If the observed temperature fluctuations between one year and another stay the same as during the 20th century, than it will be very likely that the higher mean temperature will increase the likeliness of extreme hot summers, marked by more serious heat waves. As some researches found that the yearly fluctuations in temperature might become even more pronounced, an increased occurrence of heat waves seems likely. There however is still much uncertainty about this issue (IPPC, 2001a; Marbaix and van Ypersele, 2004).

The impact of higher summer temperatures and the possible increase in the occurrence of heat waves on human and natural systems is also function of precipitation. It is clear that the expected status quo or decrease in summer rainfall will add to the severity of temperature related impacts in summertime.

d) *Directly linked effects*

(1) Sea level rise

There is strong evidence that global sea level gradually rose in the 20th century and is currently rising at an increased rate. Sea level is projected to rise at an even greater rate in this century. Estimates for the 20th century show that global average sea level rose at a rate of about 1.7 mm a year. Tide gauge data for the Belgian coast indicate a relative sea level rise from 2 mm/year for high water, 1.5 mm a year for mean sea level and 1mm/year for low water over the past century (Van Cauwenberghe, 2000). The two major mechanisms behind global sea level rise are thermal expansion of the oceans (water expands as it warms) and the loss of land-based ice due to increased melting. (IPCC, 2007a and den Ouden et al., 2004)

For the different climate change scenarios projected global average sea level is likely to increase by 18 to 59 cm between 1980 - 1999 and 2090 - 2099. Because understanding of the effects driving sea level rise is too limited, these estimates are not an upper bound for sea level rise. Besides, sea level is not rising uniformly around the world. Regional realities can be quite diverse. Sea level rise in Western Europe will not deviate much from the world average. One, however, needs to take into account that the Belgian surface will decline by about 5 cm over the 21st century. (Beersma, 2004; IPPC, 2007a; Marbaix and van Ypersele, 2004).

Impacts of sea level rise also play inland as it directly influences tidal rivers. The increase in high water levels in the river Scheldt, caused by sea level rise, is several times larger than sea level rise itself. Consequently, extreme high water levels will occur with increasing frequency. (IRGT-KINT, 2004; MIRA, 2005)

(2) Flooding

River discharges and groundwater quantities are determined by many factors: climate, land use, soil type, flow regulation, … This complex system of numerous factors interacting with each other will obviously be affected by the changes of temperature, precipitation and evapotranspiration, resulting from climate change (IRGT-KINT, 2001).

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. Indeed, winter precipitation will increasingly take the form of rainfall (due to higher temperature) and will hence provoke rapid run-offs and a higher flood risk (EEA, 2005[a]).

Interesting evaluations of climate change impact on European rivers have been presented during the research project RIBAMOD (Samuels, 1999). For instance, increases in flood peaks of up to 10% were predicted for a basin in Italy, while changes of up to 20% are expected for two basins in Great Britain.

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. This annual drainage change may be in-between 5% increase and 30% decrease (Commission Nationale Climat, 2002).

The effect of climate change on the discharge regime of the Meuse has been specifically studied by means of hydrological simulations performed on the Meuse basin in the framework of the Dutch National research Programe on Global Air Pollution and Climate Change (de Wit et al., 2001).

Monthly averaged time series have been used for climate parameters and no changes have been introduced in the time distribution of rainfall (though in reality this too is likely to be modified).

Results are presented as monthly average discharge change values, which result from both precipitation and evapotranspiration changes.

It has been concluded that climate change would lead to an increase in the average discharge at the end of winter and at the beginning of spring, while a decrease of the average discharge is expected in autumn. However, natural variability of the Meuse discharge is large and differences over long time intervals are rather small, so that it becomes hard to clearly quantify those long term changes.

The results reveal a damping effect. Indeed, changes in the discharge regime are found to be less pronounced than those in the precipitation regime. This lower sensitivity can be explained both by the increase in the evapotranspiration and by the natural storage capacity of the catchments.

Uncertainties are mainly attributable to the selection of the climate change scenario used to perform the simulation. Indeed, the difference in the predicted change of the average monthly discharge regime that results from using different hydrological models is smaller than the difference that results from using different climate change scenarios.

Recent studies show that the increase in the flood peaks in the Meuse River since the 1980s needs to be explained mainly by climate variability rather than by landuse changes (Ashagrie et al. 2006, Tu et al. 2005b). Nevertheless, de Wit et al. (2001) have show that, in terms of future discharge regime in smaller rivers such as Ourthe or Mehaigne, the impact of changes other than climate induced ones (e.g. changes in land use…) may be as important as impacts resulting from climate change. This suggests that relevant adaptation measures (land use changes, water management, flow regulation ...) could reduce peak discharges.

For eight Belgian catchments, Gellens and Roulin (Gellens and Roulin 1998) have simulated impacts of climate change on surface flow as relative values of monthly differences. Relative values enable to compare impacts on rivers with very different discharges but the effects are inevitably enhanced during low flow stages.

According to this study, regarding flood frequency, the Belgian catchments present an increase for most climate change scenarios. Besides, all Belgian catchments with prevailing surface flow are undergoing an increase in flood frequency during winter months.

The computed impacts (Gellens and Roulin, 1998) have been demonstrated to be strongly catchment dependent (Wit et al., 2001), because they depend not only on the selected climate change scenario but also on the properties of the catchment itself. For instance, the Dijle catchement (Scheldt basin) is characterized by a low runoff coefficient (< 20%) whereas in the Berwinne catchment (Meuse basin) and in the Zwalm catchment (Scheldt basin) surface runoff ranges from 40 to 60%. In the Dijle catchment, a high increase in spring precipitation and a high decrease in summer precipitation result in relatively small changes of the surface flow. On the contrary, the same two changes in precipitation result in much greater responses in the Berwinne and the Zwalm catchments (+ and – 30%). Hence, catchments which are characterized by a dominance of fast runoff components, are more vulnerable with respect to both floods and low flows. Those catchements are especially located in the regions of rocks (eastern upper part of Chiers and Semois) and in the Ardennes massif (upper Ourthe, Lesse Vesdre and Amblève) (Wit et al., 2001).

The increase in flood frequencies during winter months for the catchments where surface flow prevails is the only common response to the different scenarios investigated by Gellens and Roulin (Gellens and Roulin, 1998). As a conclusion, the effect of climate change on river discharges must necessarily be studied for each catchment specifically (IRGT-KINT, 2001).

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 (Commission Nationale Climat, 2006). Other recent studies (e.g. Tu et al., 2005a) report that flood peaks in the Meuse River and some of its tributaries have significantly increased since the end of the 1970s or the early 1980s, mainly as a consequence changes in precipitation patterns.

Hence, future increases in groundwater levels and river discharges are expected to take place, especially in winter, as a result of the change in precipitation (Commission Nationale Climat, 2002; Marbaix et al., 2004). Similarly, though it remains difficult to quantify the potential changes in flood frequency, more precipitation on a soil saturated with water in winter and spring is very likely to lead to a higher flood frequency (IRGT-KINT, 2001).

Although more studies are needed concerning the detailed effects of climate change on flood risk in Belgium, various analyses provide already an insight into the most probable evolutions. Können (2001) states that, in 2100, Flanders and Zeeland will experience "an increase in the river peak discharges" (FLOODSITE, 2006). A specific study on the river Meuse upstream of Borgharen in Belgium and France predicts a small decrease of average discharge (~5%) but an increase in extreme discharge and variability (5-10%) (Booij, 2003).

E. Secondary impacts of climate change

The integrated flood risk assessment methodology is focused on the effects to economic, social and ecological systems.

1. Economic aspects

This part is composed of the description of the potential impacts of climate change in Belgium throughout the climate change policy and a wide range of economic sectors. The services sector was studied after the analysis of tourism, energy, transport and financial services. The production sector was examined by way of the study of agriculture, fisheries, the automobile industry and to a lesser extent the building industry.

a) The economy and linkages to climate change policy

Governments have deployed measures which aim at reducing the effects of climate change as well as tackling them both at a national and an international level. These decisions obviously have economic consequences for each individual but also for all of the industrial companies together. The ensuing effects could either be felt positively or negatively.

b) Overview of some political measures

The "Sigma plan "and the "Plan PLUIES" are two policy decisions on adaptation measures in Belgium.

After the inundations of 1976 along the river Scheldt, induced by a violent northwest storm in the North-sea, the authorities launched the Sigma plan in order to protect the tidal part of river. Recently a new philosophy is emerging, combining safety, economy (harbour) and nature (Maris et al., 2006). Giving more space to the river through controlled inundation areas offers the opportunity to protect against flooding (heighten the level of the dikes and protect the infrastructure of the harbours) and restore the ecological functioning of the estuary without obstructing the economic development of neither harbours nor navigation. One specific way to combine ecology and safety is the creation of a Flood Control Area (FCA) with a Controlled Reduced Tide (CRT) (Meire et al., 2005).

The plan P.L.U.I.E.S (Prévention et LUtte contre les Inondations et leurs Effets sur les Sinistrés), has been adopted by th walloon goverment in 2003. The 5 purpose of this plan are the following: improve the knowledge in risk of floods, reduce the runoff, lay out the bed of the river, reduce the vulnerability in the flooding area, and, finally, improve the management in a case of flood.

c) Human settlements

Since the beginning of time, the reason men have settled in a place comes from the facilities found in this place that are basic to their needs and enjoyment. Today, the relocation of populations and activities towards the interface « land-sea » has greatly increased since the industrial revolution, and has caused a reorganisation of land boundaries on a global level. Coastal zones are now at the heart of geopolitical and geo-economics structures, linked to them by powerful exchange fluxes.

The category of human settlements unites many sectors of activities whose reaction to the effects of climate change are to be felt in different ways. According to the experts of the IPCC, human settlements can be solicited by the climate in three ways (IPCC, 2001b):

By modification of the production capacity of the economic sectors which sustain the human settlement or of the demand for local goods and services. The type of settlement is obviously an important factor in determining this occurrence.

By direct impacts on certain physical infrastructures (distribution and transport networks), on built up properties[1], on urban services and on certain economic sectors such as tourism and construction.

By direct impacts on the population (migration, health).

d) Industry

Climate change can affect industry in several ways. The main impacts (linked to climate change) are the demands for water and energy which will greatly increase during heat wave periods. The cost of the rise in demand will obviously increase too. Elsewhere, such extreme events will also have an impact on the production and the distribution of goods and products. And so, adverse weather conditions may bring about a failure in the supply of raw materials. In the same way, the transport of commuters to their place of work will also be hit by the weather. Disruptions to the production chain will be highly probably from then on, and they will obviously be felt at the sales level as well. In the same view, the distribution of products and their retail sale will also be disrupted by climate conditions. These disruptions could even generate changes in consumer behaviour (Baron, 2006). The resolution of the problem of relocation and economical losses potential is therefore a necessary condition towards the adoption of more ambitious objectives in the future.

e) Agriculture sector

The agricultural sector is one of the main economic sectors which will be influenced worldwide by climate change. In a general way, it has to be said that on account of global warming, agricultural returns should decrease. Obviously these modifications in climate should bring with them as many beneficial effects for certain crops as negative ones (DEFRA, 2004). Nevertheless, the benefits and

[1] Experience of the latest flooding events in Belgium shows that damages on houses are the most important contribution to the total damage compared to other sources of damages.

costs that arise will not be homogenous, but will vary greatly according to region, crops, agricultural practices and the other activities (cattle breeding, horticulture, fruit farming). Generally speaking, the availability of water will represent one of the essential points of this sector with regard to future climate change.

f) Forestry sector

As a result of global warming, the different species present within the forest ecosystem will be affected in various ways.

g) Fisheries

It is difficult to foresee the consequences of climate change on the fishing industry in Belgium and Europe because of the number of influencing factors attached (rising temperature, physico-chemical evolution of the environment…). These changes will obviously lead to modifications on the food chains (phytoplanctons, zooplancton, fish...). Besides this, the overfishing seems to be the most critical factor in sustainable development in our regions (IPCC, 2001b).

h) Transport sector

An analysis of the transport sector shows that it is possible to pick out two types of consequences linked to climate change. The first one, labelled "direct" impact, is a result of meteorological conditions at the time of using transport itself. The second, identified as an "indirect" impact, is linked to the politics involved in the struggle against climate change.

With transport, it could be affected by climate change and its associated conditions (heat wave, weather stress,…). Furthermore, these modifications would affect the whole range of means of transport, all of this at different degrees, following the damage done to the infrastructures and because of poor transport conditions. Besides this, with regard to road traffic, the traffic conditions could be even more precarious in the direction of key destinations such as the sea or the Ardennes during sunny periods.

As a result of climate change, the estimated increase in transport costs via waterways is limited to 2 to 4%, in Netherlands (Netherlands Environmental Assessment Agency, 2005). In the case of extreme conditions, such as those encountered in 2003, where the water level in waterways diminished remarkably, a considerable rise in transport costs was envisaged.

As for the transport industry, and more particularly the manufacturers of road vehicles, indirect impacts will equally be felt.

The problems associated with climate change are relatively new ideas for the automobile sector (Austin, 2003). These modifications have important financial impacts. Certain adaptation measures have already been taken on the level of several makes of car in order to reduce their CO_2 emissions.

i) Tourism sector

On a worldwide scale, the tourism sector has a huge economic weight at its disposal. The criterion "temperature" is an important key in tourists' space- and time-rating. The potential effects of climate change will be positive or negative according to the influence of the meteorological conditions in situ (beautiful weather, rain, snow, flooding,…) Elsewhere, these will also play a modifying role on the pleasant atmosphere and particularly on the evolution of the landscape and the environment.

Globally speaking, it is currently difficult to give a ruling on the consequences linked to this change as far as tourism is concerned. Nevertheless, certain trends can be concluded. So it is probable that both international and local tourism will be affected by the influence of climate change. The destinations towards the south run the risk of being less appreciated than at the present time, and with conditions becoming hotter in the north, more individuals will tend to stay in their own country during holiday time (Netherlands Environmental Assessment Agency, 2005). Moreover, international tourism will also be affected with regard to transport methods due to political measures aiming at reducing the greenhouse gas emissions. Currently, the tourists have already been able to note an increase in costs of transport. Finally, the impact of the climate change will depend therefore for each country on an equation taking into account the proposed offer and the effects on the request.

j) Financial sector

The whole financial sector is affected by the problems which modifications in climate have generated. According to several members of the United Nations Environment Programme (UNEP) consortium for financial institutions, the extent of the catastrophes caused by climate change could even ruin the stock markets and the world's financial institutions (UNEP, 2002). Thus "the increasing frequency of severe climatic events, threatening the social stability or coupled with significant social costs, has the potential to exert pressure on insurance companies, reinsurance companies and banks to the point of impaired viability or even insolvency" (UNEP, 2002).

The analysis of this sector is approached from the point of view of banks (investment) and insurance companies at an international level.

k) The banking sector

This sector could be particularly sensitive to the increase in damage resulting from extreme events. Following the diversification of the financial services offered financial companies can find themselves facing a collection of risk effects for which climate change becomes a risk for their whole portfolio of activities. The companies which are unaware of this danger run a higher risk from then on. Moreover, several threats and opportunities can be brought to light for this sector.

Elsewhere, the sector for financial services of a banking kind has a role to play in the "climate – finance" relationship (investment, credit risk and new climate risk hedging products) which it must not neglect (Allianz group and WWF, 2005).

The value of businesses is now subject to new factors of assessment, such as the new policies and regulations set up to tackle the greenhouse effect, the development of an environmentally-friendly technology, evolution in climate, the growing consumer-consciousness in the face of these questions.

From now on, financial institutions must integrate the impacts associated with greenhouse gas reduction policies on the level of businesses into their own economics analyses policies. In fact, financial investors must take into account the costs associated with the new regulations and with the impact of these on the companies in which an investment has been made. On account of this statement and according to the experts' opinion, the financial sector has therefore an indirect role to play in tackling climate change. The areas most targeted are the sectors of investment, the risk analysis and prevention.

l) The insurance sector

Due to the increase of people and goods in the zone at risk, due to a greater concentration of industries in this zone, due to the rise in the number of losses when extreme climatic events occur, the insurance sector is tending to take new options as to insurance-related possibilities. In fact, within insurance companies the rise in real and insured losses has on the one hand generated a decrease in the cost-effectiveness of their product, and on the other hand, has led to the bumping up of their rates, the suppression of certain forms of cover and a growing demand for compensation and help from the State. As a result of these heavy pressures on the financial capacities of the reinsurance sector, a substantial decrease in the availability of insurance against catastrophes was recorded these last few years (OECD - Organisation for Economic Co-operation and Development, 2004).

m) Economic damage assessment

As for the economical assessment of damage in monetary terms, it is very difficult to give statistics this for the different sectors and also on the Belgian scale. Nevertheless at world level, recent studies have presented the macro-economic weight that would result from man's inactivity in the face of the threat to the climate (Ackerman and Stanton, 2006; Stern, 2006). According to these studies, the risks incurred as a result of non-commitment could cost humanity very dearly. According to the STERN report 2006 and using the results from formal economic models, the Review estimates that if we don't act, the overall costs and risks of climate change will be equivalent to losing at least 5% of global GDP each year, now and forever. If a wider range of risks and impacts is taken into account, the estimates of damage could rise to 20% of GDP or more. In contrast, the costs of action – reducing greenhouse gas emissions to avoid the worst impacts of climate change – can be limited to around 1% of global GDP each year. In another part of this same estimation, the adoption of policies to tackle these changes would allow for the increase in temperature to be limited to 2°C and would mean a reduction of more than half the damages.

2. Social aspects

Climate change impacts on society are multiple. However, the effects of climate change can cause different impacts on people. This can be explained by the fact that social impacts are dependent on the exposure of the society to direct climate change and its indirect impacts, to the susceptibility of the people themselves and to the adaptive capacity of the society. (based on Hilhorst, 2004) People vary in terms of susceptibility and societies have different capacities to cope with climate change impacts. There are mainly four properties related to susceptibility and adaptive capacity. First, they are constructed by social, political, economic and cultural factors. Secondly, they vary across regions and across social groups. Thirdly, they are scale-dependent, since impacts on the local level can be different than impacts on the national level. And lastly, the concepts are dynamic, what means that people today can be more or less vulnerable towards climate change than in the future. To conclude, assessing social impacts of climate change is complex due to the intertwining aspects and the degree of uncertainty in future climate change scenarios.

a) Unequal distribution of the effects: winners and losers

The focus in climate change research is mainly on the negative impacts that can be expected. However, it may also cause some positive effects. But problematic is the unequal distribution of positive and negative effects within and across national borders and over time. For instance, warmer summers will benefit coastal tourism, while warmer winters will harm the skiing sector. Northern-European countries will enjoy agricultural growth, while the Southern-European farmers will be threatened by droughts. People who suffer most are the most vulnerable social groups, like the poor, the migrants, the invalids and the elderly. In addition, they have the least coping capacities. As a consequence, climate change is expected to skew existing social inequalities. The question rises on who should take responsibility. The unequal relation between provokers and the affected people might be perceived as unfair and unjust. And next, the last questions concerns on how to reduce the impacts of the losers, since policy itself can generate distributional effects that might be unacceptable for the winners.

b) Less welfare, more poverty

Climate change is expected to reduce welfare in a direct and indirect way. Direct income loss is due to loss of life, damage to property, reduced value of the property or increased recovery costs caused by extreme weather events. Indirect welfare impacts are caused by increasing food and electricity prices or increasing health care costs. Remarkably, the ones that are already poor are hit the hardest, because they do not have sufficient financial, material or social resources to cope with climate change impacts.

c) Health risks

Health is affected by climate change in many ways. Firstly, climate change induces heat-related health effects, like heat cramps, heat fatigue, sunstroke, heat syncope and overheats. Heat waves can cause excess mortality, which is caused by cardiovascular, cerebrovascular and respiratory problems. Secondly, climate change might result in a larger number of people suffering from allergies. The pollen season is expected to extend. Changes in relative humidity might result in increasing in-house allergens. And the processionary caterpillar will appear more frequent, resulting in skin, eyes and air ways irritations. Thirdly, food-borne and water-borne diseases are favoured by warm temperatures, but vector-borne diseases are expected to appear more often as well. For instance, it is already demonstrated that the number of ticks, carrying Tick-Borne Encephalitis, has increased during the past few years. The disease is manifested as inflammation of the brain, inflammation of the membrane, or inflammation of brain and meninges. Another vector-borne disease is the lyme disease that is also transported by ticks. Lyme disease can result in serious health problems. Furthermore, extreme weather events may affect health by death or injury. Or by diseases related to unhygienic or overcrowded circumstances or to lack of medical aid. And lastly, climate change may slowdown the healing of the ozone layer. Warmer and drier summers may increase the exposure to sunlight and UV radiation and increase the chance to skin cancer, cataract and weakening immunity systems.

d) More social distress

Too abrupt and too large divergence of average weather conditions may cause havoc in society. Extreme weather events request re-organisation of households and communities. Distress is caused because of lack of water, electricity, food, damage to properties and infrastructure and evacuation. The chaos may go hand in hand with emotional stress and interpersonal conflicts. Crime and burglary are more frequent in these circumstances.

e) Changing risk perception and difficult policymaking

Not all people perceive climate change risk in the same way. More concrete, risk perception of the public may differ from risk perception of experts and policy makers. Different risk perception may hamper the development of appropriate policy. Therefore, risk should be communicated correctly to build trust.

f) More international instability

The effect of climate change on international stability is threefold. Firstly, the countries that are affected the hardest by climate change are not the main contributors to the green house gasses. In addition, the affected countries are often developing countries, lacking the capacity to adapt. International cooperation is required, but might be difficult to develop. Secondly, climate change may increase the flow of refugees. More concrete, they are environmental refuges, looking for a better place to live. It is expected that the number of environmental refugees will increase from 50 million in 2010 to 150 million in 2050. And lastly, international stability may be affected by increasing social instability due to deteriorating living conditions because of natural resource scarcity, demographic pressure, inequity and poverty.

3. Ecological aspects

In the last decades the scientific community indicated that effects of climate change on ecosystems should be considered on top of other human caused impacts on ecosystems (ICPP 2001a, EEA 2005c). Natural ecosystems already under stress, e.g. by water and air pollution, will have a diminished capacity to adapt to climate change. Over the last 50 years, humans have used ecosystems more intensively than in any comparable period of time in human history (MA, 2005). Because of the complexity of natural ecosystems, effects of climate change presents a series of important and immediate challenges to nature conservation and restoration (Birds, 79/409/CE, and Habitat, 92/43/CE, Natura 2000). When subject to multiple stresses, natural environments can exhibit symptoms that indicate reductions in resilience, resistance, and regenerative capabilities.

Freshwater systems are closely connected to climatic processes, by influencing or even driving global atmospheric processes that may influence climate. Because freshwater ecosystems integrate atmospheric and terrestrial events, they may be sensitive early indicators of climate change. Moreover, they are essential contributors to biodiversity and productivity of the biosphere. They also provide a variety of goods and services to the human population, including water for drinking and irrigation, recreational activities and habitat for economically important fisheries (Postel and Carpenter, 1997; Meire et al., 2005). In addition to the challenges posed by land-use change, non-point source pollution and water use, freshwater systems are expected to respond to the added stress of climate change.

Taking into consideration the socio-economical importance and the ecological values (especially biodiversity and ecosystem functions), we focused on the impact of climate change on freshwater ecosystems. Those ecosystems have historically responded to climate change and we assume that they will continue to do so. Hereby we include wetlands, lakes, streams and rivers, and estuaries as separate biota because of their distinctive biodiversity and functions.

a) Wetlands ecosystems

(1) Impact on wetlands biodiversity

The observed changes in the climate system (e.g., increased atmospheric concentrations of carbon dioxide, increased land and ocean temperatures, changes in precipitation and sea level rise), particularly the warmer regional temperatures, have affected the timing of reproduction of animals and plants and/or migration of animals, the length of the growing season, species distributions and population sizes, and the frequency of pest and disease outbreaks.

Temperatures are expected to increase as a result of increasing greenhouse gas concentrations (IPCC, 2001a). Temperatures are projected to increase by 1.5 to 5.8 by 2100 (IPCC, 2001a). This increase will affect plant communities in a number of ways. Direct response to climate through altered reaction kinetics, which could lead to increased primary production especially in regions where carbon assimilation is limited by low temperatures (Larcher, 2003). Indirect effects of temperatures increase include changes in resources availability and competitive interactions (De Valpine and Harte, 2001).

The vulnerability of wetlands to dessication, depends in large on the sources of water supply (precipitations, groundwater discharge, surface water flows) (El Kahloun et al. 2005). In general wetlands fed by precipitation are the most likely to lose wetlands characteristics in a drying climate. In groundwater dependent wetlands or fens, drought may induce internal eutrophication (Van Haesebroeck et al., 1996). The increase in nutrient availability may stimulate biomass production and induce decrease in biodiversity (Boeye et al., 1997; El Kahloun et al., 2000; El Kahloun et al., 2003).

(2) Impact on functionality of wetlands

In Belgium, wetland responses to climate change are still poorly understood and are often not included in global models of the effects of climate change (Meire et al., 2005). Therefore, only a general assessment of the relationships between wetlands and climate change can be given in this phase. It is generally understood, however, that increases in temperature, sea-level rise, and changes in precipitation will degrade those benefits and services. These changes will likely affect waterfowl that are dependent wetlands as habitats, and may contribute to desertification processes. It is important to realize, though, the degree of uncertainties associated with projections of the consequences for wetland ecosystems resulting from climate change. For most regions the projections for changes in precipitation and temperature, are highly uncertain. Further uncertainty includes the increase in frequency and intensity of extreme events, such as storms, droughts, and floods. The ability of wetland ecosystems to adapt will be highly dependent on the rate and extent of those changes.

Wetlands, coastal wetlands and peatlands represent the largest terrestrial biological carbon pool (Dixon et al., 1995). Therefore they play an important role in the global carbon cycle (IPCC 1996). Due to their anaerobic character and low nutrient availability, wetland carbon stocks increase continuously. However, as soils warm in response to climate change, mineralization generates considerable carbon emission (Maltby and Immirzy, 1993). The effects of climate warming on ecosystem carbon (C) storage remain uncertain. The role of wetlands in the global carbon cycle is poorly understood, and more information is needed on different wetland types and their function as both sources and sinks of greenhouse gases.

b) Lakes, streams and rivers ecosystems

(1) Impact on biodiversity of lakes, streams and rivers

The life processes of most aquatic species are temperature-dependent, warmer water can increase primary production. In streams and rivers, aquatic invertebrates may mature more rapidly and reproduce more frequently (Arnell et al., 1995), increasing food resources for fish. However, increasing water temperatures may also stimulate microbial activity and decreases of organic matter are expected, which may to the contrary result in less food availability for fish (Meyer and Edwards, 1990).

A temperature rise due to global warming is expected in all freshwater biota, i.e. in lakes, streams and rivers. Rare and endangered plant and animal species with sensitivity to small temperature changes often have no alternative habitat, especially in isolated areas such as those in alpine wetlands.

(2) Impact on functionality of lakes, streams and rivers

In temperate Europe, the potential for precipitation decreases that result in lower flow rates could have major implications for lakes and streams. This could lead to changes in habitat and breeding locations of aquatic flora and fauna. These hydrological changes have the potential to be more significant for freshwater organisms than a temperature increase. The effect of warmer winters that lead to less extensive ice cover of lakes is expected to affect Europe's temperate lakes and streams as discussed above. Aquatic ecosystems support delicate, deeply interconnected webs of life which are highly adapted to the physical (and biochemical) characteristics and cycles of the rivers themselves. Changes in precipitation patterns may alter seasonal flow and volume patterns in streams and rivers.

c) Estuaries ecosystems

(1) Impact on biodiversity of estuaries

One of the potential negative effects of increased runoff in estuarine zones is an increase in nutrients inducing eutrophication. Nuisance algal blooms and low oxygen in bottom waters kill fish and shellfish (Kennedy, 1990). Increased runoff will also lead to problems with toxic pollutant (heavy metal, organic chemicals) with concurrent negative impacts on biodiversity. In Belgium, high freshwater discharges by increased precipitation can influence estuarine ecology by decreasing water residence time in the main estuarine channel. The upstream tidal freshwater regions are likely to be most affected by changing freshwater discharges as the impact of marine waters is negligible (Struyf et al., 2004). Muylaert et al. (2001) have shown how short-term freshets can result in the flushing of entire diatom communities from freshwater reach.

(2) Impact on the functionality of estuaries

Sea-level rise can cause several direct impacts, including inundation and displacement of wetlands and lowlands, coastal erosion, increased storm flooding and damage, increased salinity in estuaries and coastal aquifers, and rising coastal water tables and impeded drainage (Bijlsma et al., 1996). Climate change and sea-level rise would impose serious impacts on the natural environment and human society in the estuarine zone. Primary impacts of sea-level rise are listed as inundation, exacerbation of flooding, beach erosion, changes in nutrients fluxes, and salt water intrusion to rivers and groundwater aquifers.

(a) Water purification and nutrient fluxes

Due to a long residence time of the water and the intense interactions between water, soil and atmosphere, tidal areas also play an important role in nutrient cycling and the self-cleaning capacity of estuarine rivers (Mallin and Lewitus, 2004; Middelburg et al., 1995; Van Damme et al., 2005). In Belgium, increase in precipitation will likely induce higher freshwater discharges that can further influence the Scheldt estuary ecology by decreasing water and nutrient residence time in the main channel. Nutrient and organic material are transferred more rapidly to estuarine waters, and important ecological processes (denitrification, nitrification, mineralization, nutrient uptake) in nutrient cycling have less time to act upon the large volumes of nutrients, which could lead to alterations of fluxes of N, P and Si from downstream to coastal waters (Struyf et al., 2004).

(b) Erosion control and sediment transport

Impacts on the Natural and Human systems: One of the most significant impacts of sea-level rise is acceleration of coastal erosion as well as inundation of mangroves, wetlands. Coastal erosion is considered to be one of the main impacts of sea level rise. (IPCC, 2001b). Increased coastal flooding, loss of habitats, an increase in the salinity of estuaries and freshwater aquifers, and changed tidal ranges in rivers and bays, transport of sediments and nutrients, patterns of contamination in coastal areas are amongst the main effects of coastal erosion.

Highest rainfall induced erosion rates in Belgium occur south of the Meuse and the Samber. Average soil loss in Flanders amounts to 1.18 ton/ha a year, erosion being highest on the loamy and sandloamy regions in the south of Flanders. In these regions, which extend over the North of Wallonia, yearly soil loss can be higher than 10 ton/ha (0.74mm). Based on models, the sediment export to the Flemish watercourses is estimated at 0.26 ton/ha, and at 0.8 – 1.0 ton/ha to the Walloon watercourses (IRGT-KINT, 2005). In the centre of Belgium, intense rainfall produces regularly inundations of a muddy character. This is particularly the most important downstream consequence of soil erosion in Belgium. About 53 percent of all communities in that region state to suffer from this kind of inconvenience, 15 to 20 percent being affected several times a year. In the long term, sedimentation of watercourses and flood retention basins becomes also an important consequence, causing problems with the navigability and, above all, increases the risk of flooding (IRGT-KINT, 2005).

F. Conclusions

From the research done in WP 1, we can conclude that impacts of our changing climate are still coupled with a high level of uncertainty. However, various impacts can be expected. Although the expected effects may be relatively 'limited' in comparison to some other countries, they will be considerable. Besides, we can conclude that the impacts will be distributed unequally across social groups, locations and economic activities. Therefore, it is important to understand that vulnerability to climate change differs greatly across space, people and sectors and is dynamic over time. Given the nature and magnitude of the expected effects, adaptation does make sense. The rationale behind the need for adaptation is as well economical as social and ecological.

Adaptation is about reducing the negative impacts and increasing the benefits to climate is nothing new. Throughout history, people have always tried to adapt their systems to changing conditions. To a certain extent adaptation occurs spontaneously. However, even with important reductions in greenhouse gas emissions, the expected evolutions in rainfall amounts and intensities, temperatures and sea level rise will persist for some time. Hence, the development of planned adaptation strategies to deal with the risk of climate change becomes a necessity. The increased risks from climate imply considered decisions from society. Given the complexity of the issue this requires a proper assessment of the economic, social and ecological costs and benefits of possible adaptation options. Furthermore, to generate solutions that are acceptable to anyone, all stakeholders should be involved.

To this end, the most important effects of climate change should be identified for Belgium. A timely response can help to minimize the potential costs of these effects which are disproportionately faced by the most vulnerable sectors and ultimately by society as a whole. To this end the development of a decision tool, based on an integrated assessment of the cost and benefits of adaptation measures, is an important action. In the light of the importance of climate change induced flooding in Belgium we propose flooding in the main two Belgian river basins as a case study. Given the clear impact of climate change on flooding and the existence of a series of possible adaptation measures, the subject of flooding is an interesting field to develop a methodology to guide decisions on adaptation measures.

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

A. Introduction and objectives

It should be the objective of water managers to maximise welfare. The limited resources authorities dispose of should be allocated in an optimal way, prioritising those measures that yield the highest benefits. In order to allow the selection of the most desirable measures or adaptation scenarios, being a combination of several measures, it is a prerequisite that all current and future pros and contras of a project are accounted for and equally taken into consideration. At the moment, however, policy making focuses predominantly on the direct tangible effects of flooding while indirect and intangible effects are often largely disregarded as they are either not monetised or simply not assessed at all. As long as this is the case, the adaptation measures proposed are at risk of being too limited, and thus suboptimal, in terms of risk reduction.

Climate changes influences rainfall and evapotranspiration and thereby has an influence on hydrological extremes like floods. It is advisable flood protection strategies take into account the possible influence of climate change on hydrological extremes. Currently, it is not common practise to do so. (Grinwis M. and Duyck M., 2001; Boukhris et al., 2006)

The ADAPT project aims to meet both challenges by the development of a practical methodology for assisting decision making about adaptation measures to climate change induced flooding that builds 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 builds on two case studies located in the two major Belgian river basins.

The methodology to be developed requires the use, development and integration of distinct models and methodologies. The development of the practical methodology can thus be broken down into a number of 'intermediate' objectives which have been grouped in six working packages.

Task 2.1, *evaluating the primary impacts of global change-induced flooding on river basins*, is about the adaptation of existing hydraulic models, the modeling of flood maps and the translation of hydraulic modeling results into input for the assessment of secondary impacts. Hydraulic modeling is carried out for a baseline scenario without climate change, the baseline scenario with climate change as well as various adaptation scenarios with climate change.

Task 2.2, *evaluating the secondary impacts of global change-induced flooding on vulnerable sectors in river basins*, is about the identification of those elements and systems most vulnerable to flooding, the development and implementation of three complementary flood risk assessment modules, respectively focusing on effects to economic, social and ecological aspects and the development of a method for the integration of the outputs of the three flood risk assessment modules.

Task 2.3, *determining adaptation measures*, is about the identification, development and selection of adaptation scenarios. To this end modeled flood risk will be studied in combination of a thorough investigation of the causes of the flood problem.

Task 2.4, *evaluating adaptation costs*, is about the evaluation of the cost of the adaptation scenario(s) selected. The costs of the realisation and management of the adaptation scenarios are in the first place the financial costs faced by the project initiator and manager. Besides, the realisation of adaptation scenarios is quasi always accompanied by a number of additional costs and benefits to society. Guidelines will be drawn up for the assessment of adaptation costs.

Task 2.5, *cost- benefit analysis*, is about the evaluation of one or more adaptation scenario(s) by the integration of the costs and benefits it has to society. The methodology for the integration of costs and benefits will be developed under this working package. On the basis of the input from evaluation of costs and benefits proposed adaptation scenarios may require further fine-tuning.

Task 2.6, *recommendations on adaptation of measures*, concerns the drawing up of 'generic' lessons concerning the development, selection and evaluation of adaptation measures in a climate change context.

B. Overview of the methodology

The development of the methodology for the ex-ante evaluation of adaptation measures to climate change induced flooding requires the use, development and integration of distinct models and methodologies. In order to facilitate understanding of and communication about the project a comprehensive overview of the whole process, highlighting the interactions between the different models, methodologies and data flows, is provided in Figure 3. In this section a non-specialist overview of the methodological framework to be developed is presented. This overview mainly corresponds to the different working packages.

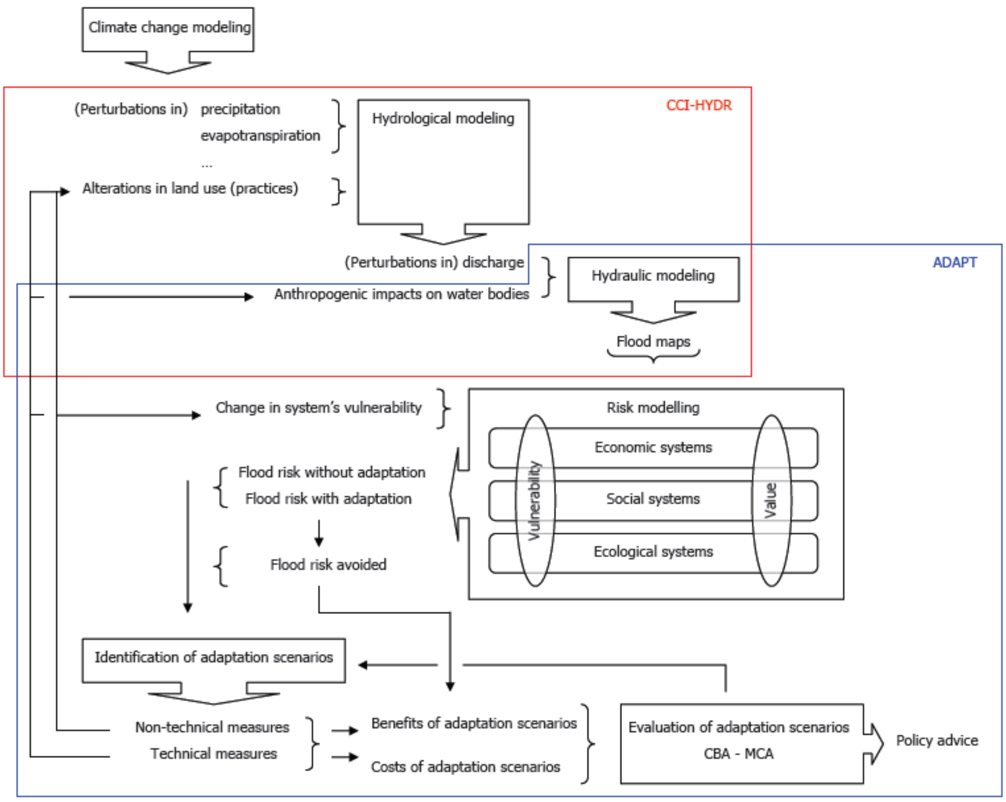

Figure 3: Flow chart of the ADAPT project and its links with the CCI-HYDR project

1. *Flood modeling*

Any evaluation of adaptation measures for reducing the effects of flooding, informing water managers about what measures or combination of measures to adopt, critically depends on the ex-ante modelling of inundation chances. This is done by flood or hydraulic modelling by means of which flood maps are created, encompassing information on various flood characteristics. The single most important flood characteristic for ex-ante flood impact evaluation is inundation depth. Other important impacts are flow velocity, rise rate, time of occurrence, duration and contaminations. Flood maps are the crucial input for flood risk modelling.

Flood maps are the output of a hydraulic computer model which simulates how a river reacts on a given supply of water. The model uses data of the depth and width of the river, the shape of constructions on and along the river, like wears and dikes, as well as the relief of the riverbanks on the one hand and data of water discharge into the river on the other hand. However, as any model a hydraulic model simplifies the complex reality. The physical characteristics of the water body and its surroundings are approximated by topographic data stemming from digital elevation models. This digital information is completed with data on hydraulic structures (e.g. operating conditions, designs etc.) and possibly also by field inspections and land use information. (HIC-WL, 2003)

The discharge or runoff into a river is obtained either from hydrological data (Ourthe case study) or from hydrological modelling (Dender case study). The hydrological data are historical time series of river discharge from gauging stations. Unless direct assumptions are applied on the expected changes (perturbations) in the peak discharge resulting from climate change, the simple use of historical data series does not allow accounting for the effects climate change may have on river flooding. A less pragmatic, but more systematic and challenging, manner for modelling the impact of climate change on flooding consists of accounting for the likely effect of changes/perturbations in precipitation and evapotranspiration on river discharge via hydrological modelling. Estimates of changes in precipitation and potential evapotranspiration are derived from climate change modelling.

The CCI-HYDR project critically contributes to the ADAPT project as it provides the flood maps for the Dender case study and provides a basis for estimating the perturbations/changes in peak discharges necessary for modelling the effects of climate change for the Ourthe case study. The outputs of the CCI-HYDR project thus are an input for the ADAPT project.

Flood maps need to be modelled for a baseline scenario with and without accounting for climate change effects. So doing the likely effect of climate change on flooding can be assessed. Next, flood models need to be adapted as to produce flood maps that account for the alterations – anthropogenic impacts on water bodies – of adaptation scenarios on flood characteristics. Finally, based on flood risk modelling (WP 2.2) and the integration of costs and benefits (WP 2.5), adaptation scenarios may need to be adapted as to be more effective.

In the framework of the ADAPT project we start from existing hydraulic models for the Ourthe case study and existing hydrological and hydraulic models for the Dender case study. The models, however, are refined and adapted to better meet the needs of doing repeated runs for new or modified adaptation scenarios.

2. Flood risk modelling

Flood risk is modelling is about the assessment of the impact flooding has on society. In order to overcome the focus on direct tangible effects of flooding to economic systems, as in conventional flood risk modelling practice, three complementary flood risk assessment modules are developed, respectively focussing on the effects of flooding to economic, social and ecological systems. It is imperative the outputs of each module (= partial flood risk assessments) can be combined and integrated to arrive at overall flood risk.

The relevant effects of flooding on economic, social and ecological systems are identified and selected. All effects are accounted for by one of the three risk module. As many effects of flooding act upon each other minimal understanding of the links between the effects is imperative. Therefore, the most important links have been described. On the basis of this preliminary work risk assessment methodologies are developed, adapted and/or or selected for the effects selected.

The assessment methodologies of the effects covered by the three risk assessment modules greatly build on the same risk assessment framework. The concept of risk, which is function of the probability that a flood event will occur and the consequence associated with that event, is crucial when considering flooding in a policy context and thus of primary importance for the development of the assessment framework. Practically, risk is made up of four major building blocks:

- the probability of flooding;
- the exposure of the elements-at-risk to a flood with certain characteristics;
- the value of these elements-at-risk and;
- the vulnerability of these elements-at-risk.

These four elements constitute the key components of the assessment framework, which is schematically represented in Figure 4. The combination of the latter three elements constitutes the consequence of flooding. The assessment methodology for every distinct element-at-risk builds, in different ways, on all of these components.

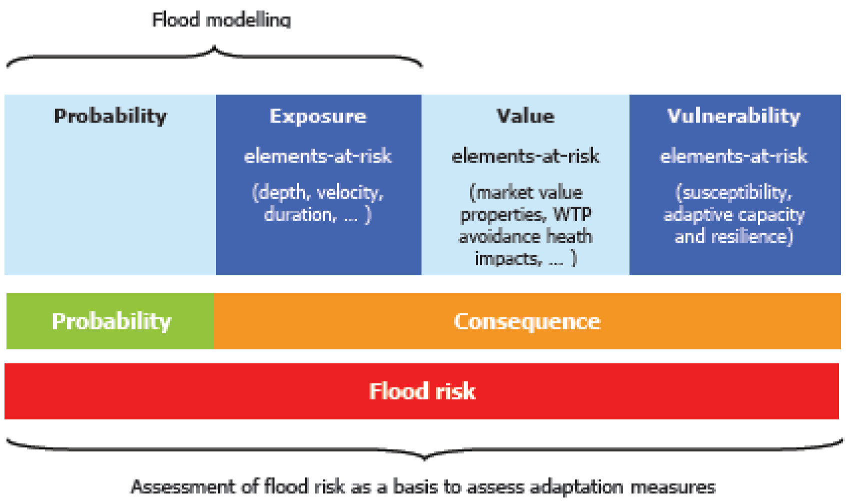

Figure 4: Components of the flood risk assessment framework

The practical interpretation and elaboration of the different components of the assessment framework is straightforward. 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. For each return period considered the hydraulic modellers provide flood maps that comprise information on different flood characteristics, needed for running the flood risk assessment methodologies.

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 concept of value goes beyond the narrow concept of financial value and also accounts for effects to the functioning of social and ecological systems which are much harder to quantify, let alone monetise. People's preferences to prevent effects from occurring can only be partly related to observed economic behaviour. In particular the assessment methodologies for the social and ecological impacts are confronted with this burden.

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

The assessment of flood risk does not only depend on the projection of future flooding (both in terms of probability and flood characteristics). Economic, social as well as ecological systems evolve constantly, meaning their vulnerability and value changes over time. Consequently, the risk assessment methodologies have to account for the likely evolutions in the vulnerability and value of the elements-at-risk. In order to account for the possible evolutions, scenarios are developed for projecting future vulnerabilities and values.

In practise, for calculating flood risk, the four components of the assessment framework need to be combined. This will, to an important extent, be carried out in a GIS environment. Flood risk will be calculated for several events or return periods. By means of an integral flood risk will be defined for a continuum of events or return periods.

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. Besides, estimates of flood risk with and without climate change impacts will allows us to assess the contribution of climate change to flood risk. Similarly, flood risk avoided (= the benefits of an adaptation scenario) can be calculated by subtracting flood risk in an adaptation scenario by flood risk in the baseline scenario.

3. Identification and selection of adaptation scenarios

Based on predicted flood risk and a thorough investigation of the causes of the flood problem adaptation scenarios need to be identified, developed and selected. These adaptation scenarios can be made up of one single measure, but may very well be a combination of several adaptation measures.

Single adaptation measures are divided into technical and non-technical measures. Technical measures act upon hydrological and hydraulic parameters and may as well impact on the vulnerability of certain systems. The main feature of technical measures is that they involve physical engineering works. Non-technical measures impact on the vulnerability of economic, social and ecological aspects as well as on the values at risk. Besides, non-technical measures may also impact on hydrological parameters. The main feature of the non-technical measures is that they make use of legislation, economic incentives, information, sensitization, aid, rescue operations, insurance, etc.

4. Evaluation of adaptation scenarios

Every adaptation scenario has to be evaluated in terms of its costs and benefits in order to support decision making by water managers. Only those adaptation scenarios that are expected to contribute to welfare are worth implementing. Benefits of adaptation scenarios therefore should outweigh associated costs.

The primary benefit of an adaptation scenario is the flood risk avoided. For any effective adaptation scenario economic, social and ecological systems will be less exposed and/or less vulnerable to flooding. The costs of the realisation and management of an adaptation scenario are in the first place the financial costs faced by the project initiator and manager. Besides, the realisation of an adaptation scenario is quasi always accompanied by a number of additional costs and benefits. All costs identified need to be assessed and accounted for in the evaluation exercise. Figure 5 gives a simplified overview of the costs and benefits of adaptation scenarios.

Costs of adaptation scenarios	Benefits of adaptation scenarios
Financial costs of adaptation scenarios	Flood risk avoided by the realisation of adaptation scenarios
Wider costs of adaptation scenarios to society	Benefits of adaptation scenarios not related to risk avoided

Figure 5: Overview of costs and benefits of adaptation scenarios

For the calculation of the flood risk avoided hydrological, hydraulic and risk models need to be adapted for the impact an adaptation scenario is likely to have on hydrology, hydraulics and the vulnerability and/or value of economic, social and ecological systems. Next, new flood maps need to be generated on the basis of which flood risk is modelled for the adaptation scenario considered. Flood risk avoided is than calculated by subtracting flood risk in an adaptation scenario by flood risk in the baseline scenario. Possible positive side effects of an adaptation scenario as i.e. recreational and ecological benefits of the development of natural inundations areas should also be added to the benefits side and integrated in the evaluation of adaptation scenarios.

Besides, the financial costs of the realisation of adaptation scenarios need to be determined (WP 2.4). These financial costs comprise the initial investment costs as well as the recurring operating and maintenance costs. As for the benefits of adaptation scenarios the costs are not limited to the financial resources for the implementation of the adaptation scenarios. The wider costs to society of i.e. permanent land use changes, social consequences of forced expropriation, ecological effects etc. should also be accounted for in the integrated evaluation of an adaptation scenario.

Finally all costs and benefits are combined (Working Paper 2.5) to enable the evaluation of adaptation scenarios. The integration and equal assessment of different types of impacts, some expressed in money terms, others quantitatively and still others qualitatively is facilitated by means of integrated assessment tools like cost-benefit and multi-criteria analysis (CBA and MCA). On the basis of the evaluation of costs and benefits the most interesting scenario is put forward. Every scenario for which benefits outweigh costs potentially adds to welfare. However, as resources are limited choices have to be made. Not all projects with a net welfare gain can be executed. Therefore, the welfare contribution per Euro invested can be calculated for each adaptation scenario. The scenario with the highest contribution per Euro invested should ideally be realised first. It is clear from the above that missing costs and benefits can lead to a non-optimal composition of adaptation scenarios. Based on insights from the evaluation of an adaptation scenario in terms of its costs and benefits the adaptation scenario may need to be adapted, as to increase its effectiveness, possibly requiring running the assessment procedure again.

C. Choice and presentation of the case studies

1. General motivation of the choice of the different case studies

Specific case study areas have been selected in the two main Belgian river basins (Meuse and Scheldt).The partners carefully investigated a series of possible locations, prior to selecting two of them offering many appealing characteristics both in terms of primary and secondary impacts. The first study area covers two distinct reaches of the river Ourthe (Meuse basin) between Poulseur and Tilff (commune of Esneux, reach n°1: between Poulseur and Esneux; reach n°2: between Mery and Tilff), while the second one is situated in the municipalities of Ninove and Geraardsbergen in the Dender sub-basin (Scheldt basin). The maps provided in Annex 1 and Annex 2 delineate the location of each case study area. Those study areas have been selected on the basis of their flood history, for their hydraulic, economic, social and ecological features (Figure 6 and 7), as well as for their complementarities. More specifically, the main motivations for selecting the Ourthe case study are the number of floods recorded during the last decade, the availability of data for hydraulic modelling (highly accurate laser altimetry and discharge evaluation for different return periods), the various possibilities of designing adaptation measures and the interest of the area in terms of secondary impacts (several localities, tourism facilities, steal and wood industries, hydroelectricity, residential camping places…). Similarly, the main reasons for selecting the Dender case study was the availability of comprehensive data on recent flood events (2002-2003), the existence of a social and political debate regarding adaptation measures in the catchment and, in terms of ecological aspects, the location of most of the natural zones in the potentially inundated areas. Two draft reports describe the geographical and socio-economic characteristics, as well as the natural and anthropogenic aspects, of each case study area. The report provides also a comprehensive substantiation for the selection of these particular areas, as well as an analysis of flood history in the areas based on literature and statistical data. The two papers mentioned are uploaded onto the ADAPT website, in section "download":

http://dev.ulb.ac.be/ceese/ADAPT/public_section/Doc/Doc/WP2_case_studies.pdf and http://dev.ulb.ac.be/ceese/ADAPT/public_section/Doc/Dender.pdf).

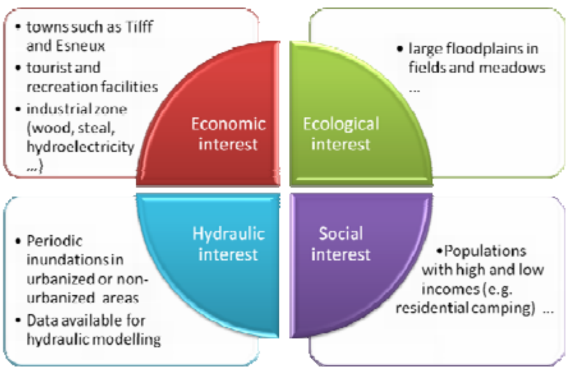

Figure 6 Interests of the river Ourthe case study

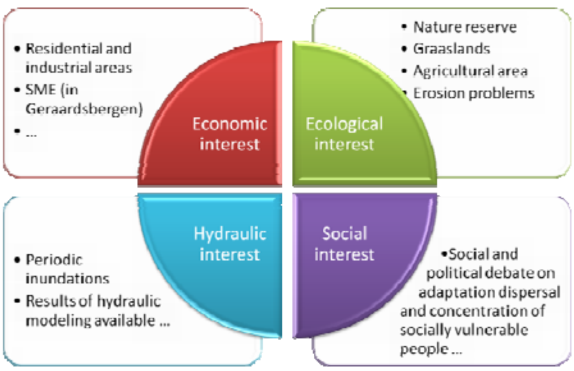

Figure 7 Interests of the river Dender river case study

2. *Case study of the Ourthe basin*

The area to be studied in the context of the analysis of the flooding problem in the Walloon region, consists of a lower portion of the Ourthe, located mainly on the territory of the commune of Esneux in the Province of Liege. This section between Poulseur and Tilff extends to a distance of almost 20 kilometers. The area under study is situated on the periphery of the urban zone of Liege, a few kilometres upstream of where the Ourthe flows into the Meuse.

During its course, the Ourthe passes through many hamlets which made their economic wealth from the river in the past (shipping, floating logs, fishing,…) accepting and putting up with its various moods. Since then, the economic landscape of these zones has changed and the damages resulting from the rise in water level are not so well accepted as in the past by a neighbouring population whose employment is no longer dependent on the river.

The commune of Esneux has a surface area of 34 km ^{2} (8411.47 acres) and the current density is estimated at 384 habitants/km^2.

This commune is characterized by undulation and ridges running north to south over the bed of the Ourthe which gives the main structure to the general relief of the area. The course of this river is marked by many meanders, of which the most outstanding is called "the Ourthe's loop".

Regarding climatic conditions, the commune falls into the continental climate category. It has a wet climate, with rainfall at its highest during December and July. The average precipitations recorded are about 809 mm.

The comparative analysis of the difference in altitude shows that the parts of valley whose slope is too steep for construction are wooded, whereas the less sloping parts accomodate the various rural zones.

On the commune level, five residential estates are currently participating in the Walloon Region's "plan HP" (Esneux Commune, pers. com., 2007) which are all located in the flood plain, and began as tourist estates. So, all the facilities conformed to regular standards (towable caravans, no fixed shelters) but in the course of time, the buildings became illegal for the most part.

The biological quality of the Ourthe is analyzed according to the *Indice Biologique Global Normalisé* (IBGN), based on the analysis of the population of benthic macro-invertebrate This index is a function of the number of species present, their sensitivity to pollution and the number of individual species counted…. . Five classes are identified according to the measurements[2] taken. The index for the whole sub-basin ranges from *very good* to *good*. Only two stations have *average* as quality, one of which is Chênée.

The sub-basin lies for the main part in a rural area, where the economic activity focuses mainly on the primary and tertiary sectors (21% and 58% respectively of businesses concerned). The main industries are agri-food, extraction and wood processing. Tourism also represents a vital economic activity for the sub-basin. The number of tourist establishments, any proportion of the establishments kept, accounts for approximately as much as 20% of all the establishments registered in the Walloon Region. Numerous campsites are in existence, mainly along the riverside. The Ourthe sub-basin also

[2] Very good (20-17, cartographic representation: blue), good (16-13, cartographic representation: green), average (12-9, cartographic representation: yellow), bad (8-5, cartographic representation: orange) and very bad (4-0, cartographic representation: red)

attracts many recreational river activities such as kayaking, fishing and walks (one of which is RAVeL[3] 5).

The Ourthe's hydrological regime is of the oceanic pluvial regime with its maximum rate of discharge generally reached in December-February, and its minimum flow in July-August. In addition, this river has a wide variety of discharge-rates throughout the year and over the course of time. During the period when the water level is at its lowest, it can go as low as 3 to 10 m^3 /s whereas at the time of the heaviest swelling it can reach 800 m^3 /s (in Angleur). Flooding events can be explained by several phenomena such as the measure of precipitation[4], the condition of a river's tributaries and the geomorphological features[5] of the rivers flowing in the sub-basin.

3. *Case study of the Dender basin*

The Dender basin is located in the Scheldt catchment, which is one of the three international river catchments in Belgium. Although the whole natural catchment of the Dender superficies 1,384 km^2, the offical Dender basin, as designed by the Flemisch authorities measures 709 km^2. The other part is located in the Walloon region. The Dender is the main river in this basin, which rises in the Walloon village Ath and flows over a distance of about 69 km before discharging into the Scheldt. Remarkably, the Dender is a spate river, which means that rainfall strongly influences the water level and the river flow rate. As a consequence, high flow rates (up to $60m^3/s$ in winter) and even floods, can occur in rainy times. The area has recently been threatend by flooding in 1995, 1999, 2001 and at the turn of the year in 2002-2003. During these floods, residential area, as well as industrial zones and nature were inundated.

Several sectors make use of the Dender and put pressure on the water systems, like the residential sector (360,000 inhabintants), the agricultural sector (arable farming and cattle breeding), the navigation sector (500,000 tonnes of goods are transported yearly and recreational navigation) tourist sector, industrial sector and water treatment plants. These sectors discharge waste water or uses water in their activities. The water is daily polluted by 19,000 kg COD, which derives mainly from the residential sector. The daily discharge of nitrogen takes 5,112kg, mainly produced by the agricultural industry. Water extraction from the Dender basin is 24.5 million m^3 a year, in particular consumed by the housing sector and the industrial sector.

The main focus of the case study is on the municipalities of Geraardsbergen and Ninove. However, to implement appropriate measures, the whole Dender basin should be taken into account. These villages are inhabited by respectively 31,380 and 35,651 inhabitants. A large part of the population is ageing. The grey pressure rates which refer to the proportion of people aged 65 years and older to the people aged 20-64 years, are respectively 42,8% and 39,8%. A majority of the people lives in owned houses. The average income of the inhabitants is near the Belgian average income. Most yielding economic activities are wholesale and retail sector, manufacturing industry and the construction sector. Most prominent land use in these villages is arable land.

[3] The Autonomous Network of Slow Ways. The RAVeL 5, also called RAVeL Ourthe. It covers two routes, one of which runs along the Ourthe valley between Liege and Comblain-Au-Pont.

[4] Persistent periods of relatively intense rainfall, extremely heavy rainfall lasting only for short periods in the small river valleys

[5] Influence of the river gradient, the presence or not of a flood plain area and the proximity of reliefs marked on the discharge.

4. Complementarities of the two case studies

	Case study Ourthe	Case study Dender
Location of the case study in the river catchment	Downstream	In the middle of the catchment
Length of the case study area	11 km	20 km
Type of floods	Long duration	Relatively short duration
Habitats at risk	Very limited habitats at risk	High number of habitats at risk
Ecological values	Limited numbers of valuables habitats	Very valuables habitats
Habitat diversity	Limited diversity (mainly forest)	Divers habitats (forest, grasslands, wetlands, riparian habitats..)
Population density	Densely populated > Belgian population density	Densely populated > Belgian population density
Average income	Higher than national average, higher than Dender case study	Higher than national average
Economic activity	Mainly the primary and the tertiary sectors	Wholesale and retail sector

Table 1: Overview of the complementarities between the case studies of river Ourthe and river Dender.

D. Hydrodynamic modelling

1. Description of the models

a) WOLF

Flow simulations for the case study of river Ourthe are conducted by means of the numerical model *WOLF 2D* (Archambeau et al. 2004; Erpicum et al. 2007; Erpicum et al. 2008).

WOLF 2D is a part of the hydrodynamic modeling system *WOLF*, which has been developed for more than ten years by the HACH research unit from the University of Liege. The modeling system includes a series of interconnected numerical tools dedicated to one- and two-dimensional modeling of a wide range of flows: open channel or pressurized flows; possibly accounting for sediment, pollutant or air transport (Dewals 2006; Dewals et al. 2008a); including sophisticated turbulence closures (Dewals et al. 2008b; Erpicum 2006) as well as extended depth-averaged flow modeling features (Dewals 2006; Dewals et al. 2006a). Optimization algorithms are also embedded in the modeling system (Erpicum 2006).

The two-dimensional hydrodynamic model WOLF 2D used here for inundation mapping is based on either the the fully dynamic *Shallow-Water Equations* (SWE) or the *Diffusive Wave Approximation*

(DWA). In the SWE approach, the only assumption states that velocities normal to a main flow direction are significantly smaller than those in the main flow direction. The large majority of flows occurring in rivers can reasonably be seen as shallow everywhere, except in the vicinity of some singularities (e.g. weirs). In contrast, the DWA approach assumes that the advective terms of the SWE can be neglected. In this case, the free surface slope is only balanced by the friction term. Although remaining nonlinear (through the friction law), the DWA model requires significantly less computation time.

The model enables the definition of a spatially distributed roughness coefficient. The internal friction may be reproduced by different turbulence closures included in the modelling system, such as simple algebraic ones but also a complete depth-averaged k-ε model (Erpicum 2006).

The numerical model deals with multiblock Cartesian grids. This feature increases the size of possible simulation domains and enables local mesh refinements, while preserving the lower computation cost required by Cartesian grids compared to unstructured ones. A grid adaptation technique restricts the simulation domain to the wet cells. Besides, wetting and drying of cells is handled free of volume conservation error (Erpicum 2006).

The space discretization is performed by means of a finite volume scheme. Variable reconstruction at cells interfaces is performed linearly, in combination with slope limiting, leading to a second-order spatial accuracy. The advective fluxes are computed by a Flux Vector Splitting (FVS) technique developed by the first and fifth authors. A Von Neumann stability analysis has demonstrated the stability of this FVS (Dewals 2006). The diffusive fluxes are legitimately evaluated by means of a centred scheme. 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. The time step is constrained by the Courant-Friedrichs-Levy (CFL) condition based on gravity waves. A semi-implicit treatment of the bottom friction term is used, without requiring additional computational costs.

WOLF 2D enables to manage large sets of topographic data. 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). Although widespread in hydrodynamic modeling, those remote sensing data require as a pre-processing task the removal of residual obstacles non relevant for the flow (e.g. vegetation impermeable to laser pulses). 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 velocity in the inundated areas, which are the main input data necessary for the evaluation of secondary impacts.

Although the hydrodynamic model is perfectly suited for dealing with unsteady flow simulations, including for instance highly transient dam break flows (Dewals 2006; Dewals et al. 2006b), the steady-state approximation is exploited in the present case (Archambeau et al. 2004; Erpicum et al. 2007). As a result of this assumption, the computation time can be further reduced thanks to an automatic mesh refinement method (Archambeau et al. 2004).

This hypothesis has been demonstrated to be valid as a result of the relatively long duration of the flood, combined with a limited possible storage in the floodplains of the rather narrow valley of River Ourthe. Indeed, comparisons have been made between inundated areas simulated on the basis of a real hydrograph (time evolution of the discharge as upstream boundary condition) and inundated areas computed based on a steady-state assumption (constant discharge close to the peak discharge of the real hydrograph). Those comparisons show that the maximum flood extents predicted by the two approaches are in satisfactory agreement. The same holds for the maximum water depth distribution. Furthermore, it has been verified that the computed volume of water stored in the inundated areas under the steady-state assumption is lower than one percent of the total amount of water corresponding to the real hydrograph (in excess of a threshold value of the discharge, under which no inundations is expected to occur). Therefore, the steady-state assumption may be considered as valid for simulating inundated areas on the River Ourthe. This approach has thus been systematically used, since it leads in addition to substantial CPU time savings.

The flow model WOLF 2D has been extensively validated and has shown its efficiency for numerous practical applications (Dewals 2006; Dewals et al. 2006a; Dewals et al. 2006b; Dewals et al. 2008b; Erpicum 2006), including in the framework of the Plan PLUIE of the Walloon Region. In particular, the model has been slightly calibrated (roughness coefficient) and subsequently validated by comparisons with flood extents and water depths observed during recent floods events (mainly the 2002 flood in river Ourthe). Reference data were collected by field surveys and deduced from aerial pictures taken during the flood.

In parallel with the flow modelling tasks described hereafter, efforts have been made to enhance as much as possible the convergence rate of the simulations. This issue is of particular importance because of the need for repeated runs both when predicting the hydraulic impact of different climate change scenarios and, later on, when evaluating and optimizing various adaptation measures. No new numerical method has been developed but comparisons have been made between different procedures based on the existing models. These procedures differ by the initial condition considered, by the hydraulic model(s) used (SWE, DWA or a combination of both) and by the optional exploitation of *Automatic Mesh Refinement* (AMR).

For steady-state simulations only, 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 grid. 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 and thus substantially decreases the total computation time, despite slight extra computation time required for meshing and interpolation operations. In the present tests, the following grid sizes have been used sequentially: 32m, 16m, 8m, 4m and 2m.

The different procedures compared are detailed in Table 3 below for the case of computing the flow for a specific climate change scenario. In procedure 2, the *modified* initial condition refers to a simple increase of the initial water depth distribution by a constant value in the whole domain (this value can be estimated for instance from the change in the downstream boundary condition ...). In Procedure 5, the DWA model is used as a "preconditioning" for the SWE model. Indeed, the DWA approach performs a first quick computation of an approximate solution, which is used subsequently as an initial condition for the complete SWE model.

Table 2 also provides the relative computation time necessary for the different procedures to converge to a steady state solution, compared to Procedure 1. Procedure 4 appears to be by far the fastest one. However inaccuracies in the results are found as a consequence of the simplifying assumption lying under the DWA approach. Those inaccuracies reach up to 50 cm locally in terms of water depth, which is unacceptable compared to the expected changes induced by climate change. Similarly, the overall efficiency of procedure 5 appears disappointing as a result of too big inaccuracies obtained at the end of step 1 (DWA), which prevent a very fast convergence of step 2 (SWE). Therefore, Procedure 3, the second fastest one, is presently identified as the most efficient one for steady-state simulations, preserving the full accuracy of the SWE.

		Initial conditions	Model used	CPU cost
Procedure 1		Flow field from the base scenario	SWE	100%
Procedure 2		*Modified* flow field from the base scenario	SWE	37%
Procedure 3		Flow field from the base scenario	SWE with AMR	36%
Procedure 4		Flow field from the base scenario	DWA	3%
Procedure 5	Step 1	Flow field from the base scenario	DWA	3%
	Step 2	Flow field from step 1	SWE	45%

Table 2: Relative computation time necessary for the different procedures to provide a steady state solution

b) WL Dender model

Results of flood modelling for the Dender case study is provided to the ADAPT project by the CCI-HYDR project. The model used is property of the Flanders Hydraulics Laboratory. The model for the Flemish part of the Dender links a hydraulic model and a series of hydrological models. The hydraulic model simulates how a river reacts on water inflows. These inflows or discharges are calculated by means of the hydrological models. The Dender model has been developed on the basis of the river modelling package MIKE 11. MIKE 11 processes rainfall data and data on the volumes in the river branches and calculates the effect of these water inflows on the Dender. (HIC-WL, 2003 and Willems et al., 2002)

c) Difference in modelling approaches

Table 3 highlights the main differences and complementarities between the hydrodynamic modelling approaches exploited for both case studies.

	Case study Ourthe	Case study Dender
Length of the case study area	11 km	20 km
Considered return periods	25 and 100 years	1, 2, 5, 10, 25, 50, 100, 500, 1000 years
Climate change scenarios	+5%, +10%, +15% (+30%)	To be defined, based on the results of the CCI-HYDR project
Time representation	Steady flow (long duration floods)	Unsteady (quick catchment response)
Upstream boundary condition: discharge obtained from …	Statistical analysis and assumed perturbation factors	Hydrological modelling
Hydraulic modelling team	HACH-ULg	KUL – Hydraulics Division on the basis of the WL Dender model
Model output	Water depth and components of flow velocity vectors in each computational cell	Discharge, water level and flow velocity in each cross-section and water quality in the river

Table 3: Overview of the modeling approaches used for the case studies Ourthe and Dender

2. Climate change scenarios used

a) WOLF

Results of Global Circulation Models (GCM) and Regional Climate Models (RCM) provide estimates of the potential increase in precipitation (mainly during winter and early spring) and potential changes in evapotranspiration as a result of climate change. In the framework of the CCI-HYDR project the likely effects of climate change on precipitation and evapotranspiration have been derived on the basis of simulations with ten PRUDENCE regional climate models. (Boukhris et al. 2007) Those predicted changes are affected by a significant level of uncertainty due to the climate models themselves and, to an even greater extent, to the discrepancies in the scenarios used for running those climate models (Intergovernmental Panel on Climate Change 2007).

Therefore, at the present stage of the research project, simple assumptions have been considered regarding the expected changes in the peak discharges of the river Ourthe as a result of climate change (CC). Indeed, according to a comprehensive literature review (De Groof et al. 2006; Dewals et al. 2007a; Dewals et al. 2007b), an increase by 10% of flood discharge may be regarded as reasonable. Moreover, in order to evaluate the sensitivity of the results with respect to this perturbation factor on the discharge, increases by 5% and by 15% have also been considered. Finally, a more "extreme" case has been simulated as well (+30%). All those assumptions will eventually be confirmed and refined by comparison with the output of the WP 3 "Impact modelling rivers" of the CCI-HYDR project, as soon as this working package is completed.

The study is performed for two different return periods, namely 25 and 100 years, for which the best flood protection strategies will be complementary, due to the significant differences in inundation extent and in the probability of occurrence. For return periods lower than 25 years, almost no inundation is observed, while hydrologic data are not sufficient to reliably extrapolate discharge values corresponding to a return period higher than 100 years.

Table 5 summarizes the different hydraulic simulations performed up to now for the two considered reaches of River Ourthe. It must be emphasized that the base scenario simulations were computed by HACH-ULg in the framework of the "Plan PLUIE" of the Walloon Region.

b) WL Dender model

The method used for calculating the impact of climate change on flooding makes use of average seasonal perturbation factors for rainfall and evapotranspiration. Available time series of rainfall and evapotranspiration, used as an input for the hydrological models, are adapted for the average seasonal perturbation factors for rainfall and evapotranspiration. The hydrological model is than run with the perturbed input series. (Boukhris et al., 2006)

In order to account for the uncertainty related to the climate models and the scenarios used for running these climate models a low, mean and high climate change scenario for Belgium have been derived. The average seasonal perturbation factors applied for each scenario are provided in Table 4. (Boukhris et al., 2007)

Scenario	Low	Mean	High
Winter rainfall	1.00	1.08	1.16
Summer rainfall	0.83	0.99	1.11
Winter ETo	1.00	1.13	1.27
Summer ETo	1.10	1.16	1.29

Table 4: 4 Low, mean and high perturbation factors for precipitation and evapotranspiration

3. *Results of hydrodynamic modelling*

a) Ourthe

(1) Climate change simulations

The assumed modifications in the expected discharges have been translated into updated evaluations of flood hazard for the two considered reaches of River Ourthe, by conducting quasi three-dimensional hydrodynamic modelling with the model WOLF 2D (unknowns: local flow depth and velocity components). Besides summarizing the discharge values considered in the simulations, Table 5 also provides average values of the change in water depths, while Figure 8 gives an example of the obtained updated inundation maps (increase in water depth in the town Tilff and 2D distribution of flow velocity). It is found that the results can be very sensitive to the perturbation factor affecting the discharge, due for instance to the reduced efficiency of flood protection structures (e.g. dikes) above a threshold value of discharge (design discharge).

The complexity of the flow fields represented on those maps recalls the relevance of exploiting a fully dynamic and two-dimensional flow model It must be emphasized that considering properly flow velocity is particularly important for the River Ourthe case study because of the steeper slope of the valley compared to River Dender.

The whole set of results is now available for the partners to evaluate the secondary impacts of flooding. For each return period and each modelling scenario, the following three maps have been generated: water depth, flow velocity and increase in water depth compared to the base scenario. The first to types of maps are also supplied for the base scenario.

		Base scenario	CC scenario n°1 (+5%)	CC scenario n°2 (+10%)	CC scenario n°3 (+15%)	CC scenario n°4 (+30%)
25-year flood	Discharge	726 m^3/s	762 m^3/s	799 m^3/s	835 m^3/s	944 m^3/s
	Reach n°1	-	+ 10cm	+ 25cm	+ 40cm	+ 75cm
	Reach n°2	-	+ 10cm	+ 25cm	+ 40cm	+ 70cm
100-year flood	Discharge	876 m^3/s	920 m^3/s	964 m^3/s	1007 m^3/s	1139 m^3/s
	Reach n°1	-	+ 15cm	+ 30cm	+ 45cm	+ 75cm
	Reach n°2	-	+ 20cm	+ 40cm	+ 60cm	+ 85cm

Table 5: Discharge and average change in water depth compared to the base scenario

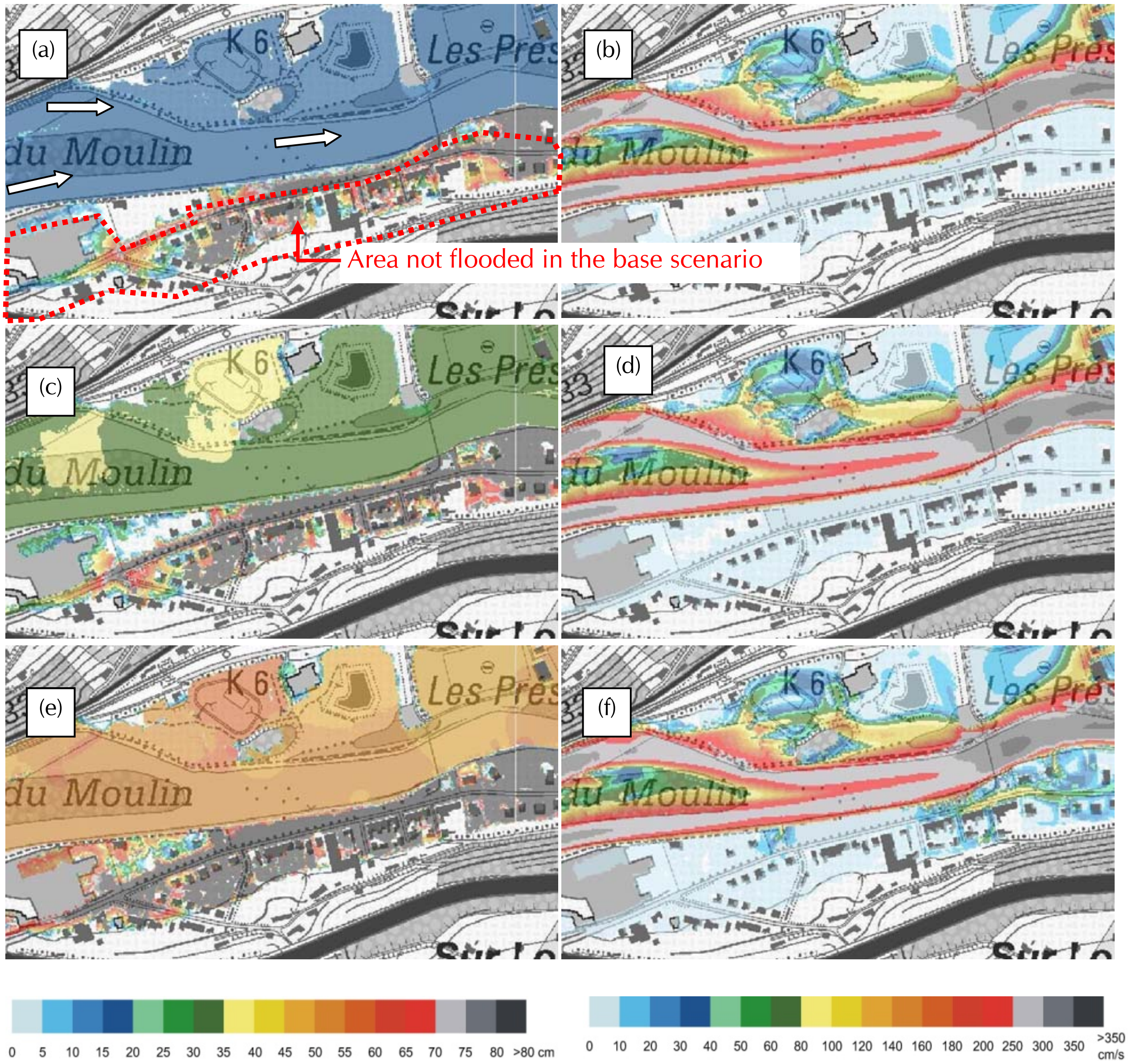

Figure 8 Example of hydraulic modelling results: increase in water depth (a, c, e) and magnitude of flow velocity (b, d, f) for a 100-year flood in the town Tilff for three different perturbation factors affecting the discharge, namely an increase by (a, b) 5%, (c, d) 10% and (e, f) 15%.

b) Dender

The output of the hydrological models, which have been run with the perturbed input series of rainfall and evapotranspiration and thus accounts for climate change effects, is used as the upstream boundary condition for the hydraulic model.

The impact of the climate change scenarios on peak discharges is rather unclear and depends the sign of the trend on peak discharges seems to be dependent on the relative importance of the increase in winter rainfall versus the decline in summer rainfall, and the relative importance of the rainfall trends versus the increase in evapotranspiration. What is clear from the simulation is that the problem of low flows will increase to a greater extent than the problem of peak flows.

The simulation results of inundation depth in the Dender basin (communities of Geraardsbergen and Ninove) for a 100 year return period can be consulted in . Simulations have been provided for a situation without climate change as well as for the low, mean and high climate change scenario. From the model results it appears that only the high climate change scenario implies higher inundation depths. The extent of the inundation remains quasi unchanged as compared to the model results without climate change. In a the low climate change scenario both the inundation depth and extent would decrease. It is, however, not possible to attribute chances to the likeliness of the different scenarios.

E. Translation of the hydrodynamic modelling results into input for the assessment of secondary impacts

By means of flood modelling information on a variety of flood characteristics is simulated. The hydrodynamic modelling results need to be exported to a GIS system in order to visualise the spatial variation in flood characteristics and to be able to combine the information embedded with other georeferenced data like land use maps, cadastral maps, biological valuation maps, address point database etc.

A GIS system is included within the modelling system WOLF, therefore this step is tightly coupled with the hydrodynamic modelling task for the case study of river Ourthe, while for the case study of river Dender, Flood mapping becomes an important subtask subsequent to flood modelling. The information embedded in the flood maps is crucial for flood risk assessment as well as the development of flood risk management strategies.

The flood characteristics embedded in the flood maps vary per point, which provides a reference value for a certain grid. Grid size of the model Wolf is 2m by 2m. Grid size of the WL Dender model is 50m by 50m and thus less accurate. Grid size of the flood maps may thus restrict the accuracy of the analysis for the case study of river Dender..

F. Integration of the effects of adaptation scenarios in a general decision framework

The decision maker needs to develop and select those adaptation scenarios that maximise welfare. The limited resources authorities dispose of should be allocated in an optimal way, prioritising those measures that yield the highest marginal benefits. As to allow a sound evaluation of the contribution of an adaptation scenario to welfare all costs and benefits need to be taken into account. This requirement touches an important shortcoming of existing flood risk assessment methodologies, and consequently also policy making, as indirect and intangible effects to social and ecological systems are often largely disregarded. The problem is not so much that risk assessors and policy makers are not aware of the effects to social and ecological systems, but relates to the fact these effects are hard to quantify, let alone monetise.

In order to overcome the emphasis on direct tangible effects it is not sufficient to simply develop assessment methods for intangible and indirect effects. The integration and equal assessment of very different types of impacts, some expressed in money terms, others quantitatively and still others qualitatively, is still an important challenge. When either the available information on effects does not allow for their integration or the decision framework is not appropriate it will be quasi impossible to evaluate the effect an adaptation scenario has on welfare.

The issue tackled in this section concerns the manner by which the results/outputs of the economic, social and ecological risk assessment modules are integrated in order to support decision making.

1. Advantages and disadvantages of CBA and MCA based decision frameworks[6]

Defining the impact of adaptation scenarios on welfare, by weighing related costs and benefits, requires information on the various effects to be brought together in a comprehensive decision framework. The integration of effects is commonly facilitated by cost-benefit and multi-criteria analysis (CBA and MCA) based decision frameworks.

The choice of the decision framework depends on the specific objectives of the evaluation exercise. When it is the objective to evaluate an adaptation scenario’s contribution to welfare and/or to fine-tune its contribution to welfare, thus going beyond the simple ranking of two or more adaptation scenarios, only a CBA based decision framework is appropriate. However, it is not because the assessment methodology should be able to evaluate a scenario’s contribution to welfare it is reasonably possible to do so and thus to use a CBA based framework. The ability to have a deliberate evaluation of a scenario’s contribution to welfare crucially depends on the available information on the different effects this scenario my have.

A CBA is a method designed to facilitate the comparison of current and future costs and benefits of projects or policy alternatives as much as possible in monetary terms. A CBA is embedded in economic welfare theory and provides an indication of the profitability of projects. Effects that cannot be valued in monetary terms are not integrated in the profitability assessment. They can, however, be added to complete the monetary evaluation. This is referred to as an extended CBA. In a CBA the costs and benefits of a project are usually represented in the form of a balance sheet. If the net benefits turn out to be positive, it will be beneficial to implement the project or adaptation scenario as this will increase welfare.

A MCA covers those methods evaluating projects or project alternatives on the basis of a set of criteria which need to be scored. The scores on each criterion have to be standardised and each criterion is attributed a certain weight. The standardised scores on the different criteria are weighted and then summed for each project or project alternative. Then the different alternatives under consideration are ranked. An MCA thus allows judging whether one alternative is preferred over another alternative, given the criteria selected and the weights attributed to these criteria.

The advantages and weaknesses of CBA and MCA both relate to the way these methods represent information and the way water managers and decision makers interpret the information provided.

A CBA is perfectly suited for supporting cost-effective policy making, allocating the resources to those measures having the highest welfare contribution per Euro invested. Complex information is assembled in a for policy makers easy to understand and workable format. This method is very useful for effects that are easy to translate in monetary terms. Opposition to the use of CBA has to do with the difficulty to translate certain effects into monetary terms. Despite the fact monetary valuation of external effects offers clear advantages for policy making the results are still subject to discussion.

As a CBA, a MCA structures complex information. It hereby, more than a CBA, provides an insight into the deliberations between different effects and the interests of the different stakeholders. This tool offers a framework to deal with quantitative (and thus also monetary) as well as more qualitative

[6] (Brouwer et al., 2004)

information in an integrated assessment. MCA allows dealing with information of a different kind in a balanced and equal way. The greatest difficulty with MCA is the definition of evaluation criteria and the weights attributed to these criteria. Deciding about weighs often requires a political decision which ideally should be based on results from a stakeholder consultation. Scoring the alternatives for each criterion can be done based on technical and/or scientific insights or via stakeholder participation. A MCA is often regarded as subjective. As a MCA is not rooted in economic welfare theory it does not allow assessing and determining the social optimum in a standardised way. Where a CBA can be applied to one alternative only, as to judge whether it is worth realising, MCA requires at least two alternatives of which the most preferred can be selected. A MCA, however, does not guarantee whether an alternative is worth undertaking from a welfare point of view.

2. Identification, organization and assessment of the effects of flooding

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?" The effects to be assessed have been identified based on an extensive literature review, expert knowledge and a comprehensive multi-partner effort. The effects have been grouped per sector to promote system thinking and thus to better grasp the links between the various effects. A thorough insight in the interactions between effects is a prerequisite for assessing the likely impacts arising from (mostly) indirect effects. Whereas direct tangible effects are often quite straightforward, this is not the case for the more intangible and/or indirect effects. The lion part of the effects on social systems are of an indirect nature.

Every effect considered will be assessed on the basis of the general flood risk assessment framework , as presented in Figure 4, which is made up of: the **probability of flooding** and the **exposure**, **value** and **vulnerability** of the elements-at-risk. The **probability of flooding** is obtained either from hydrological data (Ourthe case study) or from hydrological modelling (Dender case study). The **exposure** of the elements-at-risk is provided as part of the hydraulic modelling output. The difficulty mainly relates to the assessment of the **value** and **vulnerability** of the elements-at-risk. The strategies for the assessment of these components of the flood risk assessment framework vary according to the nature of the effect considered. Besides, these strategies are much more experimental, especially for what concerns the assessment of effects to social and ecological systems.

Having taken track of the practical implications of the assessment of the value and vulnerability of the elements-at-risk it has been decided to develop an economic, social and ecological risk assessment module. Every effect is only assessed for in one module as to prevent double counting.

The economic effects mainly are direct effects to tangible values like build-up property, but also indirect damage to the economy. Besides tangible damage, inundations also cause intangible damage, often referred to as social effects. Social effects relate to the changes inundations have on the way people live, work, think and organise. Disruption of physical and mental health, disruption of the financial situation, loss of items with a personal value, changes in risk perception, difficulties in meeting basic needs and recovering the house, etc. are just of few examples of social effects. Ecological effects of flooding relate to ecosystem service provision, being the benefits people derive from ecosystems, being affected by flooding. The effects of flooding to ecosystems are approximated by the impacts to hydrological functioning, biodiversity maintenance, carbon sequestration and nutrient cycling.

3. *Critical issues related to the integration of economic, social and ecological impacts*

The objective of the practical methodology is to facilitate welfare maximising decisions about adaptation scenarios. As MCA only allows for the ranking of two or more scenarios, the integration of the costs and benefits will make us of a CBA based decision framework. The decision framework is, however, not a pure CBA as not all relevant effects can be expressed in the same unit, usually money. The CBA decision framework is therefore extended to also include quantitative and even qualitative information about effects. The decision framework is called an extended CBA, but in practice it is a mixture between a CBA and an MCA. Notwithstanding the fact this decision framework will be able to cope with quantitative as well as qualitative information it should be the aim to monetise as many effects as possible. Besides, quantitative information is also preferred above qualitative information.

For the ADAPT project to be able to reach its objectives the project requires at least an extended CBA as decision framework. In order to guarantee a maximal integration of effects it is crucial information requirements of a CBA based decision framework are downloaded to the assessment methods and guidelines to be developed for the effects treated.

These considerations do not only apply to the assessment of flood risk avoided, for which the general flood risk assessment framework already offers a vehicle for tackling integration issues, but also extent to all other effects arising from adaptation scenarios. In a first instance, this are the investment costs as well as the operating and maintenance costs of the adaptation scenario considered. Second, any relevant wider effects, both positive and negative, an adaptation scenario may have on society also has to be accounted for. Besides ex-ante flood risk assessment methods, other effects also require specific assessment guidelines.

For what concerns the effects that can not readily be monetised or for which monetisation is not desirable, as this would add to overall uncertainty in stead of reducing it, carefully developed indicators need to be drawn up. Indicators are as varied as the types of systems they monitor. However, there are certain characteristics that effective indicators should have in common:

- relevant - does the indicator tells you those things about the system you need to know?
- easy to understand - can the indicator be easily understood? Can it be communicated to non-expert users?
- reliable – can you trust the information that the indicator provides? Is the indicator based on sound scientific grounds and well validated?
- sensitive - is the indicator sensitive to changes in the ecological, social and/or economic effects it aims to characterise?
- based on accessible data - can the required data be measured or obtained at a reasonable cost and effort? Can the required data be obtained in a homogenous way for the whole of the country?
- measurable - is the indicator measurable? Can the indicator value be compared to a reference value? Can the meaning of the indicator value be determined?

In the following sections the different effect assessment methodologies are discussed. Particular attention is given to the challenges information requirements of a CBA based decision framework impose on these assessment methodologies.

a) Economic flood risk modelling

The focus of current flood risk models is predominantly on the assessment of direct damages to tangible values. Economic flood risk modelling, which mainly focuses on potential damage to build-up property, is therefore quite straightforward. The **vulnerability** of the elements-at-risk is assessed by means of relative damage functions for the different economic damage categories considered. The damage functions used are either borrowed or adapted from existing models. For every damage category or element-at-risk considered a corresponding market **value** is derived on the basis of available market data. The output of the economic flood risk assessment methods is a monetary value. The economic flood risk assessment module thus allows for a full CBA.

b) Social flood risk modelling

The **vulnerability** of people, and their social network, to flooding is many times more complex than is the vulnerability of tangible assets. People's vulnerability can simply not be approximated via a simple depth-damage function. People's sensitivity, adaptive capacity and resilience to flooding varies according to the situation in which they find themselves. Social vulnerability to flooding is being approximated by a number of well-chosen personal characteristics: age, health status, income, family structure, nationality and property type. For each of these personal characteristics one or more indicators have been chosen. Generally, the statistical data worked with for calculating vulnerability are only available at district level and not at the personal of family level. The social vulnerability assessment methodology provides us with a very general indicator of people's social vulnerability, expressed by means of a quantitative scale, as all people living in the same district have the same vulnerability.

Based on an extensive literature review and expert judgement the seriousness of the social effects has been determined. The seriousness of the effects, being a measure of the **value** potentially at risk, has currently been scored by means of semi quantitative scales. A limited number of effects i.e. the health effects of flooding can however be monetised via the use monetary factors borrowed from valuation studies. However, for most effects no monetary factors are available.

The social flood risk assessment method provides an insight in the geographical distribution of people's vulnerability to flooding by means of vulnerability maps. The benefits of flood prevention will predominantly be expressed in a semi-quantitative manner. Only a minor part of total effects, either positive or negative, can be expressed in monetary terms. The social flood risk assessment module adds to the effects monetised, but definitely requires the use of an extended CBA framework as to not overlook the effects that cannot be monetised.

c) Ecological flood risk modelling

Like the social flood risk assessment methodology the ecological flood risk assessment methodology is experimental. Four knowledge tables provide information on the degree to which each of the four key ecosystem functions, serving as a proxy for the ecosystem services they underlie, performed by the vegetation types in the areas-at-risk are **vulnerable** for different flood characteristics. As for the social vulnerability assessment methodology these knowledge tables serve as a complex, multi-dimensional damage functions.

What are hydrological functioning, biodiversity maintenance, carbon sequestration and nutrient cycling worth? Ecosystems derive their **value** from ecosystem service provision, which crucially depends on ecosystem functioning. The main problem when wanting to include the ecological impacts of flooding in a CBA based decision framework is that the impacts to ecosystems often can not be quantified very accurately, let alone monetised as the corresponding services are not valued in markets. Alternatively, ecosystem service provision is scored by means of a simple quantitative scale for every vegetation type.

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

d) Investment and operating costs of adaptation scenarios

The assessment of the investment and operating costs of adaptation scenarios is an uncontroversial task as there is little uncertainty involved. For what concerns technical adaptation measures cost information is provided as part of the conceptual design made by an engineering firm. Cost information can be completed on the basis of in-house knowledge of water managers. For some measures basic costs functions or proxies can be drawn up on the basis of which a preliminary scanning of an adaptation measure can be performed. For what concerns non-technical adaptation measures preliminary cost information is often not readily available and may require an ad hoc assessment.

e) Wider costs and benefits of adaptation scenarios

The wider costs and benefits of adaptation scenarios are part of an integral analysis. These effects should not be disregarded as they act upon overall welfare to society. In many instances stakeholder involvement is of particular importance for the identification as well as the assessment of these costs and benefits. The procedure for the integration of these effects will consist of a checklist for facilitating the identification of effects. Again, it is the objective to have effects as much as possible expressed in monetary terms. It is advisable to have these costs and benefits assessed on the basis of the guidelines for carrying out a socio cost benefits analysis. To the extent possible it is the objective to provide robust monetary factors for assessing the most important effects.

4. Description of the method and related actions

The challenges concerning the integration of the different effects in a CBA based decision framework are multiple. A first challenge lies in increasing the number of effects that is expressed in money terms and this without increasing overall uncertainty. For those effects for which good monetary factors are available these should ideally be used. Second, effects for which valuation is either not possible or desirable should ideally be expressed quantitatively. These effects then have to be fed into a MCA framework. The unit of analysis of the effects quantified in a MCA framework will be the number of people affected for the social effects and the number of hectares affected for the ecological effects. Third, the information provided by the CBA based decision framework will be complemented by the visual representation of the location and spatial distribution of the elements-at-risk, their vulnerabilities and, to the extent feasible, their value. This should allow to better design adaptation scenarios to specific bottlenecks and thus to optimize the development of adaptation measures. To the extent possible the different challenges concerning the integration and representation of flood risk, and the components it is composed of, will be facilitated by means of GIS.

G. Economic risk assessment methodology / Evaluation of economic impacts of climate change induced flooding

1. Scientific methodology

Within the context of economic aspects, the *elements-at-risk* are mainly the build-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:

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

Within the framework of this project, the assessment of the economic impacts of flooding on the elements-at-risk, makes use of two methodologies. These two methods result from the assessment of the use value of the total economic value by the revealed preference approach:

- The market prices method: This technique is based on the price of the losses in terms of market prices.
- The hedonic price method (HPM): This technique builds on the analysis of existing surrogate markets. This approach attempts to identify what price differential can be attributed to a particular environmental difference (inside/outside of the flood area) between properties.

a) 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 for what concerns to 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 characterisation of the issues is a fundamental stage in the modelling of potential damages.

b) Damage cost assessment (market prices)

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

(1) Damage inventory and data collection

During the first stage, we gathered a maximum amount of information from different actors about the private and public goods which were damaged during previous flood events. A part of these data were provided by the "Disaster Funds". As data were lacking in homogeneity, consistency and comparability in the data collection methodology for the different big flood events over recent years, only two sources of data were used (data provided by the local authorities and the "Disaster Funds"). Unfortunately, the data are not available on an individual basis, but are aggregated by street for the whole commune for reasons of confidentiality.

In parallel, the data collection for the good characteristics of the commune of Esneux had carry out. These data have do serve to develop damage functions in order to compare these results with data provide 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 including the cadastral income for each entity, the cadastral nature, the area and year of construction for the plots built. These data are required to draw up a GIS map for georeferencing damage and to develop the damage function for the second phase of WP 2).

(2) B. Data treatment -

During the second stage, several treatments of data had to be carried out. In fact, it was obvious that there were several biases in the statistics. While undertaking these corrections, we categorised each damages according to what village in the commune it occurred in, on the basis of different maps and plans of the study area and based on the information given to us by the local authorities. This treatment allowed us to obtain a precise aggregation of the damages.

The data proceeding from the Service of Finance and "Disasters Fund" will be processed along with the development of damage functions appropriate to our case studies and probably in the general case of flooding. These data will be used, processed and compared in order to ensure optimal precision.

(3) C. Statistical analysis -

The third step consisted in analysing the data from a statistical angle, like 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.

(4) D. GIS analysis -

In 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's 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 could be carried out nowadays relatively easily by means of Geographic Information Systems (GIS).

We have already a map of the hazard (plan P.L.U.I.E.S, by the Wallonia region) area for Esneux and the others municipalities of the two case study. The risk evaluated by these map is only qualitative (high, middle or low) but it's a good source of information for our work which is quantitative.

The methodology of mapping has been eloborated by the Cemagref, (Institut français de recherche pour l'ingénierie de l'agriculture et de l'environnement), but adapted for the Walloon region. The methodology makes a distinction between the hazard (natural phenomena of flood in a region) and the risk.

The map is build using the time of occurrence and the depth of the flood (see figure 9):

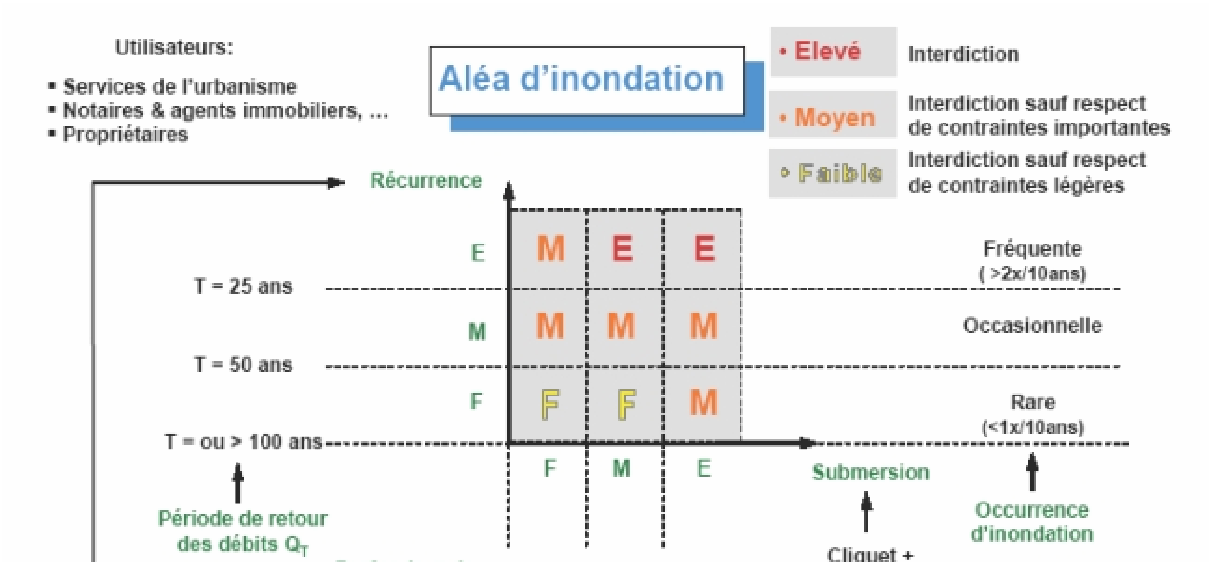

Figure 9: methodology for mapping flood areas

(5) E. Damage functions -

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 in 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 in 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, we will validate these established functions in applying our experimental data (on case study of Ourthe basin). We choose 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.

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 modelling 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.

The resulting damage functions will be aggregated individually in order to compare them with the data provided by the "Disaster Funds" which represents damages declared or accepted per street.

c) The hedonic price method (HPM) (OCDE, 2006; Terra, 2005)

Globally speaking, the HPM "*estimates the value of a non-market good by observing behaviour in the market for a related good*" (OCDE, 2006). Within the context of the ADAPT project, the HPM consists in breaking down the price of real assets as a function of the characteristics (attributes) which define them. In this way, it is possible to evaluate the influence of house prices located in flood prone areas on the market value of various real estate goods with similar characteristics. This approach allows us to identify the depreciation of the market value of these real estate goods because of them being located in an area at risk of being flooded. This reflects the value people hold for their properties being less exposed to flooding.

This method should also allow for an estimation of the value of a good to be made if adaptation measures are foreseen for this good in the event of flooding. This method requires an extensive database in order to be effective. Numerous individuals and organisms have been contacted towards this end: solicitors, geometric experts, real estate agencies. In this way, much information has been collected. Within the framework of this methodology, we encountered many problems concerning the data acquisition. Indeed, very little data are available and they are very often private. Consequently, a long administrative process is required for obtaining them. These problems greatly hamper this part of the research.

The HPM is supplemented by collecting additional information from the insurance sector in order to assess the "flood premiums" for the houses located in flooded areas. Unfortunately, insurance covering flood damage is very recent in Belgium, so only limited data are available. Nevertheless, we will continue our investigation via insurance companies which have offered this cover for several years. Moreover, the meanings of the HPM results will be analysed in comparison with the damage cost assessment.

2. (Preliminary) results

a) Damage inventory

This section presents the results of the first four steps of the "market price" analysis.

For the two case studies, several floods were considered; four events were studied for the Ourthe basin and three for the Dender basin. The damage costs obtained stem from assessments by experts at the "Disaster Funds".

For the commune of Esneux (Ourthe basin), the analysis of the damage costs and the number of affected goods both indicate that the consequences were very different for each flood event (see Table 6). Compared to the hydraulic data, the first flood studied recorded the most harmful characteristics in terms of peak discharge and water level; the other floods presenting more or less similar profiles. In the task devoted to the determination of adaptation measures, the differences in damages between these four events will be compared according to measures adopted along the Ourthe basin.

Floods events (Esneux)	Housing (€)[7]	Household goods (€)	Business (€)	Total (€)
Dec 1993 - Jan 1994	1.092.418,40	505.007,23	171.388,49	**788.905***
Jan - Feb 1995	113.182,71	55.401,01	50.322,49	**2334.905**
Jan - Feb 2002	50.575,86	32.975,83	18.959,75	**2348.509**
Dec 2002 - Jan 2003	31.877,33	10.047,01	-	**74.924**

Table 6: Damage costs in Esneux (*including damage costs from agriculture for 4.035,71 €)

For this 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.

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 the main damages are 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

b) GIS analysis

Example of information provide by that kind of map (see Figure 10): the structures (houses, roads,...) the more affected in a case of flood.

[7] Current prices

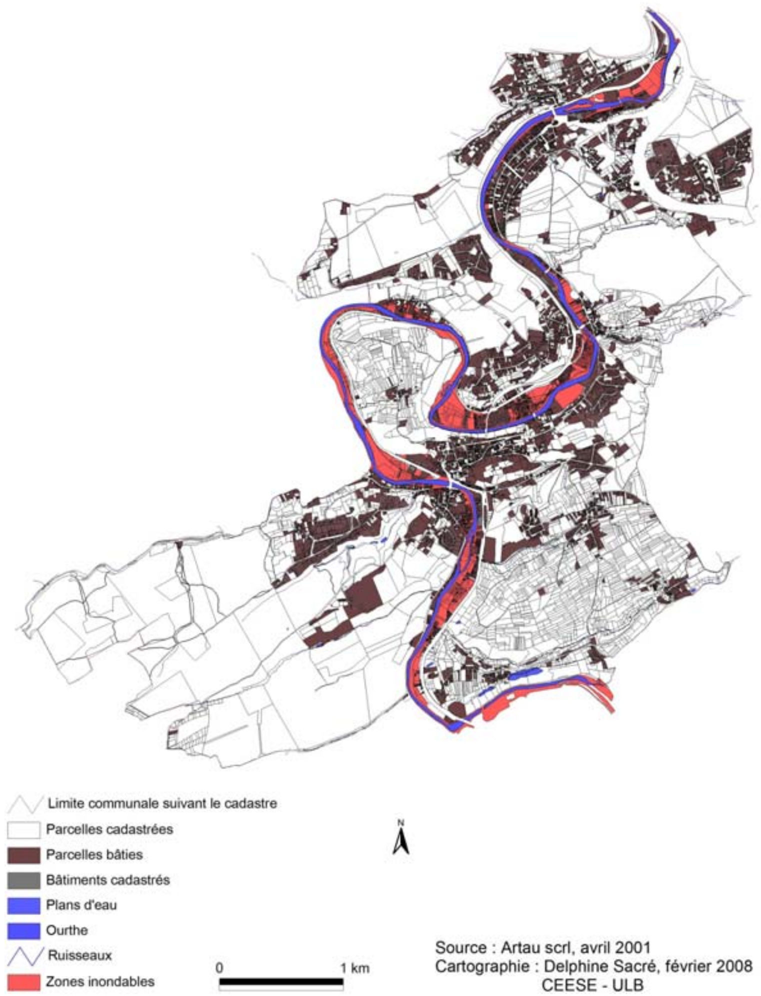

Figure 10: Map of Esneux

A more detailed information is provide by the cadstral map (see Figure 11). The cadastral map locate each property not only by a point but in form of discrete ground floor area of building and property. It provides also a differentiation of residential and non-residential use of buildings.

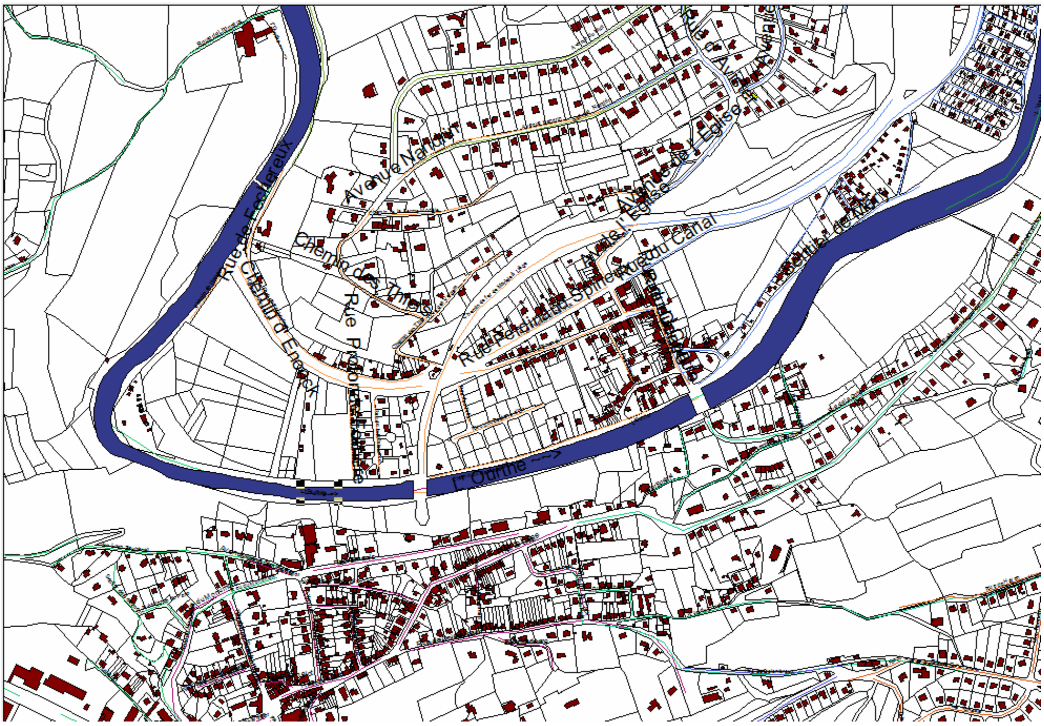

Figure 11: Extract of the cadastral map of Esneux

Several solutions of software tools have been developed up to now. GIS has become more common over the last years in the reduction of the damage calculation procedure. Some examples of such software tools are describe in the FLOODsite: HIS-SSM, MDSF, FAT and HWSCalc.

c) Damage functions

The use of data at the individual houses level would improve the quality of the global assessment of the damage and would enable us to develop appropriate damage functions when relating damage to the simulated local water depth. On the basis of the foreign experience on the damage functions (applied methods in England, The Netherlands, France and Germany) and depending on the data availability, several scenarios of work are possible:

- Development (or adaptation) of damage functions for an individual good ;
- Development (or adaptation) of damage functions per homogeneous area ;
- Development (or adaptation) of damage functions on the basis of data by streets (aggregation of individual functions according to the number of flooded houses by streets).

An example of damage functions extracted of the literature is presented in table 7.

By means of these functions, the value of the avoided damage can be assessed and compared with the costs of the adaptation measures (Phase 2, task 2.5: Cost-benefit analysis).

Flash flood, with basement :	C = 2042,81 d + 4832,63	-2,35<d< 0
	C = 2195,27 d + 4832,63	d>0
Flash flood, without basement	C = 2103,80 d + 4741,16	
Slow flooding, with basement	C = 6677,27 d + 12988,66	-1,94<d< 0
	C = 7119,37 d + 12988,66	d>0
Slow flooding, without basement	C = 4344,80 d + 670,78	0<d<0,205
	C = 7119,37 d + 91,47	d>0,205

Table 7: Damage Functions ("C" is the costs of damage and "d" is the water depth).

Sources: Collection "Etudes et synthèses"de la Direction des Etudes Economiques et de l'Evaluation Environnementale (D4E) 2007-03.

The cost units expressed in euros (€) and the water depth (d) units are in metres (m).
The value of "d" corresponds to the water depth depending on the floor level.

The concept of *flash flooding* and *slow flooding* corresponds to the speed at which the water level rises. This speed (in the rise in water level) is on the one hand related directly to the danger which the flood creates and on the other hand is most often linked to the speed of water flow. It is expressed in the following definition:

- *flash flooding* occurs on surfaces of less than 5 000 km², over a duration of 6 to 36 hours with a concentration time of less than 12 hours for river basins of 1 000 km²
- *slow flooding* : takes place over several days, is due to constant but not necessarily heavy rainfall continuing for a long time and comes from a river basin of more than 5 000 km² (*Guide d'élaboration des plans de prévention des risques inondation en Languedoc-Roussillon*, 2003)

In assessing any damage functions found in the literature, we have chosen to take in the first step as the basis for the work the damage function reported in the ICPR Rhine atlas: $D = 2 H^2 + 2 H$, where H is the water level (in m) recorded during the flooding and D designates the relative damage in percentage of the housing value.

This function relates directly damage to the water depth which is a direct outcome of the hydrodynamic simulations. The flow velocity and the flood duration may play a significant part for specific applications (e.g. dam break flows) but the water depth remains the most influential parameter for a vast majority of applications (Dushmanta, 2003).

Experience of the latest flooding events in Belgium shows that damages on houses are the most important contribution to the total damage compared to other sources of damages. Consistently, the present development of damage functions is focused mainly on this type of damage.

The damage function of 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 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 in our case study of the Ourthe basin provide by the "Disaster Funds."

H. Social risk assessment methodology / Evaluation of social impacts of climate change induced flooding [HIVA]

1. Scientific methodology

Within the context of social aspects, the **elements-at-risk** are people. The **vulnerability** that is assessed is named social vulnerability, since it is related to social characteristics of the people.

To **assess the flood risks** in phase I, two social aspects are analyzed:

- Vulnerability of people towards floods
- Social impacts/consequences of floods
- Socio-economic scenarios

a) Vulnerability of people to floods

Some people are more vulnerable to flood impacts than others. To analyze the social vulnerability, we have first reviewed the literature to understand the issues of susceptibility, adaptive capacity and resilience. These aspects are characteristics of individuals and communities that may moderate or, contrarily, worsen the social impacts. Then, we have performed an initial analysis of the indicators determining social vulnerability and adaptive capacity towards climate change. In addition, we have explored the social vulnerability indicators which are specifically related to floods. From this analysis, it was clear that most vulnerable to floods are elderly, long-term ill people, financial deprived people, single parents and non-European residents. In the near future, we will focus more on the adaptive capacity of the community to prevent flood impacts.

(1) Methodology: social vulnerability index and maps

A social vulnerability index is a tool to compare the vulnerability of people to flood impacts between different regions. In this way, we will have a clear idea about the localization of the most vulnerable people. We have developed a index-methodology based on the indicators of the Social Flood Vulnerability Index (Tapsell S.M. et al., 2002) of the FHRC (Flood Hazard Research Centre), which has a large experience in examining social aspects of floods. We have slightly adapted this methodology to apply to the Belgian context in general and the case studies in particular. First, we have collected data on the social vulnerability indicators in the case study areas from several data sources. The social vulnerability indicators are:

In accordance with FHRC - method

- Financial situation, health status, age and family structure

We also include:

- Race and ethnicity: because in Belgium, non-European residents are at this moment a vulnerable social group often not well integrated in society
- Property type: some properties like cottages and one-level houses are more vulnerable than others.

The data are collected on the level of a statistical sector (district level), which is the smallest available level of the data. This data is extracted from the most recent population census (2001). But we are confronted with some problems. First, not all data are available, like data on health status. It is possible that we have to eliminate this indicator due to lack of information. Secondly, not all data are available at the smallest statistical level, like unemployment. The data are statistically analyzed and transformed into a social vulnerability index that enables comparison between the statistical sectors. By using GIS-software, we have developed social vulnerability maps for the baseline situation (2001). An scientific innovation is to combine the social vulnerability maps with data on address points and flood maps. This analysis will enable us to identify which social groups are most vulnerable to flood impacts, whether socially vulnerable people are concentrated in flood risk areas and whether future floods will harm socially vulnerable people.

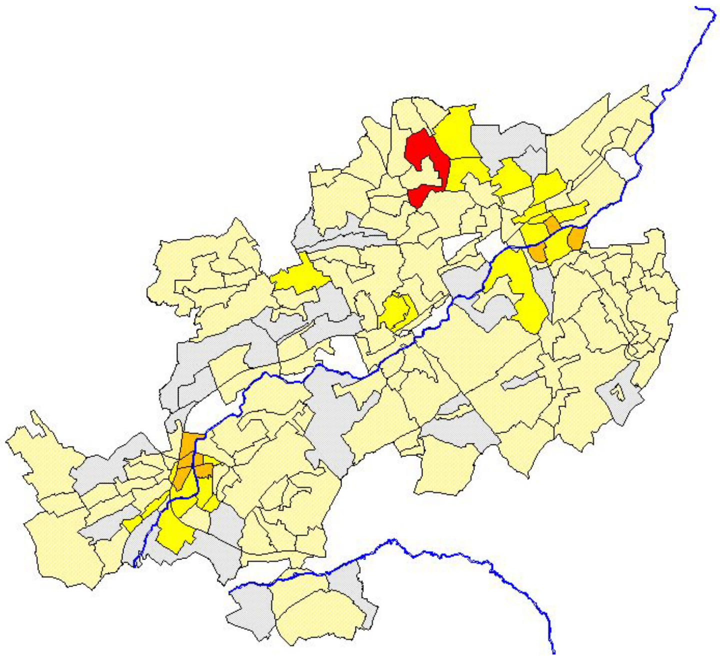

Figure 13: Social vulnerability map of Geraardsbergen and Ninove (Scale: 1: 120,000)

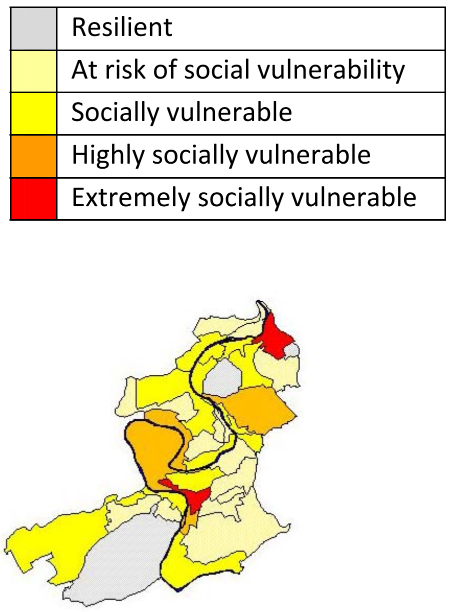

Figure 12: social vulnerability map of Esneux located in the Ourthe Basin (Scale 1: 120,000)

b) Social impact assessment of floods

Another issue is the analysis of the social impacts of floods. Social impacts refer to changes in the way people organize, live, work and relate to each other. These social impacts, that are intangible, can be related to economic impacts that are most of the time tangible impacts. In addition, the extent of the economic damage triggers social impacts. 'The dwelling acts as a lens which either attenuates or magnifies the (social) effects of the flood upon the households.' (stated by Green C., 2006). When the damage is large, the social impacts will be larger as well. Examples of social impacts are health impact, changing risk perception, disruption of family life, impoverishment of the neighborhood and increasing inequality.

(1) Methodology: social impact assessment

To assess the impacts in a climate change context, we have developed a 5-step methodology based on the SIA-method of Burdge (Burdge, 1994). The main idea of the methodology is that ex-ante forecasting social floods impacts can be done by evaluating the social impacts of floods in comparable locations in the last 10 years.

- The first step is the description of the study areas since social impacts are context-driven.
- The second step is the analysis of stakeholders, which is required to distinguish social impacts and to evaluate social acceptance of adaptation measures (in task 2.3) These stakeholders are distinguished according to characteristics like their interest in flood risk management and their power to influence flood risk policy. This approach will enable us to discern which stakeholders are the 'players', the 'subjects', the 'crowd' or the 'strategy context setters'. The 'players' have both interest and power on the decision-making of adaptation measures. These are for instance ministries. The 'subjects' on the other hand, have also a large interest in flood risk management, but do not have a large power to develop flood risk management. These are flood victims like inhabitants or farmers. 'Strategy context setters' do not have a large interest in flood risk management per se, but have power to develop it like the media. And lastly, the 'crowd' does not have interest, nor power to develop flood risk management. They are in fact outsiders. (Eden et al., 1998)
- The third step is the forecasting of flood occurrence in the future, which will be carried out by HACH-ULg and the CCI-HYDR team.
- The fourth step, the core of the methodology, is the identification of the full range of probable social impacts of floods. These are divided into impacts on the individual/household and impacts on the community. Therefore, we are developing a social flood impact matrix. This impact matrix will be used to understand what is already known on the social impacts of floods, on the relation between vulnerability characteristics and social effects and between flood characteristics and social effects. In addition, we also analyze the role of social networks in adaptive capacity of the community and social flood impacts. The knowledge is mainly based on the results of quantitative surveys that can be generalized to a large extent. A problem is that only a few large-scale quantitative surveys have been carried out to date, in particular in the UK. As a consequence, there are still knowledge gaps and uncertainties about some relationships that are figured in the table, which will be labeled as issues for further research.

The final step of the method is the assessment of the likelihood of occurrence of specific social impacts in the case study areas. Therefore, we will make use of the social impact knowledge table (top-down approach), as well as local knowledge (bottom-up approach). The local knowledge will be collected by face-to-face interviews with key stakeholders, which will be the most effective way to gather accurate data.

2. *(Preliminary) results*

a) Vulnerability of people to floods

(1) Intermediary results: social vulnerability index and maps

The intermediary results of the social vulnerability maps clarify that in the Flemish case study area, the number of extremely socially vulnerable people is limited to 26, while the number of socially vulnerable and highly socially vulnerable is 11,816 and 5,469 respectively. In the Walloon case study, the number of extremely socially vulnerable people is 464, while 7,764 people are socially vulnerable and 407 are highly socially vulnerable. Combining the social vulnerability maps with flood maps will demonstrate more accurate figures of the number of people actually at risk. This will happen in the next few months.

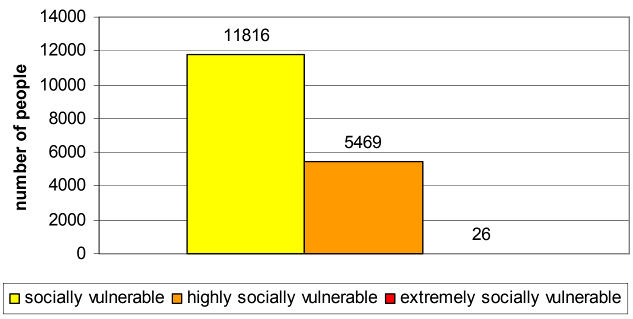

Figure 14 Vulnerable people in the case study Debder

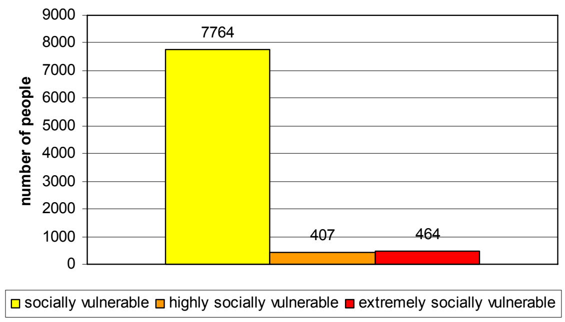

Figure 15 Vulnerable people in case study Ourthe

However, we are aware that some drawbacks are currently known. Firstly, the index is sensitive to the number of people living in the area. But many indices are liable to this problem and a solution is not yet offered. Secondly, data is not available for some indicators. Thirdly, there might be disagreement on the selection of specific variables. But indicator selection is arbitrary in every research, and we have opted to select those variables that are demonstrated to be significant. And lastly, not only susceptibility, but adaptive capacity of the community plays a role in the final experience of social impacts as well.

b) Social impact assessment of floods

(1) Intermediary results: social impact assessment

At this moment, steps 1-3 are finished. There is a clear view on the stakeholders in both study areas. The information on potential floods in the future is provided by HACH-ULg and the CCI-HYDR team. Step 4 and 5 are almost finalized. We have explored the literature on existing understanding of social impacts. Based on this information, we are developing a social impact matrix that clarifies the likelihood of experiencing social flood impacts. It illustrates the relation between social susceptibility characteristics and social impacts, and between flood characteristics and social impacts. Lastly, we have developed a framework to analyze the adaptive capacity of the community. The result will be paper based on the literature review. By developing the social flood impact matrix, we were confronted with two problems. The first problem is the existence of knowledge gaps on social impacts. Several social impacts are not yet researched in detail, nor have their relationships with vulnerability characteristics or flood characteristics been clarified. And the second problem is that for several impacts, it is uncertain whether the evaluation should be positive or negative, for instance in some cases proof was found that the relationship between flood victims and their colleagues at work worsened. But in other cases, the flood victims could rely on understanding and emotional support from their colleagues.

c) Development of socio-economic and social vulnerability scenarios

In order to assess flood impacts that will happen in the future, it is necessary to explore how the world may look like at that moment in time. Scenarios are useful tools to project future world images. First we have explored the existing socio-economic scenarios. The key variables of socio-economic change are economic growth, technology change, governance, demography and social values. Then, we have selected the most useful scenarios that could be applied to our case study. Next, the literature was reviewed to understand the correlation between socio-economic change variables and social vulnerability indicators. Based on this information, we have extended and adapted the existing scenarios to the case study. In a later phase, we have quantified the narrative storylines and have developed social vulnerability maps for each of the future scenarios. . Four scenarios are developed based on existing scenarios of the IPCC and the UKCIP. These scenarios are named Global Economy, Sustainable Development World, Self-contained Nation and Local Responsibility scenario. Each of them is described in a narrative way and contains the key elements of socio-economic change. In addition, they are extended to be used as social vulnerability scenarios. However, discussion with the end-users will clarify in what way scenarios will be used in the integrated decision tool

I. Ecological risk assessment methodology / Evaluation of ecologic impacts of climate change induced flooding

1. Scientific methodology

Investigations will emphasize changes in ecosystem structure and functioning and changes in the frequency and intensity of disturbance processes anticipated to have significant consequences on the habitat values of the ecosystems. These alterations include altered productivity, changes in biodiversity and species invasions, and changes in carbon, nitrogen, and water cycles. This ecosystem approach will provide a good basis to guide the formulation of climate change mitigation policies and conservation of biodiversity. To assess the ecological vulnerability of habitat to flood different steps were carried out:

a) Inventorying Ecosystem Good and Services EGS for the element/habitat at risk

Risk of flood hazard will be substantial for habitat close to the river where flooding will increase erosion and loss of habitats, this would have serious consequences for terrestrial biodiversity as for aquatic biodiversity, particularly for fish populations. Based on the literature survey, the most important good and services of habitats at risk of flood were determined. Biodiversity, buffering capacity (nutrient retention), hydrological functioning (water retention capacity), and carbon sequestration were the most relevant EGS. An important aspect of monitoring and evaluation the impact of climate change induced flood is the choice of suitable criteria and indicators, which should be, whenever possible, meaningful at the site, national and possibly international level, as well as consistent with the main objectives of the project or policy intervention. Therefore we pay special attention to select the most relevant indicators for assessing the vulnerability (on biodiversity and functionality) of the element/habitat at risk in the selected case studies.

(1) Biodiversity maintenance

For the terrestrial habitats we used the Global Ecological Values to characterize the biodiversity in the potential flood areas. The Global score for the Ecological Values (GEV) of each habitat type is calculated based essentially on the BWK (Biological Values Maps) and the score of the presence of rare species (NARA report. 1999). For the aquatic systems we used the Fish Index as indicator for the biodiversity.

The FI is used to evaluate the integrity of fish community. It contains five classes in accordance with the European Water Framework Directive.

(2) Functionality: hydrological functioning, nutrient cycling, carbon sequestration

Based on the literature study of national nature reports and previous scientific publications, the functionality of each habitat was assessed. Here each habitat type was characterized by the most important functions (such as capacity of buffering/nutrient retention, water retention and carbon sequestration..).

b) Evaluating the theoretical vulnerability of ecosystems to flood (based on literature study and experts judgment)

As mentioned before, for the ecological aspects, habitat/or vegetation community was used as elements/unit at risk. Based on the first literature survey, we noted that the vulnerability of habitat services (biodiversity and functionality) depends on different flood characteristics (frequency, depth, velocity, duration, and water quality), on the adaptive capacity and on the capacity of each habitat/vegetation type to recover from flood. Specific vulnerable elements include loss of habitat for biodivers fauna and flora, increases in extinctions and invasions of exotics, loss of water retention capacity, and potential exacerbation of existing pollution problems such as eutrophication. Starting from the Biological Valuation Map (BWK), the methodology consisted in grouping the 970 categories into 54 vegetation communities or habitats based on potential indicators for vegetation communities (Figure 11). After that, and based on literature the response of each habitat to different combinations of flood characteristics is analysed. The combinations (48 combinations) of different flood scenarios with different flood characteristics are:

period of flooding: summer flood; winter flood

flood frequency: rare (<1 per 25 years); irregular (1/10 to 1/25 years); regular (1/2 to 1//10 years); and frequent (1/2 years).

flood duration: >14 days; <14 days

flood depth: <20 cm; 20 cm<x< 50cm; > 50cm

The results of this survey are four matrix tables (biodiversity, nutrient retention, carbon sequestration, and water retention). The matrix is a scoring table where the compatibility and vulnerability of the biodiversity and functionality of each vegetation community to flood characteristics is translated into a score (1: very sensitive; 2: sensitive; 3: tolerant; and 4: very tolerant). Some habitats (especially low productive floodplains) may have some compatibility/tolerance for flood showing a re-establishment of valuables divers wetlands communities and those wetlands can act as sink for Carbon. However, the water quality (oligotrophic water) of flood is determinant for maintaining the low productivity and biodiversity of these habitats.

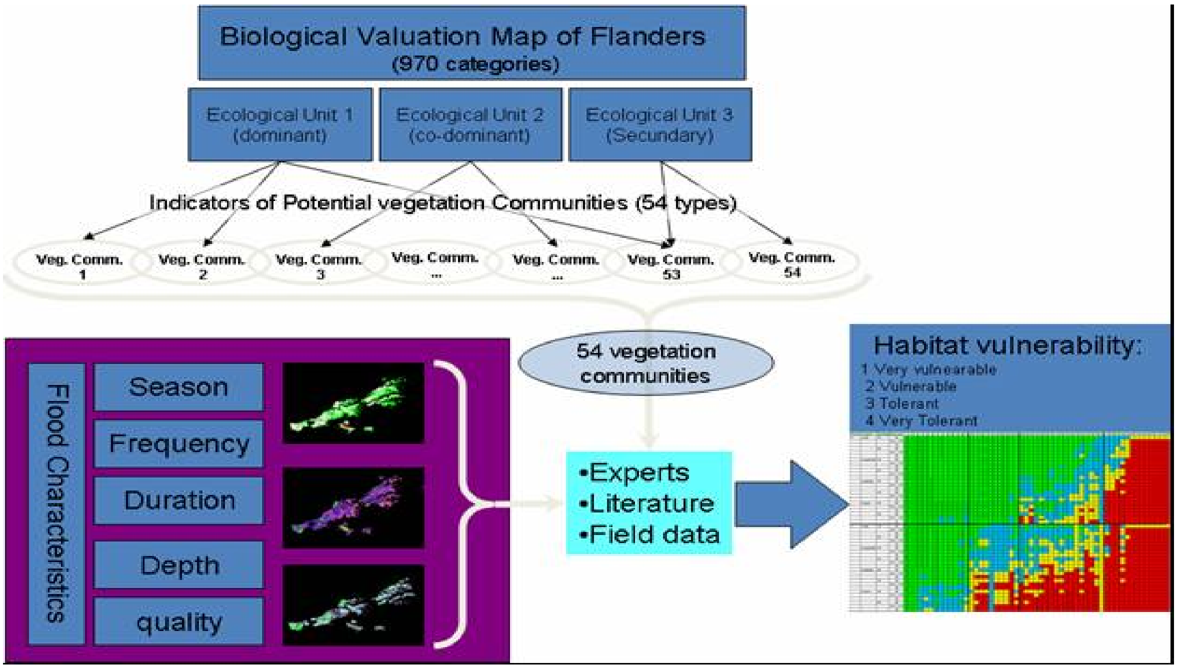

Figure 16: Conceptual model for assessing the vulnerability of habitats to flood

Therefore for our description of the functionality and biodiversity, not only floods regime (frequency, duration and period) are considered, but also water quality is taken into consideration (flood water rich in nutrients and poor in nutrients). The scoring for those habitats is also subject to a very constructive discussion between experts on the field of habitats quality and ecohydrology.

c) Assessing impact of different flood characteristics on habitat in the case studies: ecological vulnerability maps

The first step was the screening the current habitat/vegetation types that can be potentially flooded in the Dender basin. This was achieved by overlaying the potential flood areas with the BWK map of the Dender catchment (the 54 vegetations communities in the catchment). The potential flood areas were estimated by the union of the historically natural flooded areas (NOG), recently flooded areas (ROG) and modelling flood areas (MOG) generated by the CCI-HYDR team from KULeuven. The methodology was applied for all the Dender catchement, but to be in concordance with socio-economical aspects we focused more on Ninove and Geraardsbergen as showed in figure 17.

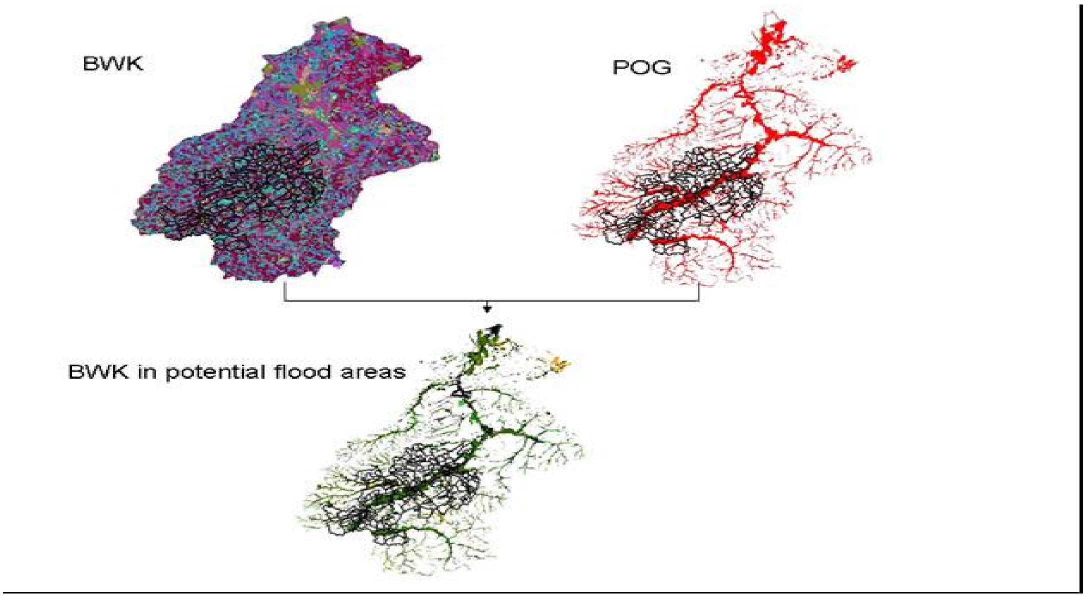

Figure 17: Schema showing the BWK map in the potential flood areas (NOG-ROG-MOG) in the Dender basin.

After characterizing the functionality and the biodiversity of actual habitats in the potentially flooded areas, the impacts of floods on each vegetation type, were assessed using information derived from the matrix tables. Each vegetation community is represented within a database that related to various parameters of flood-tolerance. As mentioned before, the flood-tolerance is substantiated by an extensive literature study on the effects of flooding on the vegetation. The critical parameters (flood characteristics) that are derived from this study will then be used to determine the compatibility/vulnerability of flood characteristics with the vegetation types. The information is aggregated in knowledge tables that indicate the critical tolerance for the different flood characteristics using the GIS tool. The results are four vulnerability maps of habitat biodiversity maintenance; nutrient retention capacity, water retention capacity, and carbon sequestration in the Ninove and Geraardbergen (Dender basin).

d) Assessment of ecosystems vulnerability to flood in climate change context using flood scenarios

In this phase, we will use the forecasting of flood occurrence in the future, which will be carried out by HACH-ULg and the CCI-HYDR team to assess the impacts of climate change induced flooding on ecological functions of the habitat types at risk. The different scenarios of flood will allow us to evaluate the changes in the biodiversity and functionality of the actual habitat types, using the results from the theoretical analysis of vulnerability previously described.

2. (Preliminary) results

From the first results, we noted that the natural habitats in our study area are very divers and their functionality is very complex. Because of this complexity of natural habitats, effects of climate change inducing flood presents a series of important and immediate challenges to nature conservation, protection, and restoration. When subject to different flood characteristics natural habitats can exhibit symptoms that indicate reductions in resilience, resistance, and regenerative capabilities. Therefore climate change inducing flood is likely to further stress sensitive ecosystems which are already adversely affected by a variety of other human impacts, such as deterioration of water quality and habitats fragmentation.

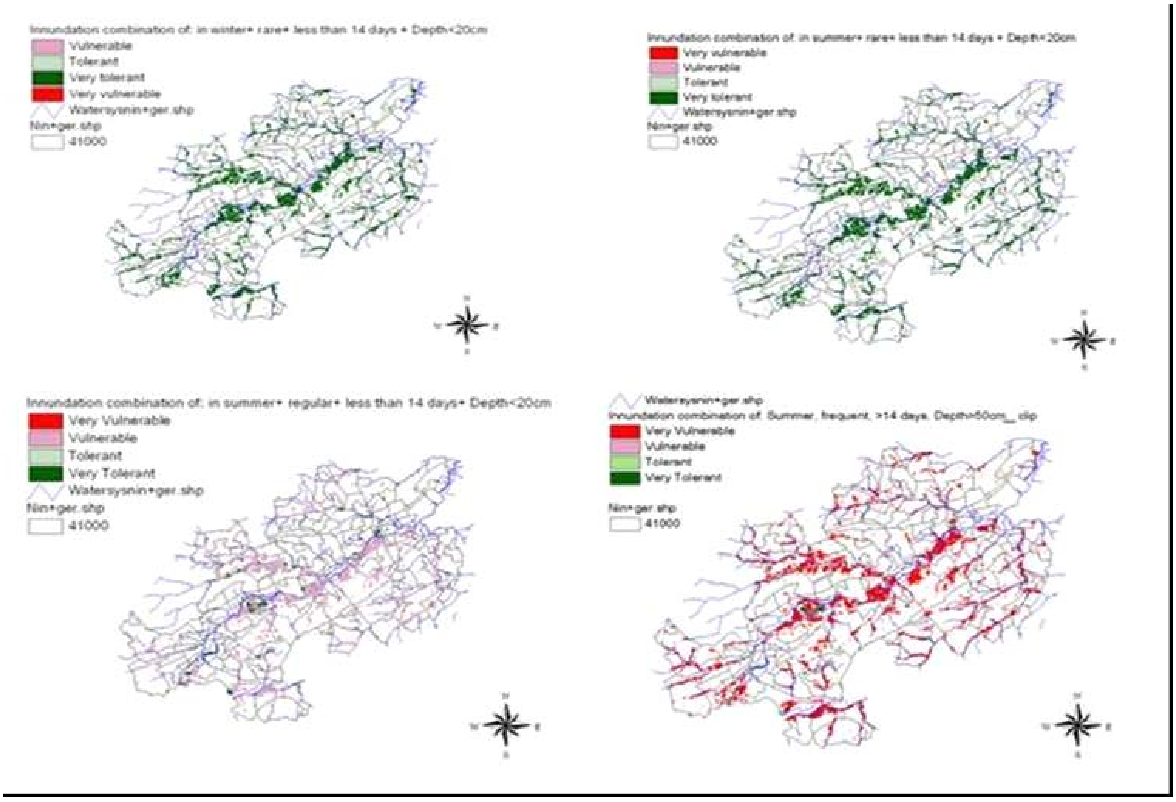

Figure 18: Impacts of flood on the biodiversity of habitat in Ninove and Geraardsbergen areas (Dender basin).

First results of the impact of flood on habitat biodiversity shows that the natural habitats in the study area are very tolerant to rare winter flood (one flood in 25years) with flood depth less than 20 cm. However when the long flood occurs in summer with more than 50cm depth, almost all the habitats shows a very vulnerable reaction (Figure 18). In between the two extreme combinations the natural habitats shows moderately vulnerability to flood. Currently we are still progressing with the theoretical impact of flood on habitats functionality. The results of those theoretical habitats vulnerabilities will be used to asses the impacts of flood in a climate change context using the flood scenario generated by HACH-Ulg and the CCI-HYDR teams.

After habitats screening and field inventory of the area of Esneux, we noted that the area contain well some habitats with high ecological values (Figure 19), however those habitats are located in areas with high topographical levels from the river and that the areas close to the river are mostly urban areas. From this we concluded that the most important habitats with high ecological values are not at risk of flood (see figure 20). The vulnerability of the natural habitats to flood in the Ourthe was less important than in the Dender case study were the most areas are lowlands.

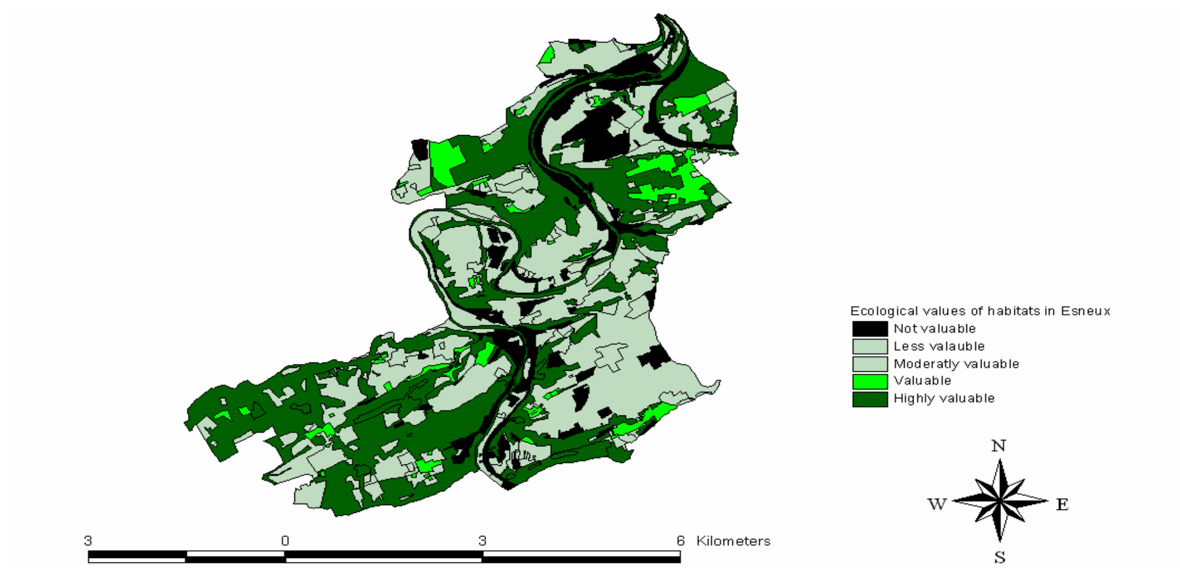

Figure 19: Ecological values of habitats in Esneux (Ourthe basin).

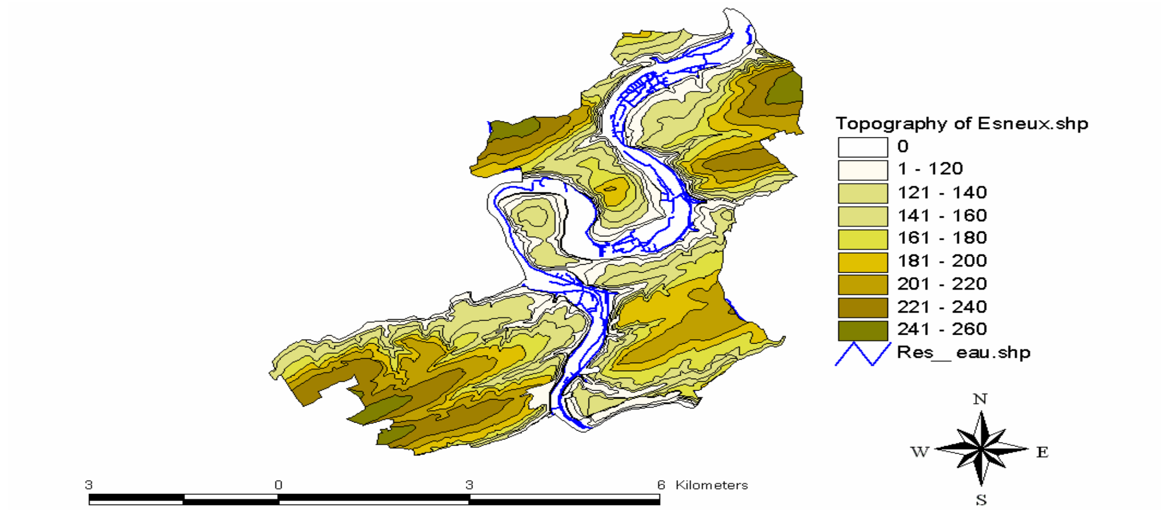

Figure 20: Topography Esneux area in the Ourthe basin.

J. Determining adaptation measures

WP 2.3, determining adaptation measures, is about the identification and development of adaptation scenarios, being one adaptation measure or the combination of two or more measures, to be evaluated in terms of their costs and benefits.

The ADAPT project focuses on the development and selection of those flood risk reduction strategies that are expected to contribute to overall welfare. This is fully in line with the paradigm 'protection against damage' that currently governs flood risk management. However the ADAPT project accounts for the possible effects of climate change it is not the objective to focus on the marginal contribution of climate change to flooding, but to treat the flood problem as a multidimensional problem. The adaptation scenarios proposed should be an integrated answer to the (future) flood problem in a given area.

This section on adaptation measures covers the categorisation, identification and characterisation of measures. In a second time reference is made of the adaptation scenarios that have already been identified and are being studied by hydraulic modelling for river Ourthe.

1. Categorisation of measures

Adaptation measures to (climate change induced) river flooding are designed to arm socio-economic and ecological systems against the effects of flooding. The way different adaptation measures act upon flood risk is very diverse and needs to be studied first as to facilitate the development of cost-effective adaptation scenarios. Therefore a threefold division of adaptation measures has been developed. Each division approaches the flood problem in a different way and thus offers different insights:

- according to what components of the general flood risk assessment framework (equation) are influenced;
- according to the intervention of measures in the DPSI-chain;
- according to the means – technical and non-technical – used.

a) Categorisation of measures according to the components of the flood risk assessment framework used influenced

Flood risk – in its most aggregate form – is made up of the **probability** and **consequence of flooding**, see Figure 4**Error! Reference source not found.**.

The **probability** that a flood with certain characteristics occurs is dependent on the **physical characteristics of the drainage basin** of the river and the **weather** to which it is exposed. Both factors are to an increasing extent influenced by human activities.

The physical characteristics in a drainage basin are influenced by activities impacting on the permeability of the surface (i.e. construction works and land use practises in agriculture), actions influencing the space for water, technical measures impacting on the flow of rivers (i.e. straightening the natural flow of water ways for navigation and/or the faster transport of water), flood protection measures (i.e. heightening of dikes, creation of flood control engines, etc.). The likeliness of extreme weather events, to the contrary, is influenced by human interference in the climate system.

The **consequence** of flooding depends on the **exposure** of the elements-at-risk to certain characteristics of a flood, but also on the **value** and **vulnerability of the elements-at-risk**. If the value of the elements-at-risk is zero i.e. when no values are located in the potential inundation area there is no risk. The same holds for the vulnerability of the elements-at-risk. When the elements-at-risk are simply not vulnerable to flooding there is no damage and thus no risk. The reduction of the value as well as the vulnerability of the elements-at-risk is thus a complementary strategy to measures influencing the occurrence and/or characteristics of floods.

b) Categorisation of measures according to the intervention of measures in the DPSI-chain

Internationally, the DPSI-chain is a commonly used analysis framework in the study of environmental impacts. The DPSI-model is an ideal framework for the systematic analysis of the genesis of environmental problems in terms of their driving forces, pressures, state and impacts. Measures (responses) can be differentiated on the basis of their intervention in the DPSI-chain or the flood problem. The closer measures intervene to the origin (driving forces) of the effect, the more effective measures are to prevent flooding. Doing this exercise has led us to draw up a four-level hierarchy differentiating between preventive, source oriented, effect oriented and curative measures in which every adaptation measures fits, see Figure 21. Despite the fact that there is a solid basis for this hierarchy, welfare maximising decision making is about choosing the most cost-effective measures and not simply the most effective ones. Nevertheless, guiding decisions about adaptation measures on the basis of their intervention in the DPSI-chain is a valuable heuristic rule.

Preventive measures act on the driving forces of the flood problem and tackle the root of the problem. These kinds of measures aim to limit the damage potential of floods (i.e. spatial planning on the basis of flood mapping) and try to limit the peak discharge by enhancing the natural water retention capacity of soils and flood plains and thus limiting the run-off (i.e. the renaturalisation of water bodies and limiting the (intensive) use of flood plains as to promote local infiltration of water).

Source oriented measures try to buffer peak flows and to reduce the stress on the river by evacuating water from the river (i.e. by the construction of areas for controlled flooding).

Effect oriented measures are primarily developed to ensure human safety and to protect property locally. The stress on the river and flood defence systems is not reduced. (i.e. construction of dikes, walls, …)

Curative measures aim to limit the impacts of flooding. Unless the installation of preventive, source oriented and effect oriented measures there always remains a residual risk of flooding. Curative measures enhance the capacity of society to cope with the effects (i.e. by early warning systems, setting up of flood management plans, training of rescue workers, relief aid, insurances,…)

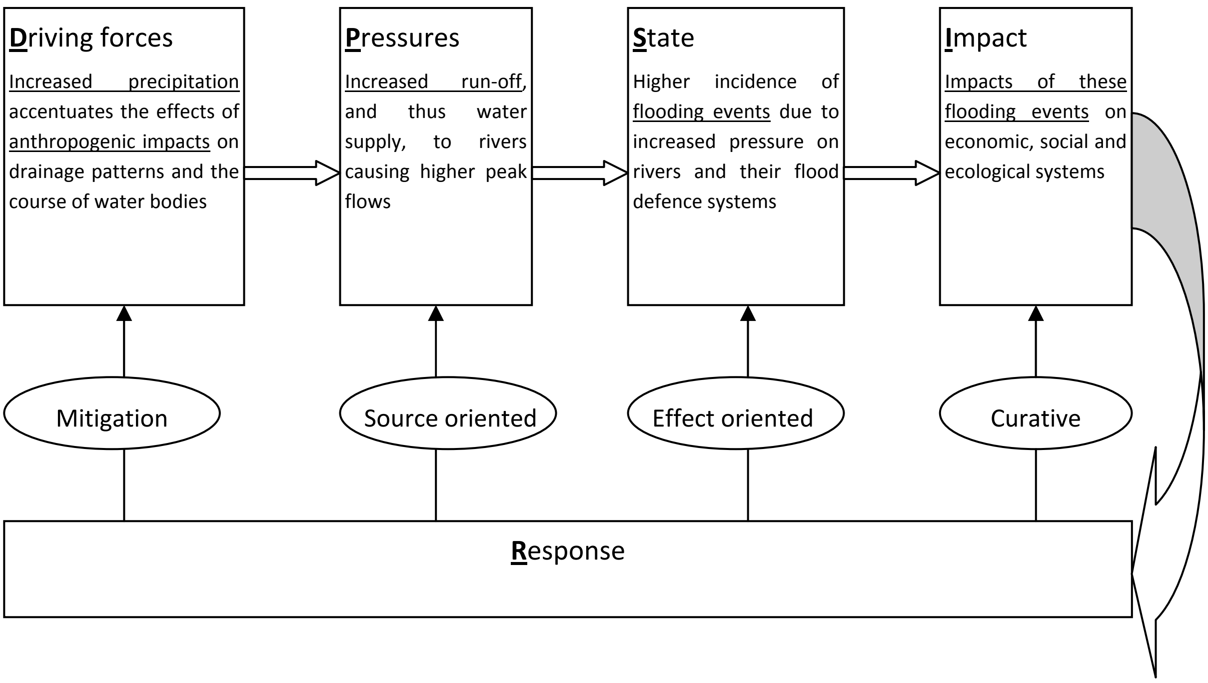

Figure 21: Schematic representation of the intervention of adaptation measures (Responses) in the DPSI-chain

c) Technical and non-technical measures

A third way for categorising adaptation measures is according to the means – technical and or non-technical – used.

Technical measures act upon hydrological and hydraulic parameters and may as well impact on the vulnerability of certain systems (i.e. the reinforcement of buildings). The main feature of technical measures is that they involve physical engineering works impacting on the river system and/or its drainage basin as well as a systems' vulnerability.

Non-technical measures impact on the vulnerability of economic, social and ecological systems as well as on the values-at-risk. Besides, non-technical measures may also impact on hydrological parameters. The main feature of non-technical measures is that they make use of legislation, economic incentives, information, sensitization, aid, rescue operations, insurance, etc. in order to:

- balance human activities with flood risk;
- strengthen systems' resilience and adaptive capacity;
- limit systems' susceptibility.

d) Listing of measures

The combination of two or more classifications of adaptation measures allows for a better qualified and thus informative designation of measures. In Annex the most important adaptation measures identified are listed and categorised according to the policy instruments used as well as their intervention into the flood risk assessment framework and the DPSI-framework.

It has been argued by the EEA that only the integrated application of a package of measures can be fully effective in combating flood risk (EEA, 2001). An adaptation measures like i.e. the heightening of a dike should be accompanied with an awareness raising campaign and possibly also with legislative actions like construction prohibitions and financial incentives.

Traditional flood control measures generally implied engineering works aimed at controlling floods such as i.e. the heightening of dikes. Current efforts, however, are directed towards comprehensive flood risk mitigation planning, integrating multiple views and a variety of complementary strategies.

2. Identification and development of measures

a) Analyse flood risks

The output of flood risk modelling is the critical input for the identification of potential 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. For this the DPSI-framework will be applied case by case.

The involvement of the public will be facilitated by the organisation of focus groups with citizens who have been confronted with floods or who live in risk areas. The goal of this is to gain more information on the impacts of past flood events.

b) Identify potential measures and develop adaptation scenarios

Local water managers have been contacted for reviewing local flood risk reduction practises and policies. As part of the discussions water managers indicated a series of problem areas, critical bottlenecks and possible future measures. This information has been collected to make sure any adaptation scenario put forward would complement well overall policy. The possible future measures, put forward by the water managers, will be studied as part of a first adaptation scenario.

During the identification and development phase of adaptation scenarios attention should be paid to limit negative side effects as far as possible and to take full advantage of potential positive side effects. This will partly be achieved by studying how the integrated application of a package of complementary measures can be fully effective in combating flood risk. To this end the focus groups will be used to discuss the support for a number of possible adaptation measures/scenarios and to focus on the conditions guaranteeing a public support base.

c) Optimisation of adaptation scenarios

After one or more adaptation scenarios have been evaluated in terms of their costs and benefits further fine-tuning of these scenarios may be required. The development and determination of a truly cost-effective adaptation scenario typically is an iterative process. A careful preliminary qualitative assessment of adaptation measures guarantees to reach an acceptable adaptation scenario with the least iterative steps possible, but it is definitely not a panacea.

3. Characterisation of measures

The main adaptation measures identified will be critically discussed. For the technical adaptation measures the discussion will cover functionality, reliability, operation and maintenance. A list of key references will be drawn up for each individual measure.

Adaptation scenarios do not only influence society by tackling flood risk, as they often have wider effects, both positive and negative, on society. These effects ideally need to be accounted for when evaluating adaptation scenarios in terms of their costs and benefits. During the identification and development phase of adaptation scenarios attention should be paid to limit negative side effects as far as possible and to take full advantage of potential positive side effects. To this end the most important potential effects will be identified for every measure. The identification of the relevant effects will be based on literature review, expert knowledge as well as on stakeholder consultation. For each relevant effect an indicator will be developed for quantifying and communicating the impact adaptation scenarios may have. These indicators will than serve as a basis, either with our without using monetary factors, for integrating the likely effects on socio-economic and ecological systems into the CBA based decision framework.

The construction of a controlled flood area requires lots of space. Land, but possibly also houses or other buildings, may need to be expropriated. Cities cannot grow unrestrained. The revenue potential of the land is decreased as extensive grazing is sometimes the only revenue generating land use left. Besides, the construction of extra dikes may hamper the view of the houses located close by. Houses may also be confronted to a rise in the water table. A controlled flood area, however, also offers opportunities for creating/restoring ecological values, at least if water quality is fine. Tourism and recreation may benefit as well. The concept of 'multi-functional land use' has been introduced to characterize the challenge of transforming designated areas into more sustainable, multi-functional retention basins. A vital question is how to communicate with the stakeholders in the different stages of the transformation process. What communication strategy applies to what situation? And equally important, if a communication strategy is developed, how should it be instrumented? What will the message be, how are the target groups identified and addressed, what mediums should be applied? And, more important, what kind of public participation is required to enable cooperation and avoid opposition to the transformation process? In general, four basic communication strategies can be identified: co-knowing, co-thinking, co-working and co-deciding. To conclude the installation of a controlled flood area may also serve as the ideal starting point for an awareness raising campaign about flood risk.

4. Adaptation scenarios simulated for the case study of river Ourthe

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 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 of 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.

The adaptation measures considered up to now involve either pumping, topography modifications for locally reducing flow resistance and the transformation of passive floodplains into active ones. As shown in Figure 22, 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 (by 50 cm in the example of Figure 22). 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.

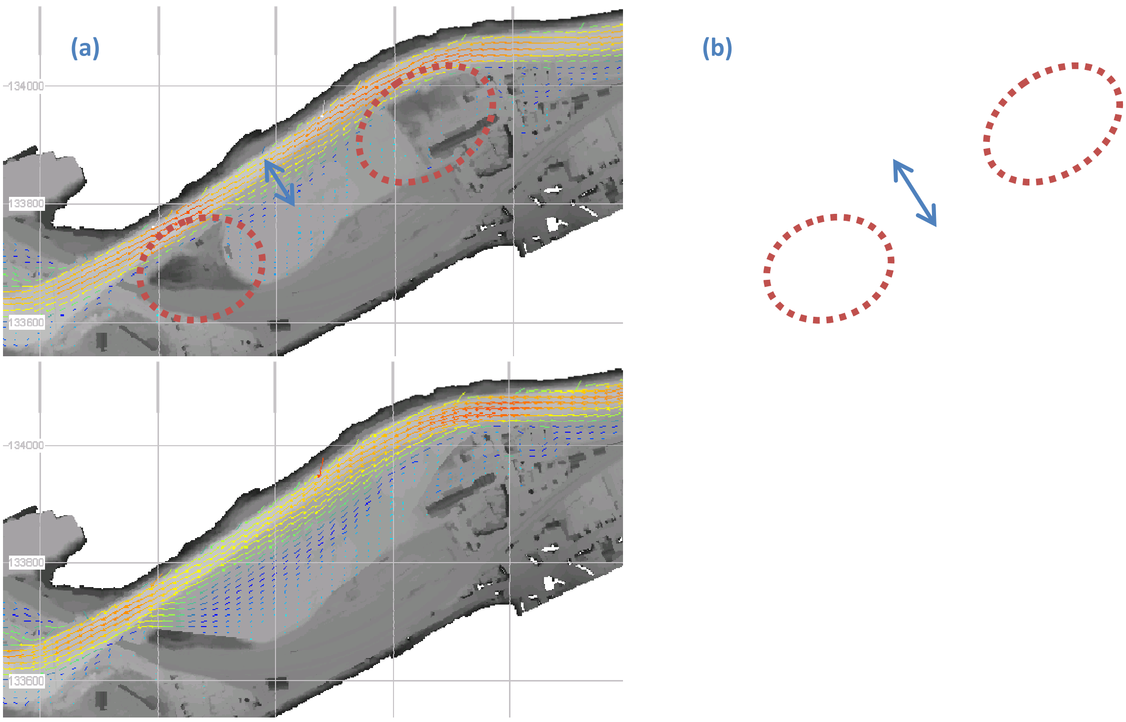

Figure 22: Velocity field (colour) and topography (grey) in Poulseur (upstream part of the case study of river Ourthe). (a) situation without floodplain activation; (b) floodplain activation. Topography changes (▪▪▪▪▪) and effective flow widths (——) are highlighted

VI. PRELIMINARY CONCLUSIONS AND RECOMMENDATIONS

A. Conclusions and recommendations on Working Package 1

In Europe, flood hazard is known to increase, especially in winter time. For the River Meuse, climate change is expected to lead to an increase in the discharges at the end of winter and at the beginning of spring, while a decrease in the discharges is expected in autumn. Those impacts are strongly catchment dependent. Catchments characterized by a dominance of fast runoff components, are more vulnerable. Impacts of climate change on floods in European rivers have been studied during several European research projects. For instance, increases in flood peaks of up to 10% were predicted for a basin in Italy, while changes of up to 20% are expected for basins in Great Britain. In Belgium, the frequency of recorded floods has already increased during the last decades but long-term trends remain hard to quantify.

Some trends could, however, be identified in Belgium:

- Climate change will affect the whole of Belgian society
- Changes in mean river discharges are found to be less pronounced than those in the rainfall regime.
- Climate change effects on river discharges have to be studied for each catchment individually, because the response depends very much on the catchment properties.
- There exist multiple interactions between the impacts (impacts in cascade). Climate change is expected to increase conflicts of interest between various socio-economic and ecologic interests.
- Social impacts of climate change and floods are rarely given extensive consideration, probably due to the problems of accounting for intangible effects. Social impacts of climate change are in particular related to the increasing inequity between social groups and its impact on well-being.
- Aquatic ecosystems are the most vulnerable to climate change. However ecological impacts of climate change are very divers and complex. Impacts are very difficult to predicts, because the vulnerability of habitat is directly related to increasing land use changes and its impact on ecosystems.
- We recommend promoting research aimed at reducing uncertainties about climate change and its impacts on natural and human systems.

Therefore, orders of magnitude of peak discharge changes found by previous studies and consistent with expectations for Belgium will be exploited as an input for hydraulic modelling during WP 2.

B. Conclusions and recommendations on Working Package 2

1. Task 2.1 Evaluation of the impacts on river basins - primary impacts

- Because of the complexity of topography in floodplains, a two-dimensional flow model is considered as the most credible approach to reliably represent the dynamics of inundation flows. It also leads to a better understanding of the flow paths, which will influence the optimal design of adaptation measures.

- Most uncertainties in the results of the present flow simulations arise from input data such as the assumption on the perturbation factor affecting the discharge. Therefore, to make progress on climate change adaptation, there is a need to improve climate models and scenarios at a detailed regional level, especially for extreme weather events.
- The validity of the steady-state assumption has been demonstrated for flow computation of inundation events on River Ourthe.
- The fastest and most reliable flow computation procedure for repeated runs has been identified and exploited. It relies on an Automatic Mesh Refinement.
- For the case study Ourthe, the sensitivity of water depth, velocity field and flood extent with respect to changes in discharge has been evaluated for two return periods and for four different perturbation factors on the discharge (representing four climate change scenarios).
- The whole set of results of hydraulic simulations available to all partners (for economic, social and ecological evaluation of secondary impacts). Those results will include, in a proper format (high resolution maps with georeferencing), the following information for each return period (25 and 100 years) and each climate change scenario:
  - flood extent and difference compared to flood extent in the base scenario,
  - water depth and difference compared to water depth in the base scenario,
  - velocity field and difference compared to the in velocity field in the base scenario.

2. Task 2.2 Evaluation of the impact on river basins – secondary impacts

a) Conclusions

- Secondary impacts, and thus flood risk, are evaluated by using an integrative framework linking the probability of flooding, the exposure of the elements-at-risk to flooding and the value and vulnerability of the elements-at-risk exposed. The probability and exposure are provided by hydraulic engineers, while the value and the vulnerability of the elements-at-risk are defined by sociologists, economists and ecologists. For the impact assessment, all researchers rely on results from the other partners.
- Methodologies are being developed to assess the vulnerability to flooding of the many different elements-at-risk as to enable flood risk assessment. The joint use of GIS software to produce vulnerability maps promotes a thorough integration of the different assessment approaches.
- In current practice with CBA, where deliberate social considerations are left out of the flood risk assessment, there is a systematic bias towards the overprotection of richer districts to the detriment of poorer quarters. This is exacerbating the fact that poor people and groups are generally also more vulnerable to flooding.
- Direct tangible damage triggers social (intangible) impacts.
- The stakeholder analysis reveals that there are disparities in terms of interest and power.
- Ecosystems alteration resulting from climate change is difficult to ascertain because of human interference.

- The flood risk assessment methodology will be built on the frequency, duration, period and/or depth of flooding. However, other flood characteristics may be also of importance.

b) Recommendations

- From an economic as well as a social perspective, good quality data was often lacking. We are in contact to obtain cadastral data and damages (per house) data with the necessary authorities to have more precision.
- The first results of the impact analysis by means of the market price method show that great attention must be paid to data gathering. It would therefore be interesting to have flood damage recorded after a flood event in a way that directly meets research needs. Besides, it is advisable to make data of private as well as public institutions more accessible to researchers studying flooding.
- We recommend that more in-depth research is needed to understand the relations between social impacts, social vulnerability characteristics and flood characteristics.
- The assessment of socio-economic as well as ecological impacts requires both general scientific and local knowledge (top-down and bottom-up approach)
- Impacts of flooding are not always negative. Flooding may stimulate social bonds, make people more responsible, induce policy change, etc. Besides, the increase of flooding can potentially restore or re-establish some valuable floodplains with high biodiversity, if water quality is not eutrophied. From an ecological point of view restoring floodplains to act as a controlled flood area during high peaks is therefore an important adaptation measure.

3. Task 2.3. Determination of adaptation measures

A hierarchy of adaptation measures, based on the place where they intervene in the DPSI-chain, is a good starting point for identifying effective measures. This hierarchy, however, does not tell anything on the cost-effectiveness of measures.

The evaluation of current flood risk management practices reveals quantitative cost benefit evaluations are rarely made. During our discussions with water managers we understood they recognise the added value of risk based and ideally full CBA based approaches for the development and evaluation of adaptation measures.

Preliminary examples of local technical adaptation measures suitable for the case study Ourthe have already been identified and their effects on inundation characteristics have been successfully tested by hydraulic modelling.

VII. FUTURE PROSPECTS AND PLANNING

A. Continuation of "Evaluating the primary impact of global change induced flooding on river basins"

1. River Ourthe

For the case study of River Ourthe, 2D detailed flood maps have been provided by the team HACH-ULg for the base scenarios as well as for four climate change scenarios. With a resolution as fine as 2m by 2m, the maps detailing the distributions of water depth, increase in water depth and flow velocity are fully available for the partners. Apart from refining the interpretation of the climate change scenarios as soon as the corresponding results of the project CCI-HYD will be available, the hydrodynamic modelling tasks dedicated to the prediction of the impact of climate change on the case study of river Ourthe are thus completed.

The HACH-ULg team also contributes to the development of geomatic numerical procedures for facilitating and optimizing the inclusion of the highly detailed hydrodynamic results available with the subsequent damage evaluation. For this purpose, the quality land use information plays a major part. For the case study of river Ourthe, two types of detailed geographic database are available: *Top10vGIS* and *PICC*. They are issued respectively by the National Geographic Institute (IGN) and the Walloon Ministry of Facilities and Transport (MET). The IGN database includes 18 layers of information, among which following data layers will be exploited: residence, industry, road network, agriculture (crops, fields) and forestry. Among other sets of very useful information, the PICC database contains the cornice height of the buildings, which enables the identification of individual dwellings within a group of adjacent houses. By combining these two complementary datasets with the output of the 2D hydrodynamic simulations, damage evaluation will be made possible at a house scale without requiring extensive field surveys.

2. River Dender

Water managers have been contacted for reviewing local flood risk reduction practises and policies. As part of the discussions water managers indicated a series of problem areas and possible future measures. These measures, mostly retention basins, will be the first candidates for one or more adaptation scenario(s). The hydraulic model will be adapted for the different adaptation scenarios developed and flood maps will be drawn up.

B. Continuation of "Evaluating the secondary impact of global change induced flooding on river basins"

1. Integration

In order to facilitate welfare maximising decision making a CBA based decision framework is necessary. Effects should be monetised when this would not add to overall uncertainty. Effects that not monetised should be quantified and presented in a meaningful way to the project assessor. To this end the ADAPT team will continue to identify chances and bottlenecks for integrating effects in the best possible way in an extended CBA. The information requirements of an extended CBA framework are taken as a starting point when developing new effect assessment methodologies. Key actions related to the search for appropriate monetary factors and the development of comprehensive quantitative assessment methods and scales of scoring the effects. Besides, the presentation of the various components of flood risk in a GIS system is a constant preoccupation as an insight in the spatial distribution of effects is a key factor to make the development of adaptation scenarios more efficient.

2. Economic risk assessment methodology

The first step will be to finalise damage functions, in order to assess damages as a function of the water depth recorded during the flood event and which use the available data or information. Then the hydrodynamic modeling can simulate these water depths and to forecast potential damages. These forecasts mean we can determine consequent adaptation measures, which in turn will be analysed in determining their costs and elaborating a precise CBA.

The Hedonic price method attempts to identify what price differential can be attributed to a particular environmental difference between properties (inside/outside of the flood area and property with/without an adaptation measure). This technique which will be studied could permit to confirm (with the help of the CBA) whether an adaptation measure will be economically attractive or not in each case.

The economic risk assessment methodology will continue to focus mainly on the development and the analysis of adaptation measures.

3. Social risk assessment methodology

The social risk assessment methodology will be finalised by the development of a framework for adaptive capacity analysis. In the next step, we will use the findings on flood events, as provided by HACH - ULg and CCI-HYDR to estimate the social impacts. As a consequence, estimations can be made on the most appropriate adaptation measures.

4. Ecological risk assessment methodology

As mentioned in the previous ecological analysis, the last step in evaluating the secondary impacts is the risk assessment of ecosystems to flood in climate change context using flood scenarios. We will use the forecasting of flood occurrence in the future, that will be carried out by HACH-ULg and the CCI-HYDR team to assess the impacts of climate change induced flooding on ecological functions of the habitat types at risk. The different scenarios of flood will allow us to evaluate the changes in the biodiversity and functionality of the actual habitat types, using the results from the theoretical analysis of vulnerability previously described. The changes or impacts on biodiversity status and functionality of each habitat will be translated in maps using the same methodology as previously explained. This results will allows us to have an idea on the adequate adaptations measures to avoid the negative impacts and give us an idea on the cost for the restoration of the damaged habitats.

C. Continuation of “Determining adaptation measures”

- Linkage and synthesis of the conclusions of the different partners on adaptation measures;

- For the case study of River Ourthe, the hydraulic numerical model WOLF 2D will be extensively exploited by the HACH-ULg team to continue simulating technical adaptation measures in order to evaluate their hydraulic effects. Several significant technical flood defence measures are being defined and simulated, including additional activations of passive floodplains and the rehabilitation of reaches of the ancient Canal parallel to river Ourthe.
- In combination with the subsequent damage analysis, performed partly within WOLF, the sets of hydrodynamic modelling results, obtained for each technical flood protection measure along river Ourthe, will directly contribute to the overall assessment of the cost-efficiency of the considered adaption measures. Therefore, this stage will also confirm both the applicability and the efficiency of the hydrodynamic modelling system WOLF for quantifying the benefits of technical flood protection measures in terms of reductions in inundation extent, water depth and flow velocity.
- In both study areas, focus groups will be organized with citizens who have been confronted with floods or who live in risk areas. The goal of this is (1) to gain more information on the (past) social impacts of the floods and (2) to measure the support for a number of (future) adaptation measures. We will also focus on potential conditions for having public support, and on possible compensation measures increasing support.
- Analysis of the gathered data (both quantitative and qualitative), formulation of conclusions and policy recommendations on the conditions on how to maximize public support for adaptation measures.

D. Evaluating costs of adaptation measures

Information on the costs of adaptation measures in Belgium still remains somewhat patchy and has to be analysed in accordance with the different categories of measures to be considered. As a result, certain measures require investments which are initially costly (structural measures) but need little maintenance, whereas other measures require more regular maintenance but less initial investment (e.g. dredging operations to reduce the impact of flooding in retention traps). In addition, there are also possible measures based on warning and precaution in situ, insurance cover, and accepted risks. Choices (trade-offs) arise, therefore, notably in terms of allocating resources to the different (current and future) options described above.

Within the context of integrated management, this part of the project proposes a thorough investigation of the state of knowledge, existing practices and current initiatives, in order to contrast them against the major strategic options presented.

Methodological elements concerning the evaluation of adaptation measures in monetary terms will be developed jointly with the partners involved in the determination of adaptation measures. They will focus on existing programmes, and on measures to be planned. Concerning the latter, methods for classifying cost elements will be considered, in view of a possible integration in macro-economic aggregates. Special attention will also be paid to the harmonization of these methods with respect to those adopted by other international programmes (Bureau fédéral du Plan, 2000). Recommended methods to minimise the costs of adaptation measures will be described and analysed. CEESE-ULB has already developed and applied a cost-effectiveness methodology in the framework of the EC project STAIRRS (STAIRRS, 2002). In this study, net present value calculations had been achieved for medium and long term periods.

The evaluation of adaptation costs requires the use of cost functions. Cost functions can comprise two terms: fixed costs (investment, annual depreciation, labour resale price, taxes and insurance, etc.) and variable costs (dependent on the type of measures, use, labour, maintenance and consumption of resources). Such an evaluation relates first of all to the costs of using the various mitigation options: the costs of structural measures (such as dikes, controlled inundation areas) and of non-structural emergency response (such as increase of insurance cover). These will be studied jointly with the technical part of the project. For this task, particular attention will be paid to the flood return periods in the evaluation of the costs. Indeed, measures aimed at long-term protection may prove to be excessively expensive as to measures targeted at short flood return periods. In that context, various options exist, including non-structural measures; the increase of insurance cover is an option that ought not to be neglected. One of the objectives of this section will be to evaluate the economic implications of resorting to (new) adaptation options within the framework of selected scenarios.

The resources to be used in the implementation of the adaptation options will also be examined in the light of environmental, economic and social criteria. An important requirement for adaptation measures to be implemented successfully, is the social acceptance. Therefore, perceptions of all stakeholders on adaptation measures should and will be integrated in the evaluation. Preferences on adaptation measures shall be analysed in both study areas by means of focus groups in order to generate a better understanding on the social acceptance of the measures.

E. Cost-benefit analysis

In the context of integrated management, this part of the project proposes to answer the question of resource allocation using the decision-making tool of cost-benefit analysis, which will allow the main strategic options to be compared, and the preferred one to be identified.

This decision-making tool allows for the integration of environmental damage costs into the decision-making process, in the form of externalities that can be compared to mitigation costs. These two aspects are currently the object of investigation, and can be used for the justification of the orientations given to climate change policies (EEA, 2004; CIDD-ICDO, 2004). It is worth remembering that the decision-making principles advocated by international programmes stipulate that adaptation measures must reflect a potential to produce benefits that exceed their costs. (EEA, 2004; IPCC, 2001).

As mentioned above, also another methodology will be investigated and used in complementarities to cost-benefit analysis to overcome the typical difficulties of a CBA-approach. This complementary methodology will be based on conventional impact assessment using sustainability criteria's.

Also, in defining the costs and benefits of each scenario, particular attention will be paid to the stakeholders to whom these costs and benefits accrue. This will allow us to identify potential winners and losers, hence appreciating the acceptability of each adaptation measure to different groups of stakeholders.

The methodology of cost-benefit analysis will weight the costs of adaptation measures against the benefits of reducing the risks or impacts, and compare them since cost and benefit (avoided damage).

F. Recommendations on adaptation measures

This last task will be devoted to providing a synthesis of the overall results of the project and preparing recommendations involving all partners as well as the opinion of all the stakeholders.

VIII. USER COMMITTEE

The three first meetings with the Follow-up committee took place the 29 September 2006, the 1st June 2007 and the 10 January 2008.

Members of the Follow-up committee are following :

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A. Remarks:

The ADAPT project and the CCI-HYDR project organized the meetings with the follow-up committee, with the aim of presenting the two projects to the different members of the committee. A whole day was dedicated to these events in order to allow for discussion between the members of the projects and the members of the follow-up committee after each presentation. Another reason for meeting was to present the links and collaboration between the two projects along with their future interactions. A good exchange of information (reports) between the partners and the members of the committee was made. For the ADAPT project, relatively few comments have been made but many individual interactions with the members of this committee have taken place; so much information has been provided (economic information on the damages and the "flood insurance", works carried out by the regional authorities on the subject,…).

B. Summary of main comments made during the first Follow-up committee meeting:

- When quantifying the socio-economic impact of climate change (ADAPT project), future changes in the economy, the population growth, the land use planning, the water management trends, etc. should be taken into account. Only scenarios dealing with the increase in the greenhouse gas emissions (change in climatologic conditions) were presented by the work plan.
- The risk of dike breaching in not taken into account in the flood estimation procedures. The probability of occurrence of dike breaching is indeed an order of magnitude lower in comparison with the probability of flooding by dike overtopping, but flood damages are much higher. Methods to quantify the probability of dike failure are still very premature, but need to be considered in the later phase of the project.
Activity report intended for the intermediary evaluation - Document G 75
- Perception of the climate change impact by the public needs to be considered in the ADAPT project; as well as the issue of communication of the results for both the CCI-HYDR and ADAPT projects (e.g. identification of the best procedure for communication in view of the perception investigated).
- M. de Wit made the point that the assessment of future flood risk (and eventually the weighing of costs and benefits of adaptation measures) is coupled with various uncertainties. How will you account for the future (and thus uncertain) decisions and evolutions that may impact the results of the overall assessment (i.e. economic downturn because of other countries and regions taking over the lead, prohibition of certain activities in flood prone areas,…)
Answer: The methodology for carrying out the impact assessment, of course, only allows for an approximate assessment of the actual impact. All major changes in the relevant socio-economic variables (number of people living in flood prone areas, number of good in flood prone areas, economic situation, social composition of the population etc.) are hard to predict. Upgrading our assessment methodology will not lead to undoing the corresponding uncertainties. The ADAPT team will develop one or more scenarios of the likely change in such socio-economic variables.

However, as the actual situation is by far the most certain estimate of any future situation, the scenario(s) will only differ very little from the actual situation. The major visible socio-economic trends will be extrapolated, but no shocks will be included as these would induce more uncertainty than they would solve.

C. Summary of main comments made during the second Follow-up committee meeting:

- Next to the A2 a B2 greenhouse gas emission scenario simulations provided by the PRUDENCE project, also the A1 and B1 scenarios should be considered. RCM simulations over Europe do, however, not appear available for these scenarios. GCM simulations are available but require additional downscaling.
- Making reference the presentation of projections for precipitation changes in Belgium, presented by the CCI-HYDR project, M. Marbaix raises the question of the relevance of studying by hydraulic modelling a more extreme increase in flood peak discharge than 15%. This option will be tested in future hydraulic simulations carried out by HACH-ULg.
- Johan Bogaert (of the Flemish Ministry of environment, nature and energy) had a comment on the DPSIR approach as a tool for (1) analysing and understanding flooding and (2) prioritizing adaptation measures. He missed attention for "protecting and restoring the natural river roughness", which according to him is a key element in flood risk management. The capacity of a river and its surroundings like i.e. the Dijle upstream of Leuven to manage flooding quasi automatically is often overlooked.

Answer: The adaptation strategies that were shown, making use of the DPSIR-framework for prioritising adaptation measures, did not cover all possible measures. In our view the preservation of the natural river dynamics or the denaturalisation of the river basin is a key element and ranks among the measures intervening in the driving forces. In order to get the maximum input of the Mr. Bogaert the ADAPT team send him their poster and a working document on adaptation measures so he could comment on it. His input was considered very valuable on some points and helped to push forward our thinking about adaptation measures.
- Wouter Vanneuville (Flanders Hydraulics) wondered whether the ADAPT team will develop a special base scenario to start from for assessing the change in flood risk under the different adaptation scenarios.

Answer: It is our ain to make our project as relevant for policy makers as possible. This does not only come down to the development of the tool, but also to the exercise we will do in our two study areas. The ADAPT team develops a baseline scenario which more or less corresponds to the actual situation adapted for the adaptation measures that are very likely to be implemented in the (near) future. To this end it has close contacts with the relevant authorities and water managers. By doing so the flood risk in the various scenarios, accounting for climate change and several adaptation strategies, will be compared to a policy relevant baseline. The results will thus of the case studies will be thus of immediate relevance to policy makers and water managers. The methodology and experiences for developing such a base scenario will be clearly described in order to facilitate doing this when applying the tool to other areas.

D. Discussion with the members of the follow-up committee during the third Follow-up committee meeting

Are the parameters in the ETo calculations depending on temperature such that the impact of climate change on these parameters is taken into account? Answer: we have used the Bultot method for ETo calculations. Because this method is based on empirical investigations in Belgium, we have tested an alternative formulation for the infrared radiative balance which is valid for a wider range of

climate conditions and hence less sensitive to climate changes, and we have also tested the use of the downward infrared radiation simulated by the RCMs.
Can the algorithm developed by the CCI-HYDR team to perturb rainfall and ETo series be made available to the end users? Answer: Yes, the algorithm will be made available on the CCI-HYDR website one of the next weeks.
Can the algorithm perturb a 10 minutes series as well (for urban drainage applications)? Answer: Yes, it will (based on the downscaling methodology presented).
Next to the perturbation in de number of wet days, is also a change in intensities for the dry days considered? Answer: Perturbing the number of wet days automatically also adjusts correspondingly the number of dry days. Because only the wet days have significant amount of rainfall, only the rainfall intensities for the wet days are perturbed.
How are we going to include the regional differences in our climate change scenarios? Answer: this will be done by applying regional adjustment factors; more detailed approach will be discussed in the CCI-HYDR project the next weeks.
How are we going to deliver to the ADAPT project the %change in rainfall-runoff for the hydraulic modelling by ULg ? Answer: Because the ADAPT project does not incorporate the rainfall-runoff
Belgian Science Policy - ADAPT and CCI-HYDR projects 3rd follow-up committee meeting component, the impact on the rainfall-runoff will be predicted by the rainfall-runoff models used in the
CCI-HYDR project (for the Meuse basin, this will be based on the SCHEME model of KMI/IRM; based on the runs with this model and the CCI-HYDR climate change scenarios for rainfall and ETo, the % change in peak rainfall runoff conditions will be predicted and delivered to B.Dewals of ULg).

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X. LIST OF PUBLICATIONS

A. Publications of the teams

1. Peer review

HACH-ULg

Dewals B.J., Archambeau P., Erpicum S., Detrembleur S. & Pirotton M. (2007), Identification d'impacts locaux du changement climatique et évaluation de mesures d'adaptation grâce aux modèles hydrologiques et hydrodynamiques WOLF. Conference: Variations climatiques et hydrologie - Colloque de la Société Hydrotechnique de France, Lyon, 27-28 mars 2007

Dewals, B. J. *et al.* (2007). Hydraulic modelling approach in the development of a decision-support tool for integrated flood risk management considering climate change. *Workshop on Integrated Water Ressources Management*, Aachen, Germany.

Erpicum, S., B. J. Dewals, P. Archambeau, S. Detrembleur and M. Pirotton (2008). Detailed 2D numerical modeling for flood extension forecasting (accepted). *Proc. 4th Int. Conf. on Fluvial Hydraulics: River Flow 2008*.

Dewals, B. J., S. Detrembleur, P. Archambeau, S. Erpicum and M. Pirotton (2008). Detailed 2D hydrodynamic simulations as an onset for evaluating socio-economic impacts of floods considering climate change (accepted). *European Conference on Flood Risk Management - FloodRisk 2008*, Oxford, UK.

HIVA-KUL

Coninx I. and Bachus K. (2007) The integration of social vulnerability towards floods in a climate change context. Paper presented at CAIWA 2007 International Conference on Adaptive & Integrated Water Management. Coping with complexity and uncertainty. November 2007. Basel, Switzerland.

2. Others

HACH-ULg

Dewals, B. J. and K. Piroth (2008). RIMAX-Projekte MEDIS und REISE an der Universität Lüttich vorgestellt. *RIMAX Newsletter*: 5-6.

HIVA-KUL

Non-scientific journal

Bachus K. and Coninx I. (2006) *Het water staat ons tot de lippen: het klimaat anno 2006*. De Gids op Maatschappelijk Gebied. 97 (7), pp. 54-56.

Press article

Coninx I. and Bachus K., *Mediterraan klimaat of puffen onder de hitte?*, De Morgen, 10.04.2007

B. Co-Publications

1. *Peer review*

HACH-ULg and Ecolas NV

B.J. Dewals, R. De Sutter, L De Smet, M. Pirotton (2007), Synthesis of primary impacts of climate change in Belgium, as an onset to the development of an assessment tool for adaptation measures. Geophysical Research Abstracts, Vol. 9, 11217, 2007

Ecolas NV and HIVA-KUL

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. Conference Proceedings Watersysteemkennis: mensen en watersystemen. 33. pp. 30-36.

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Ernst, J., B. J. Dewals, E. Giron, W. Hecq and M. Pirotton (2008). *Integrating hydraulic and economic analysis for selecting flood protection measures in the context of climate change*. Proc. 4th Int. Symp. on Flood Defence, Toronto, Canada, Institue for Catastrophic Loss Reduction.

Dewals, B. J., E. Giron, J. Ernst, W. Hecq and M. Pirotton (2008). Integrated assessment of flood protection measures in the context of climate change: hydraulic modelling and economic approach. *Environmental Economics*. K. Aravossis, C. A. Brebbia and N. Gomez**:** 10 p.

Dewals, B. J., E. Giron, J. Ernst, W. Hecq and M. Pirotton (2008). *Integration of accurate 2D inundation modelling, vector land use database and economic damage evaluation (accepted)*. European Conference on Flood Risk Management - FloodRisk 2008, Oxford, UK.

2. *Others*

CEESE-ULB, HIVA-KUL, HACH-ULg, ECOBE-UA, Ecolas NV

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. 83p.

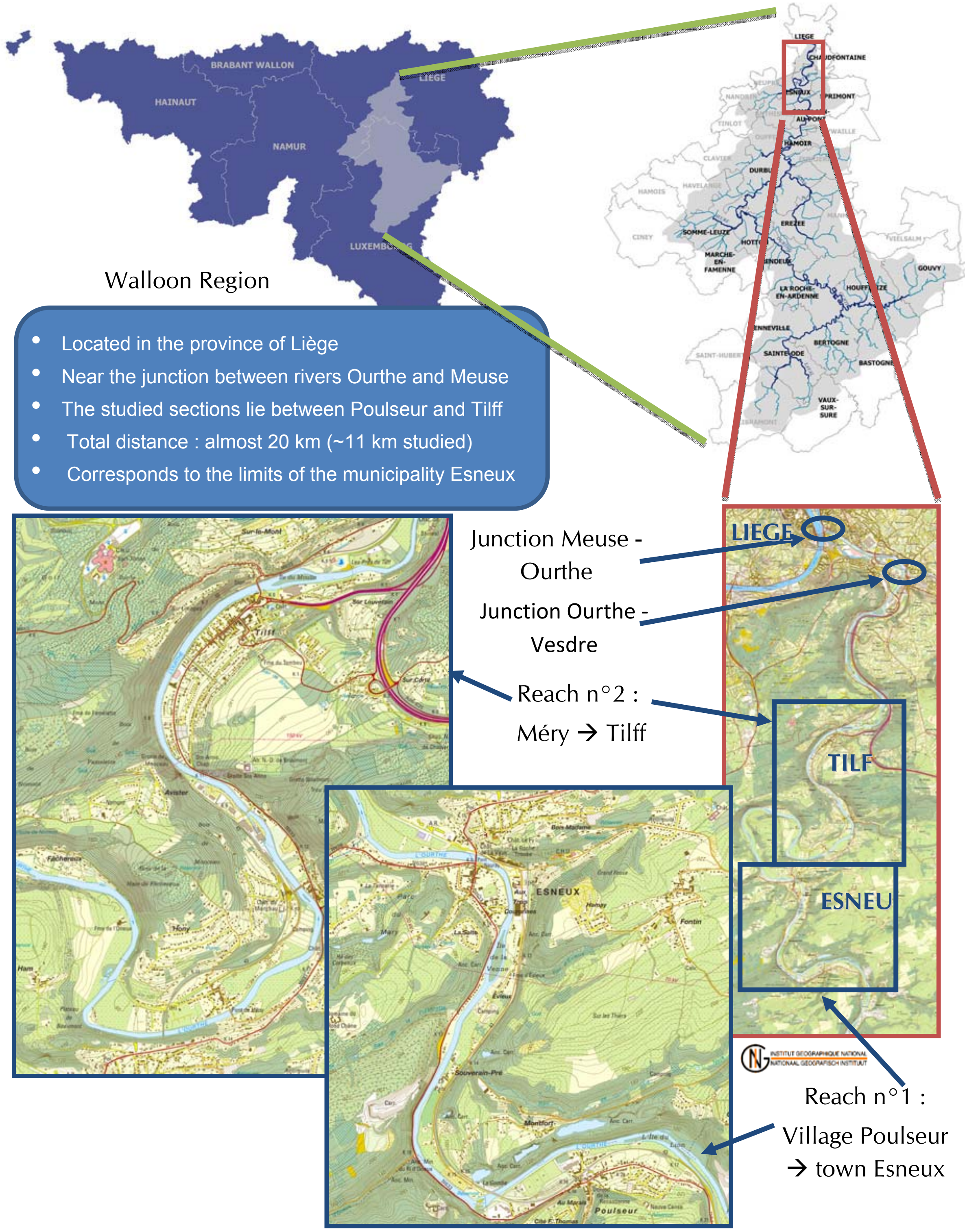
Website

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. (2007), *Flemish case study: the Dender basin near Geraardsbergen and Ninove: draft*. Belspo.

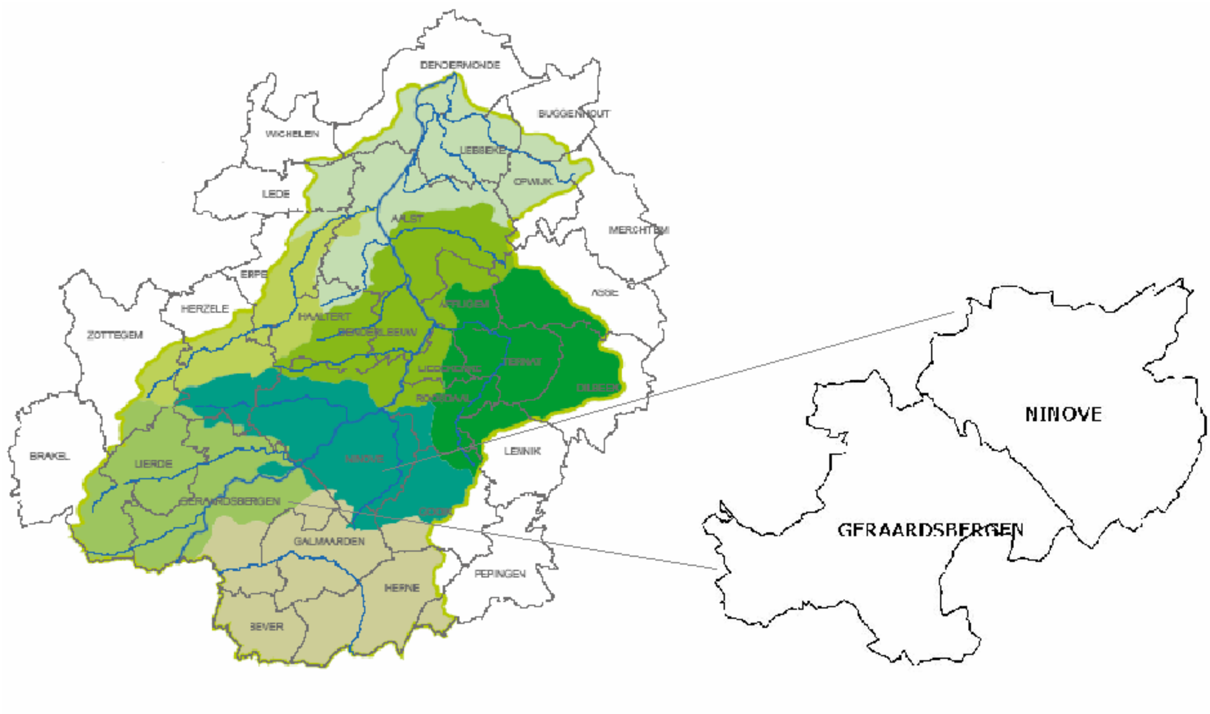
De Groof A., Hecq W., Coninx I., Bachus K., Dewals B., Pirotton M., El Kahloun M., Meire P., De Smet L., and De Sutter R. (2007), *Walloon case study: the Ourthe basin near Esneux: draft*. Belspo.

XI. ANNEXES

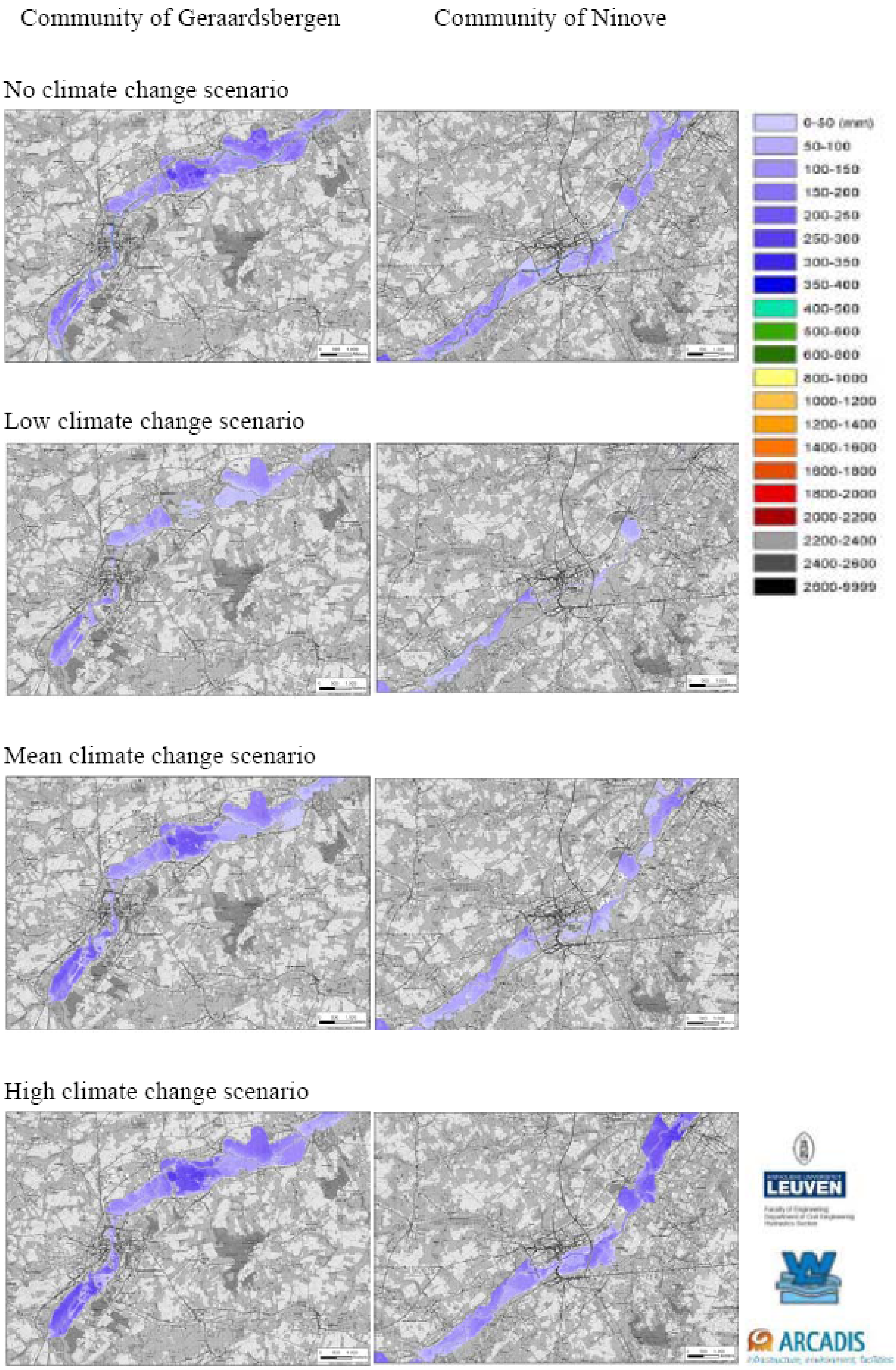
Annex 1 Location of the Ourthe case-study



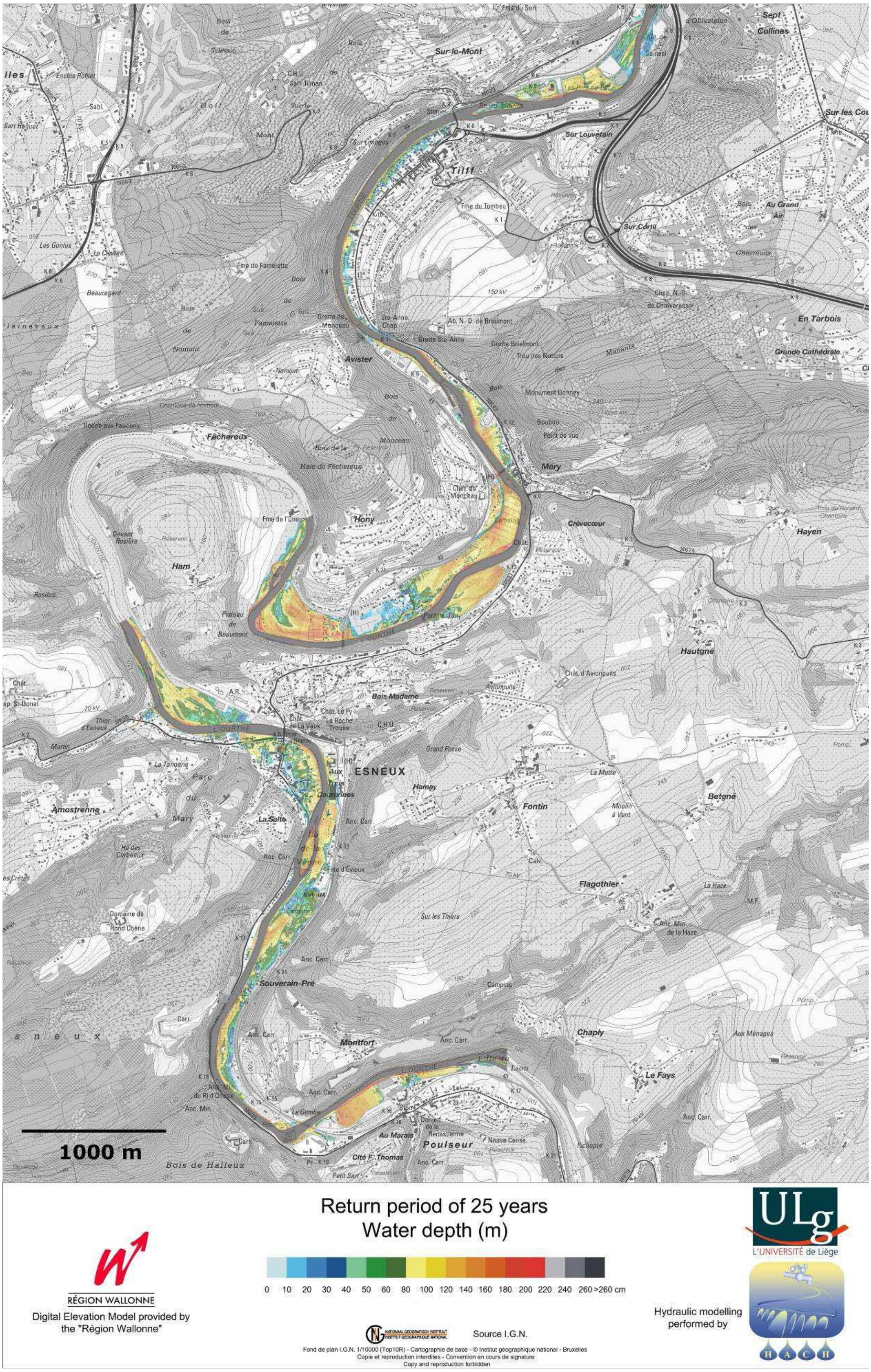
Annex 2 Location of the Dender case-study

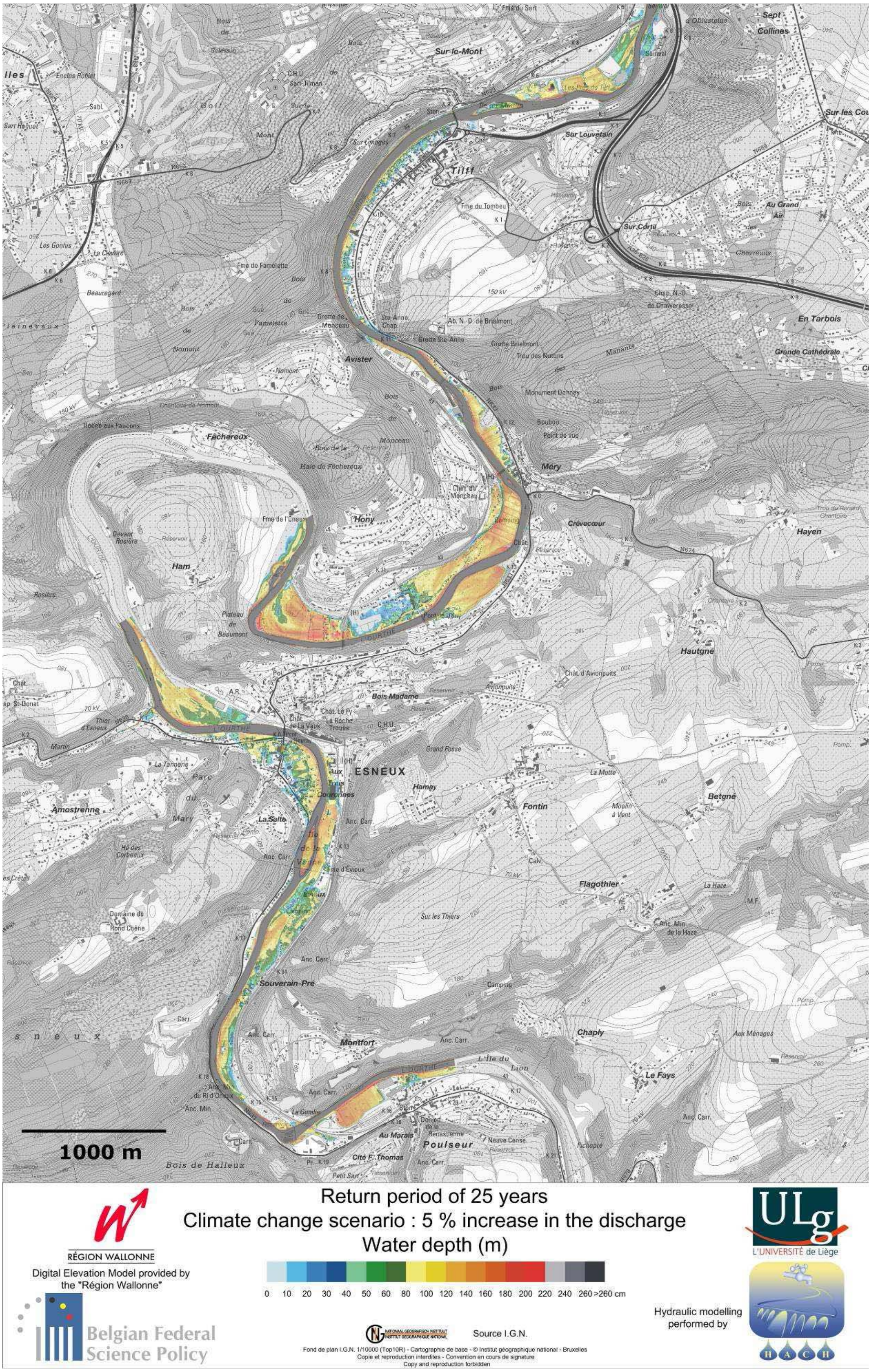


Annex 3 Inundation depth (in mm) for a return period of 100 years



Annex 4: Flood hazard maps (the Ourthe basin – commune of Esneux)




1000 m
ESNEUX
Tilff
Return period of 25 years
Climate change scenario : 5 % increase in the discharge
Water depth (m)
0 10 20 30 40 50 60 80 100 120 140 160 180 200 220 240 260 >260 cm
RÉGION WALLONNE
Digital Elevation Model provided by the "Région Wallonne"
Belgian Federal Science Policy
Source I.G.N.
Fond de plan I.G.N. 1/10000 (Top10R) - Cartographie de base - © Institut géographique national - Bruxelles
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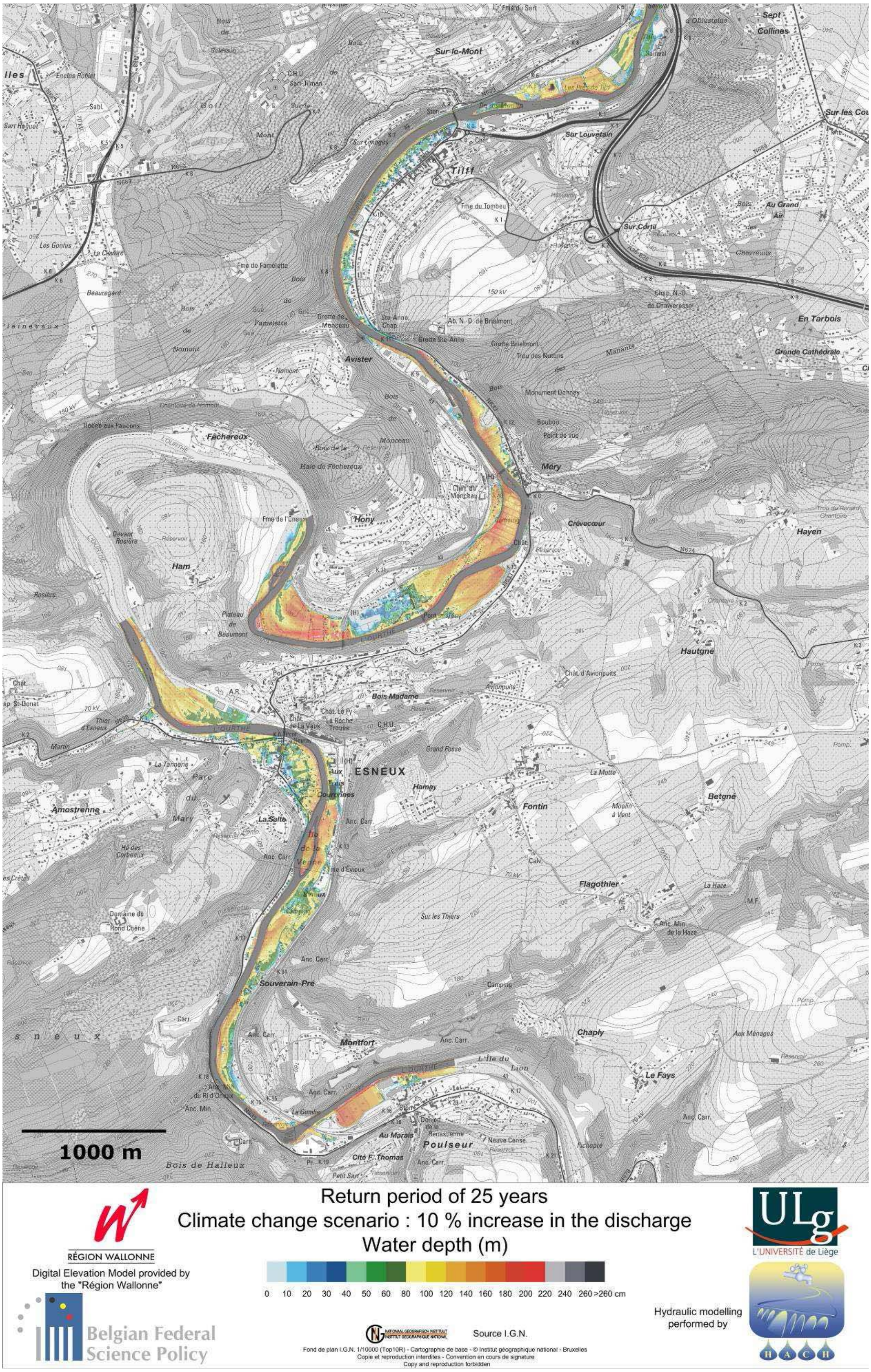
1000 m
Tilff
Sur-le-Mont
Sur Louveterie
Avister
Méry
Hony
Ham
Crèvecœur
Hayen
Hautgne
ESNEUX
Amostrenne
Fontin
Flagothier
Souverain-Pré
Montfort
Chaply
Le Fays
Poulseur
En Tarbois
Betgné
Return period of 25 years
Climate change scenario : 10 % increase in the discharge
Water depth (m)
0 10 20 30 40 50 60 80 100 120 140 160 180 200 220 240 260 >260 cm
RÉGION WALLONNE
Digital Elevation Model provided by the "Région Wallonne"
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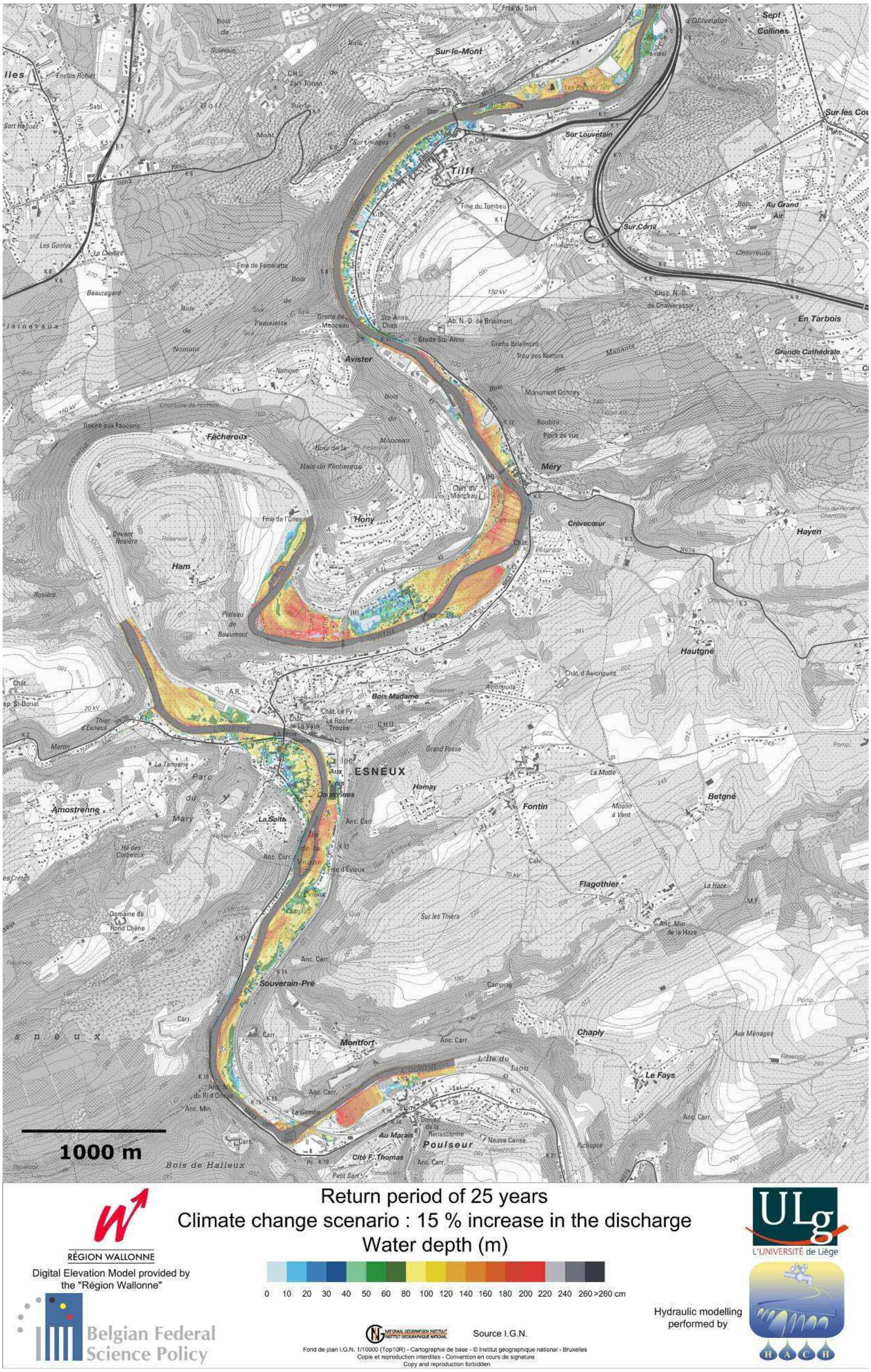
1000 m
Return period of 25 years
Climate change scenario : 15 % increase in the discharge
Water depth (m)
0 10 20 30 40 50 60 80 100 120 140 160 180 200 220 240 260 >260 cm
RÉGION WALLONNE
Digital Elevation Model provided by the "Région Wallonne"
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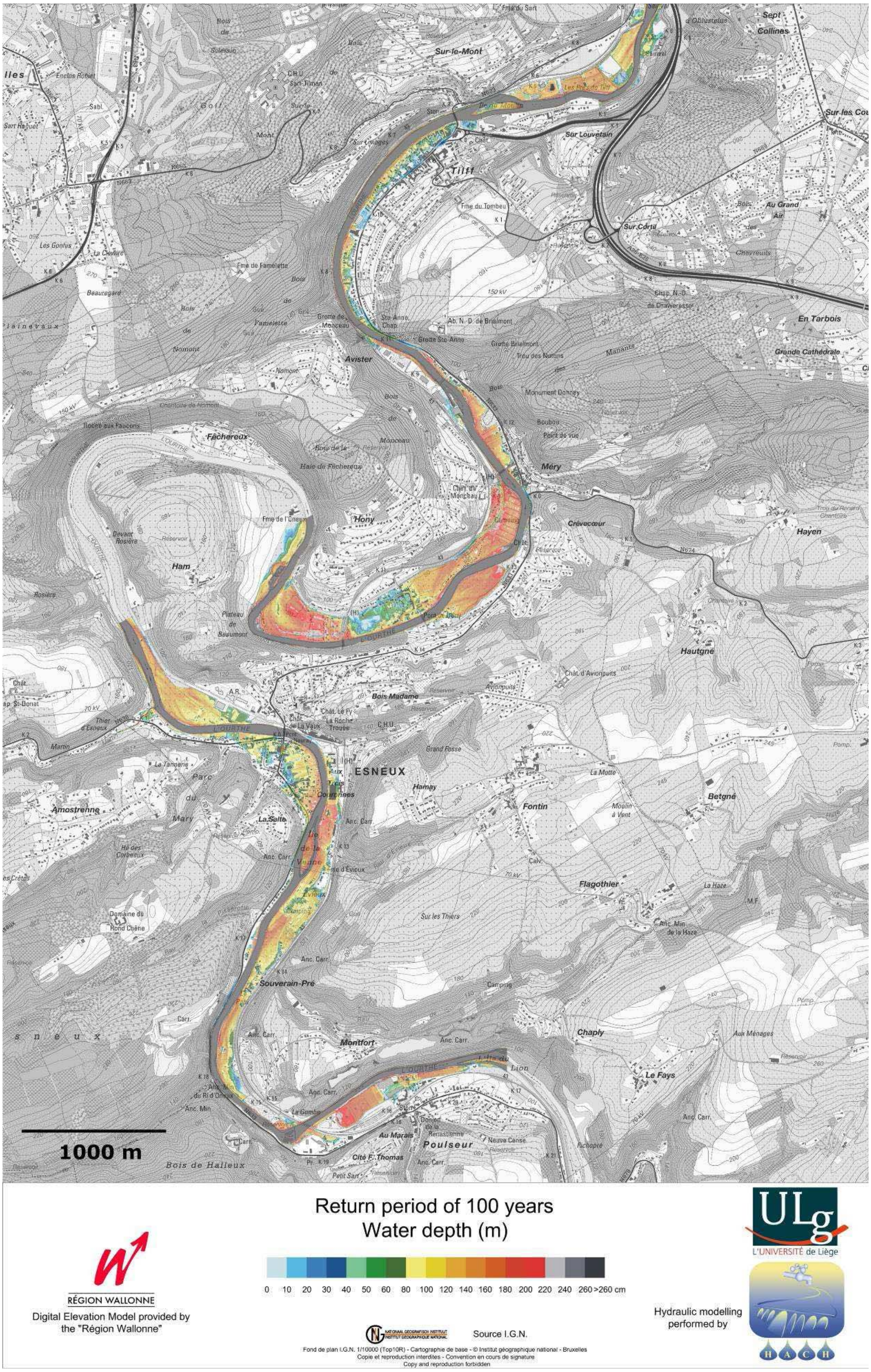
Tilff
Méry
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Poulseur
Montfort
Souverain-Pré
1000 m
Return period of 100 years
Water depth (m)
0 10 20 30 40 50 60 80 100 120 140 160 180 200 220 240 260 >260 cm
RÉGION WALLONNE
Digital Elevation Model provided by the "Région Wallonne"
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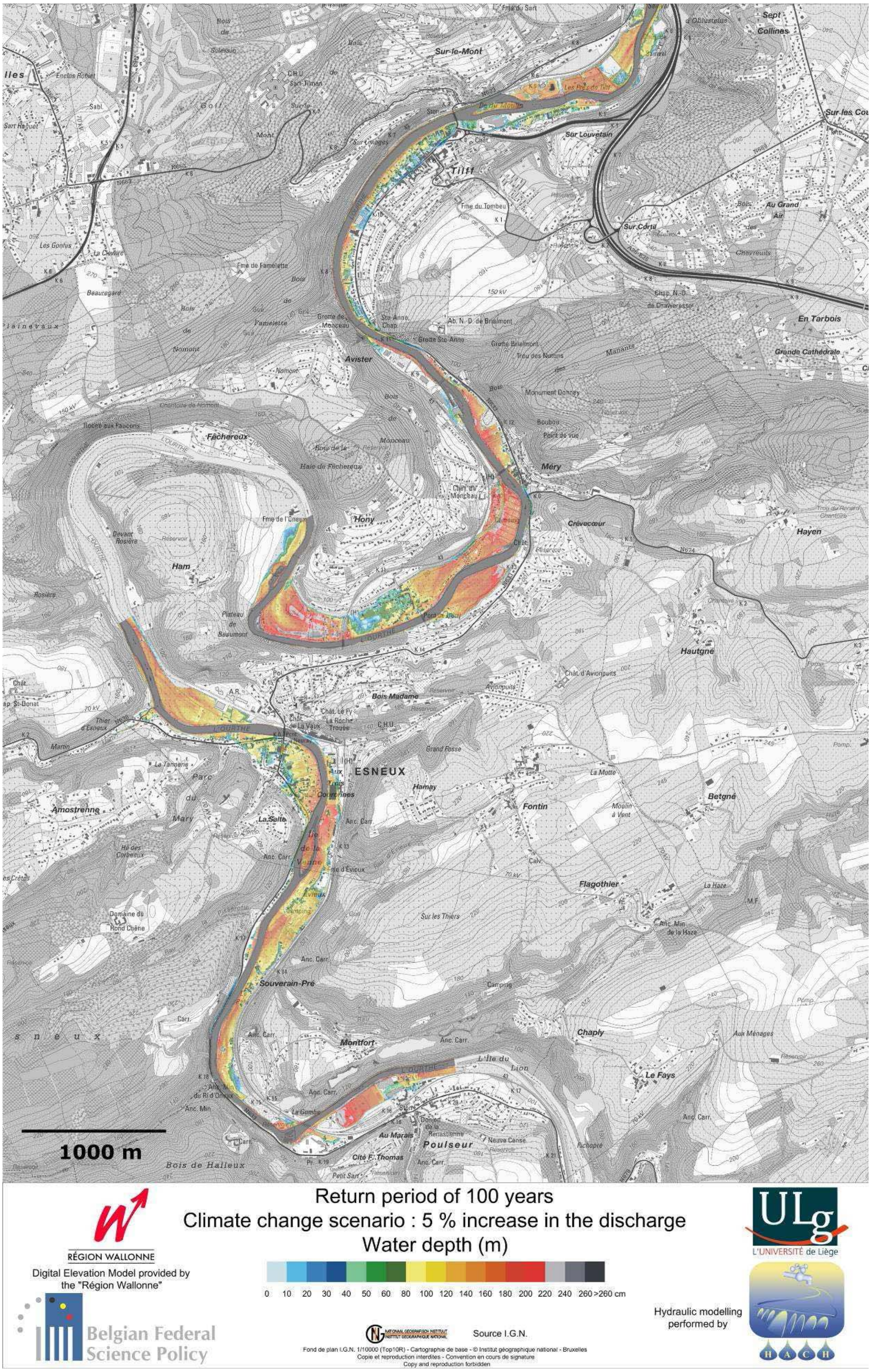
1000 m
Tilff
ESNEUX
Poulseur
Méry
Hony
Avister
Return period of 100 years
Climate change scenario : 5 % increase in the discharge
Water depth (m)
0 10 20 30 40 50 60 80 100 120 140 160 180 200 220 240 260 >260 cm
RÉGION WALLONNE
Digital Elevation Model provided by the "Région Wallonne"
Belgian Federal Science Policy
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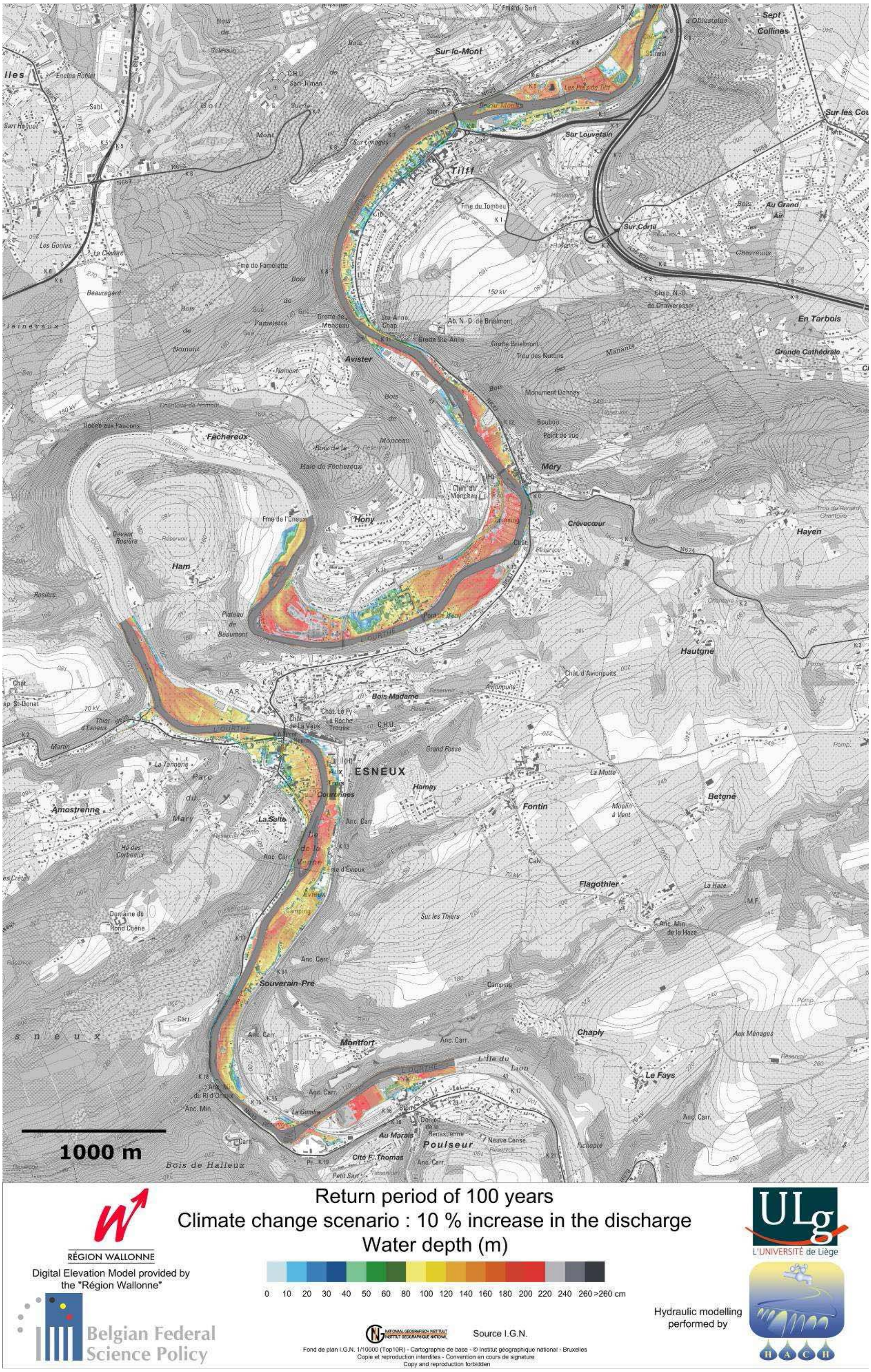
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Return period of 100 years
Climate change scenario : 10 % increase in the discharge
Water depth (m)
0 10 20 30 40 50 60 80 100 120 140 160 180 200 220 240 260 >260 cm
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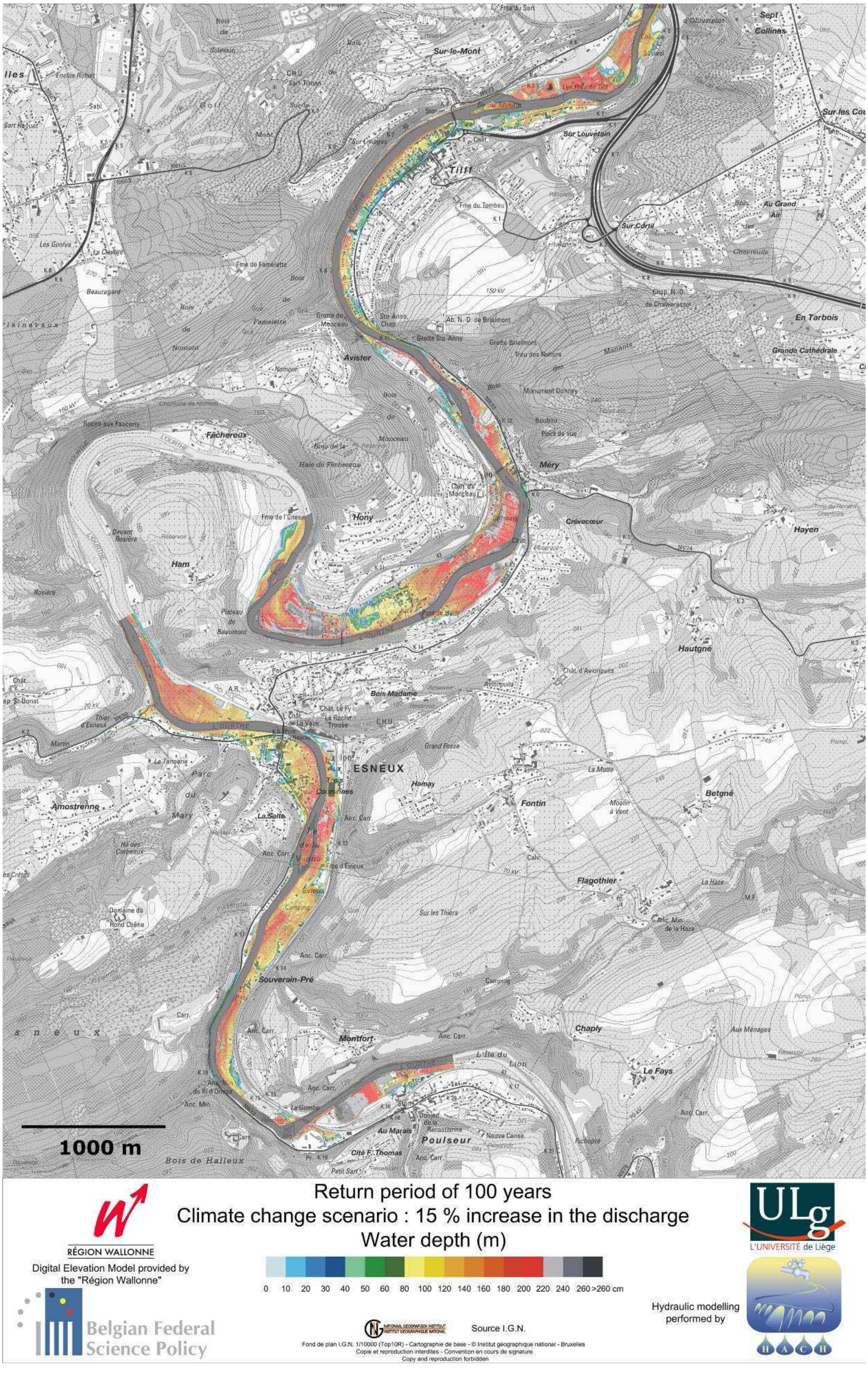
1000 m
Return period of 100 years
Climate change scenario : 15 % increase in the discharge
Water depth (m)
0 10 20 30 40 50 60 80 100 120 140 160 180 200 220 240 260 >260 cm
RÉGION WALLONNE
Digital Elevation Model provided by the "Région Wallonne"
Belgian Federal Science Policy
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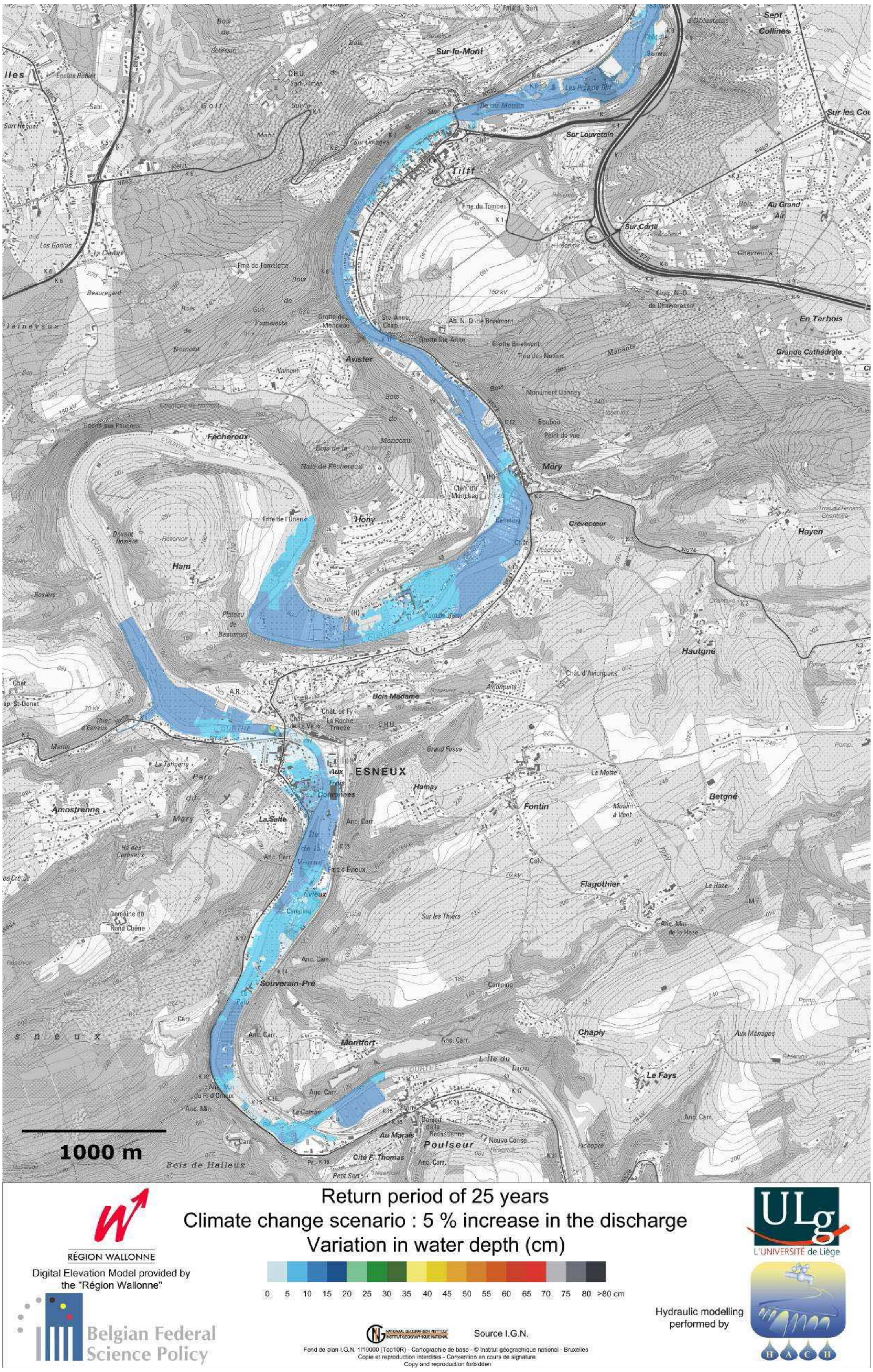
1000 m
Return period of 25 years
Climate change scenario : 5 % increase in the discharge
Variation in water depth (cm)
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 >80 cm
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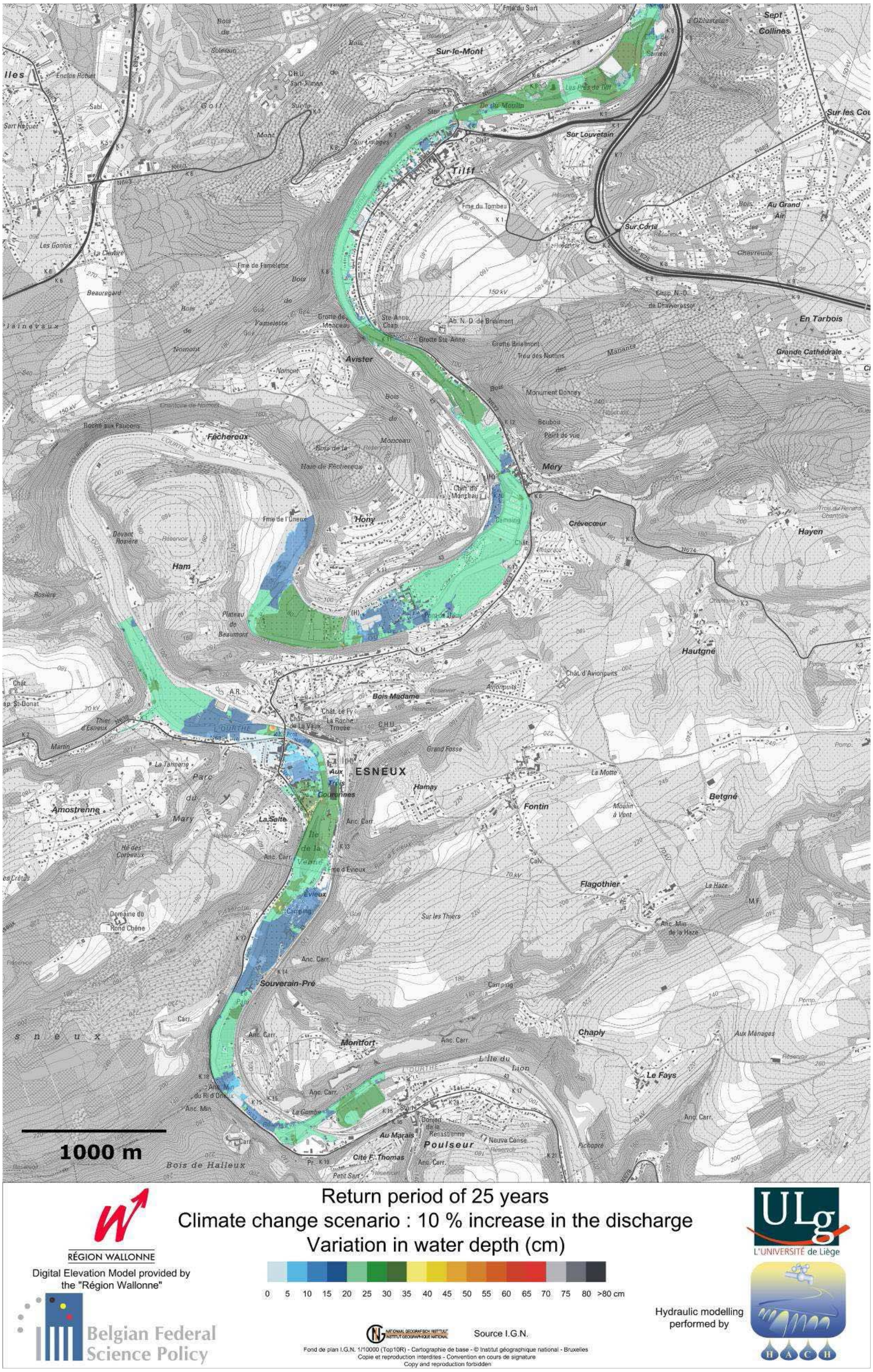
Sept Collines


1000 m
Return period of 25 years
Climate change scenario : 10 % increase in the discharge
Variation in water depth (cm)
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 >80 cm
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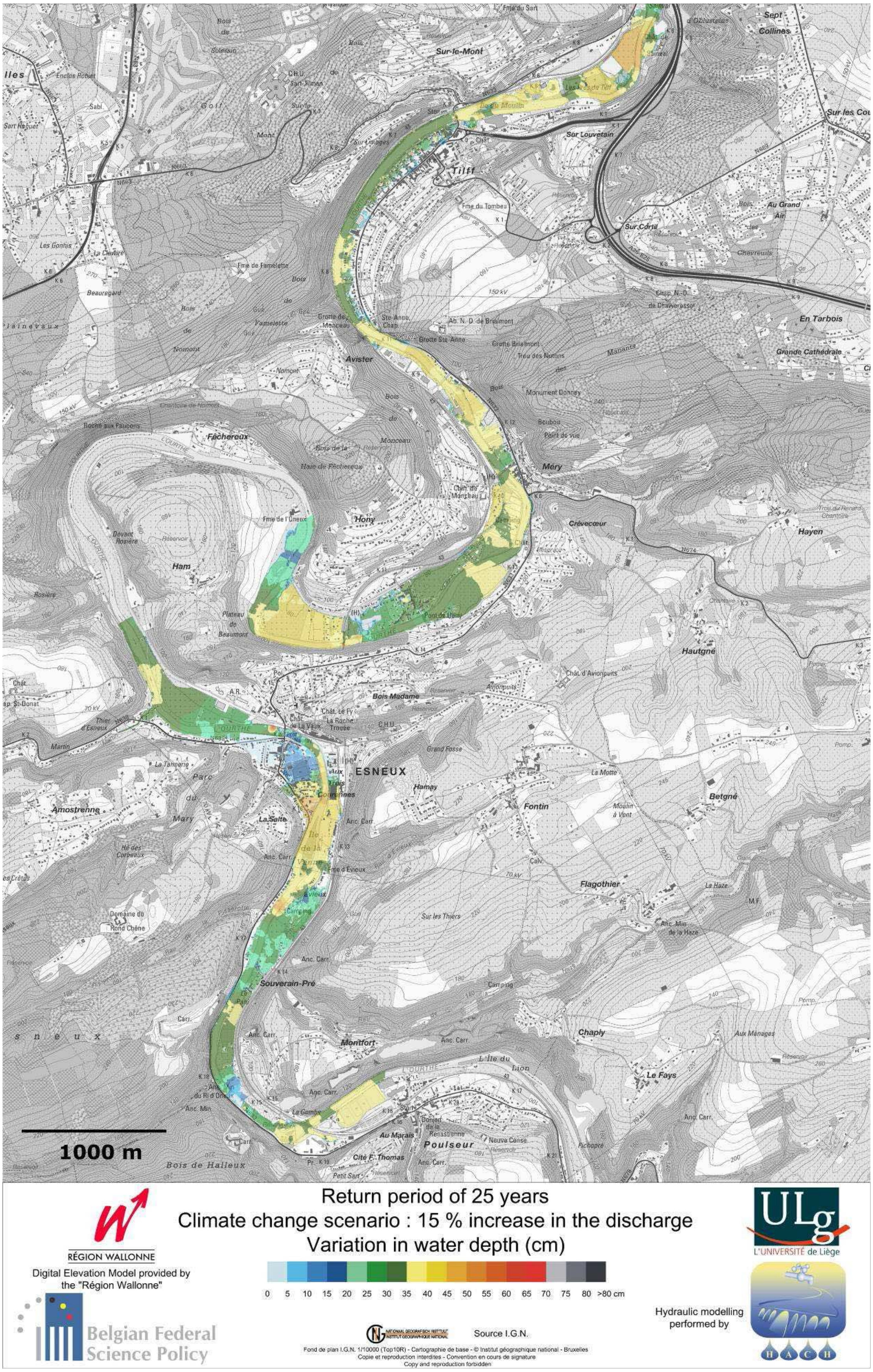
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Return period of 25 years
Climate change scenario : 15 % increase in the discharge
Variation in water depth (cm)
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 >80 cm
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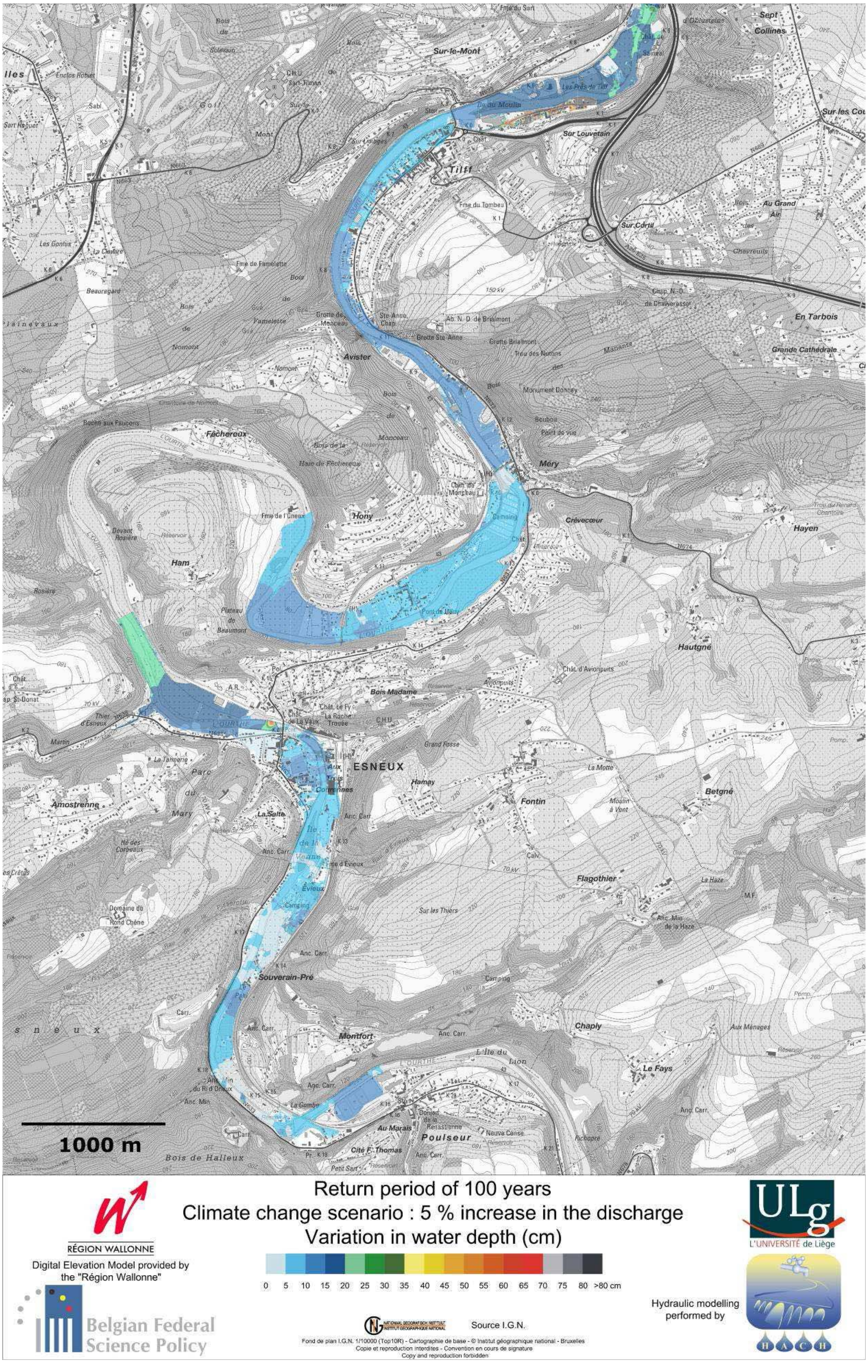
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Return period of 100 years
Climate change scenario : 5 % increase in the discharge
Variation in water depth (cm)
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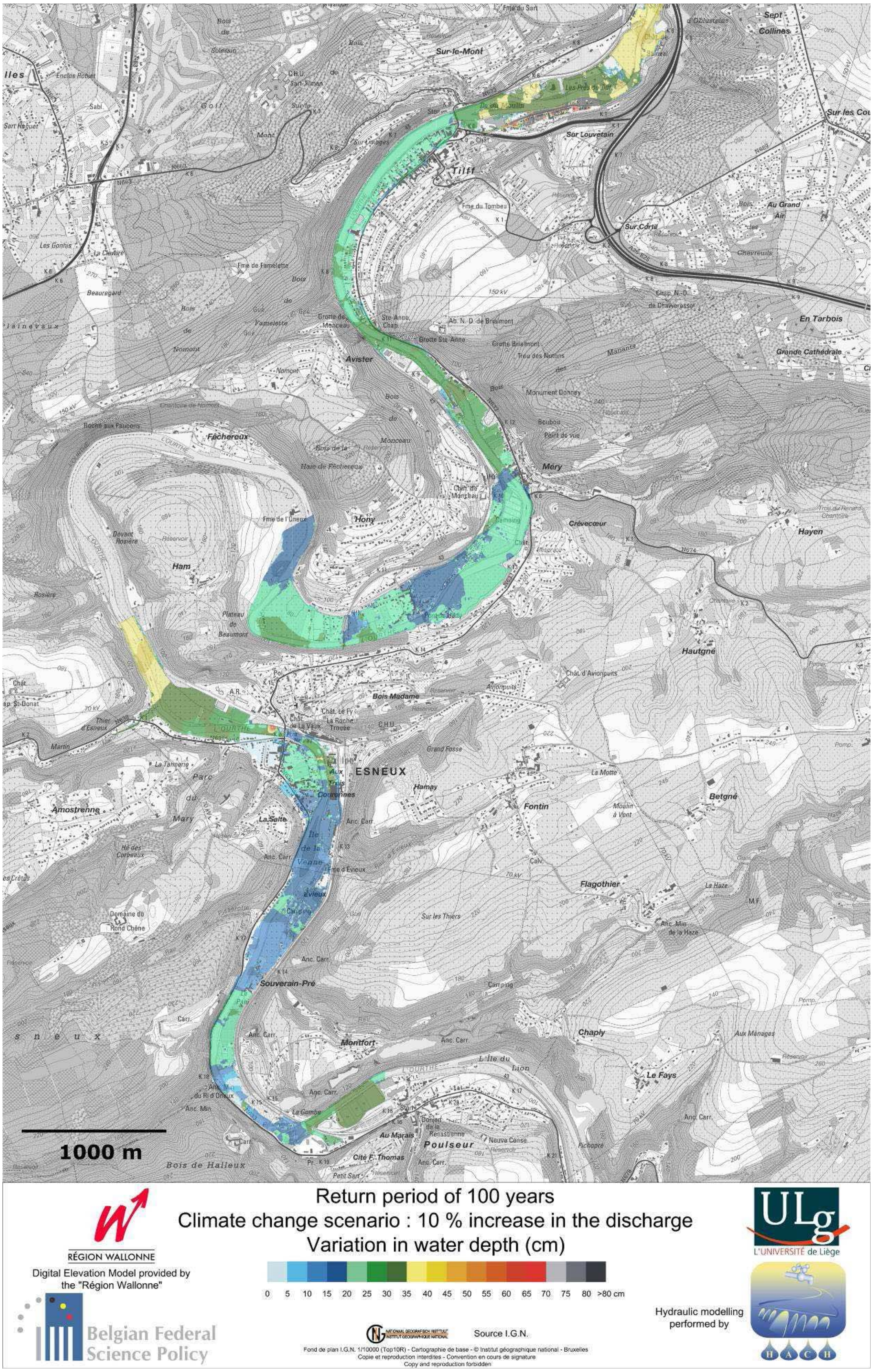
1000 m
Return period of 100 years
Climate change scenario : 10 % increase in the discharge
Variation in water depth (cm)
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 >80 cm
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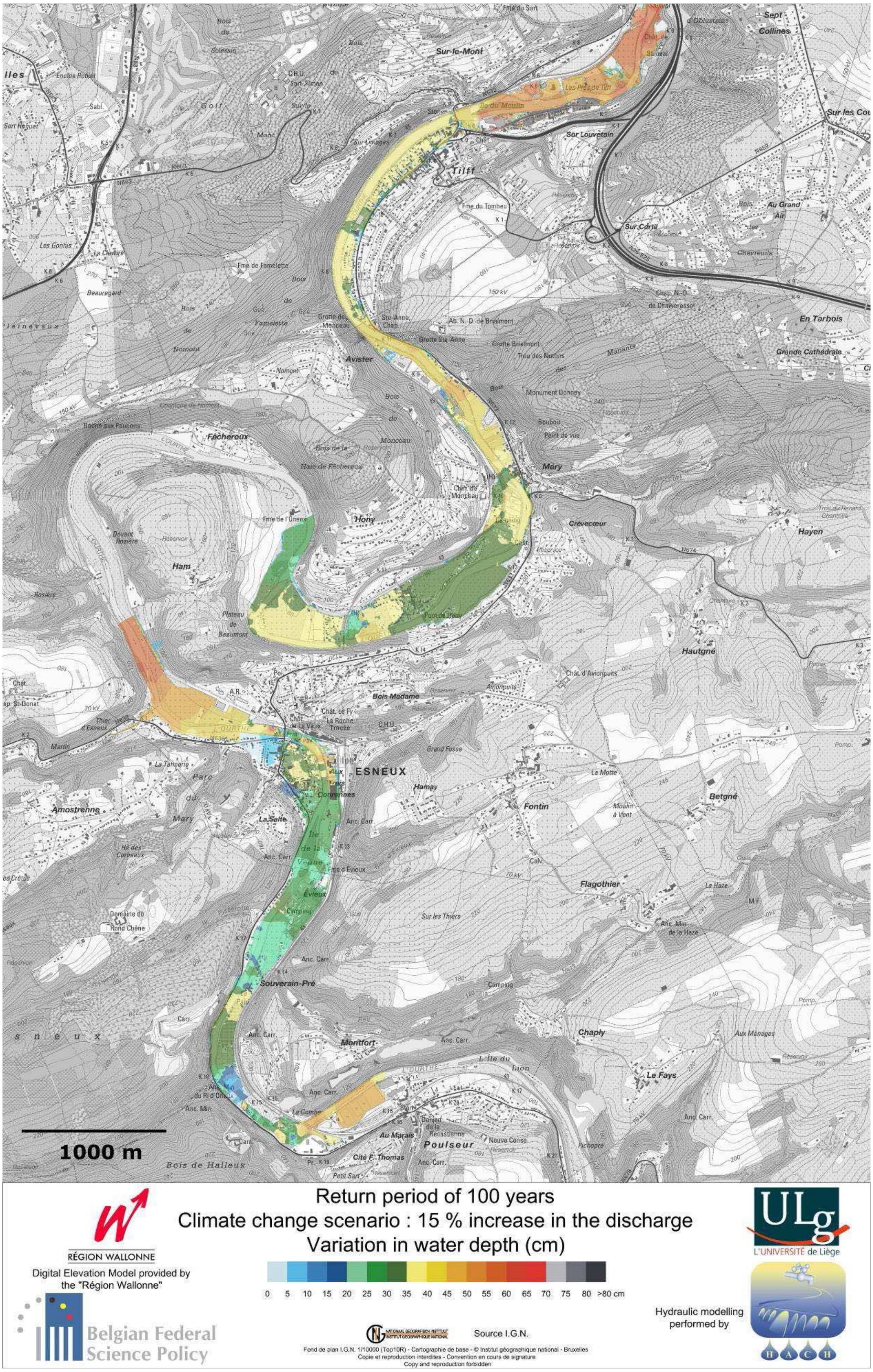
1000 m
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Return period of 100 years
Climate change scenario : 15 % increase in the discharge
Variation in water depth (cm)
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 >80 cm
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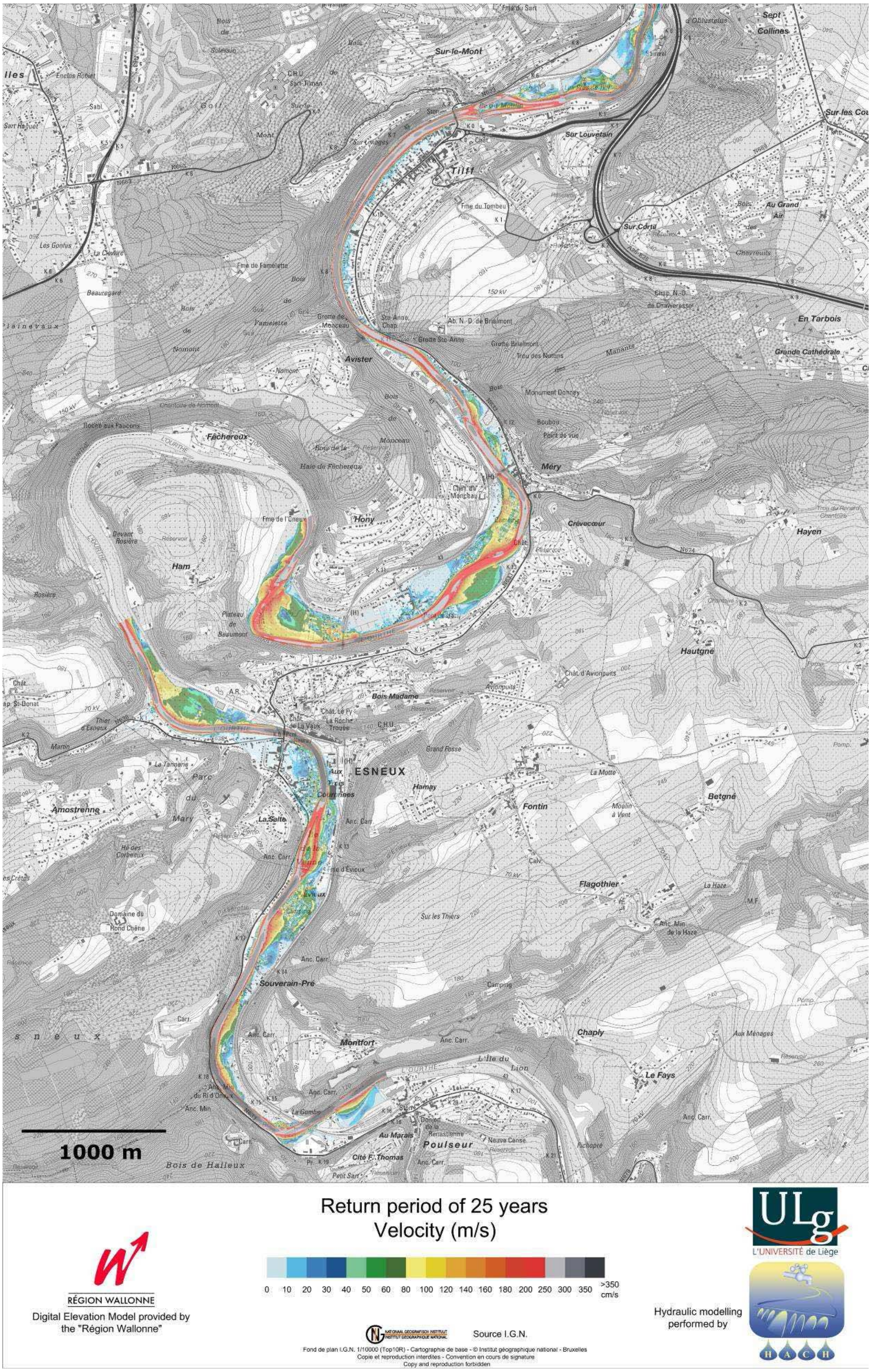

Return period of 25 years
Velocity (m/s)
0 10 20 30 40 50 60 80 100 120 140 160 180 200 250 300 350 >350 cm/s
1000 m
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Grande Cathédrale
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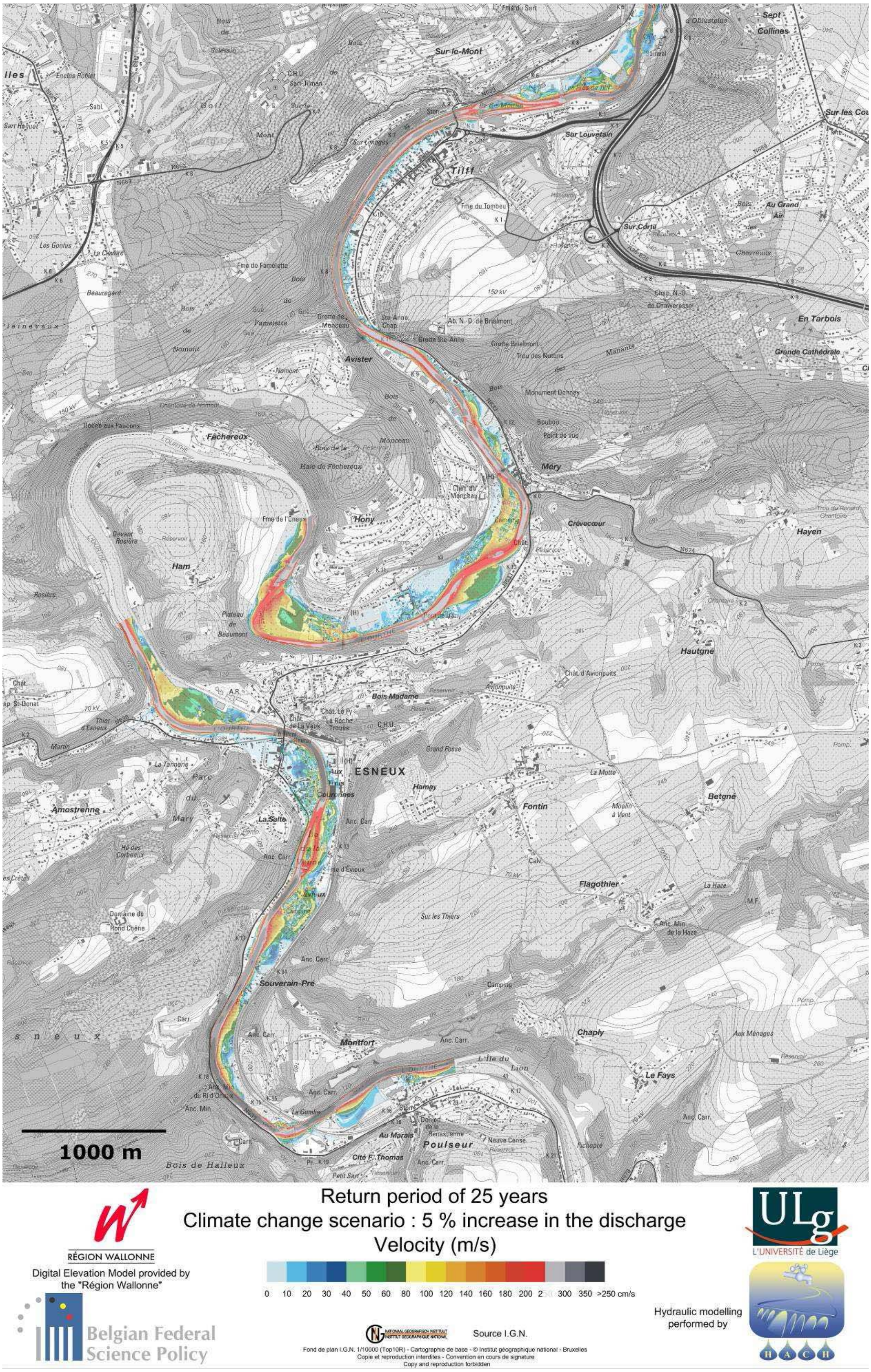
Bois de Halleux


1000 m
ESNEUX
Return period of 25 years
Climate change scenario : 5 % increase in the discharge
Velocity (m/s)
0 10 20 30 40 50 60 80 100 120 140 160 180 200 250 300 350 >250 cm/s
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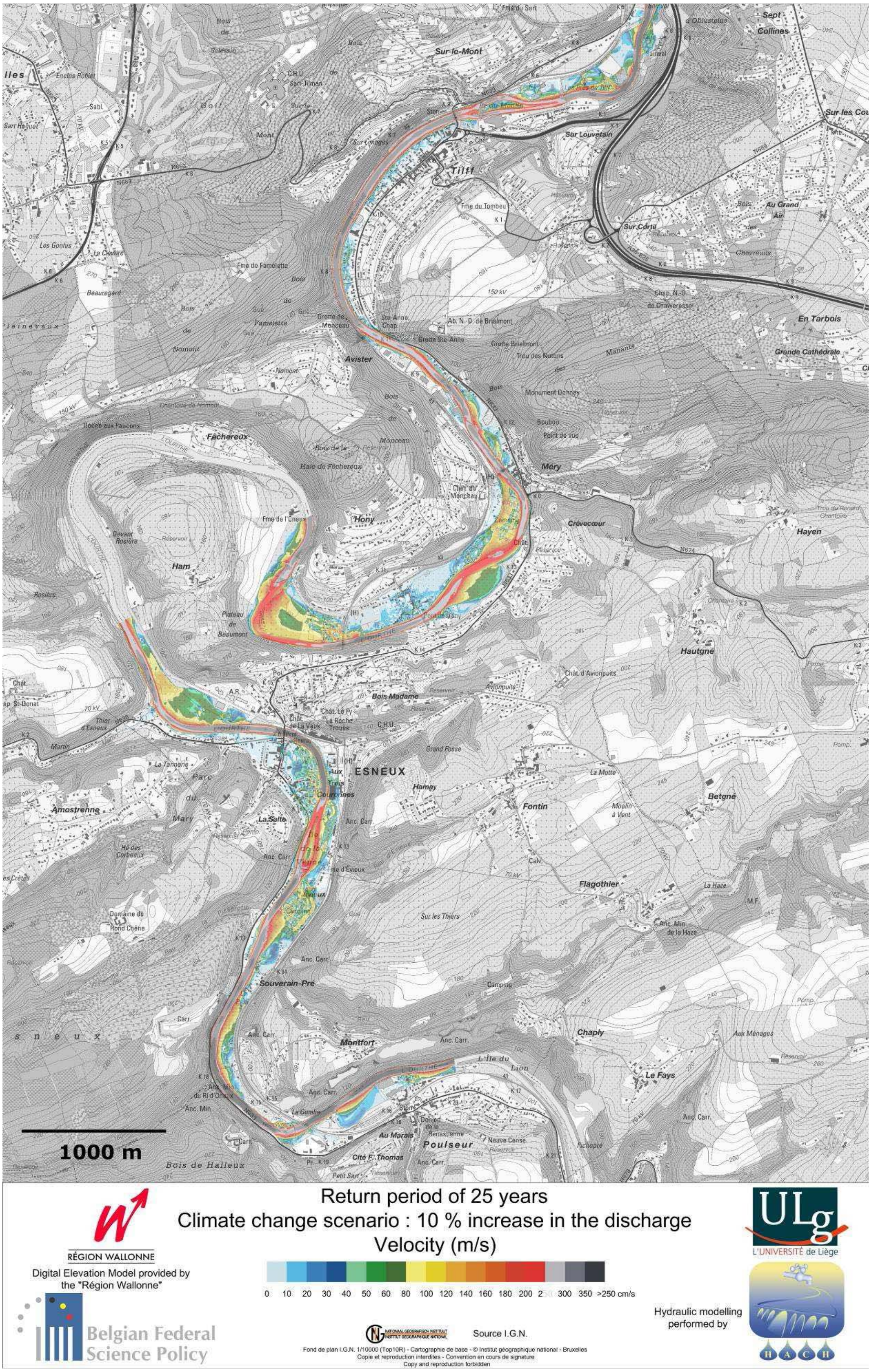
1000 m
Return period of 25 years
Climate change scenario : 10 % increase in the discharge
Velocity (m/s)
0 10 20 30 40 50 60 80 100 120 140 160 180 200 250 300 350 >250 cm/s
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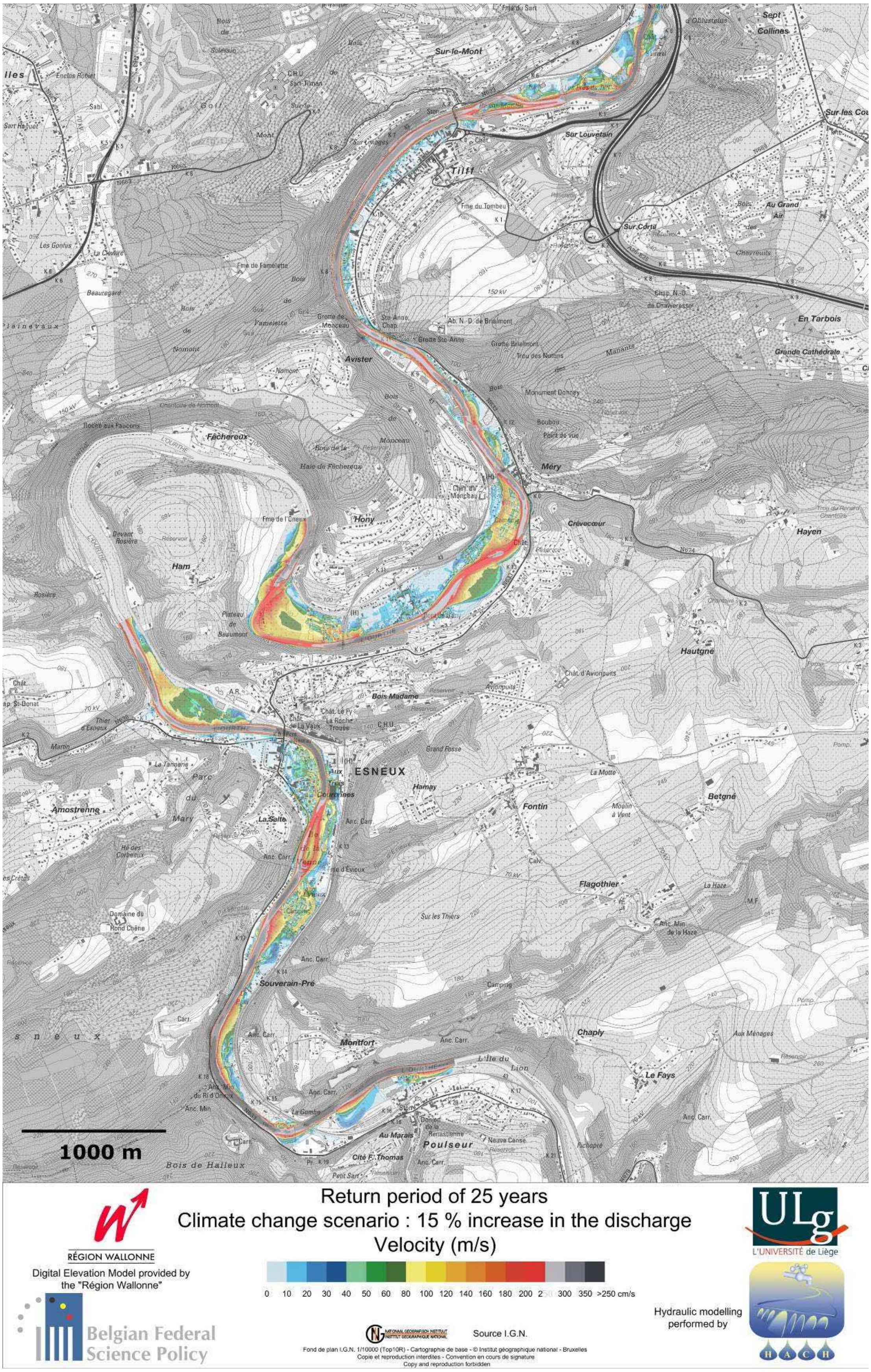
1000 m
Return period of 25 years
Climate change scenario : 15 % increase in the discharge
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0 10 20 30 40 50 60 80 100 120 140 160 180 200 300 350 >250 cm/s
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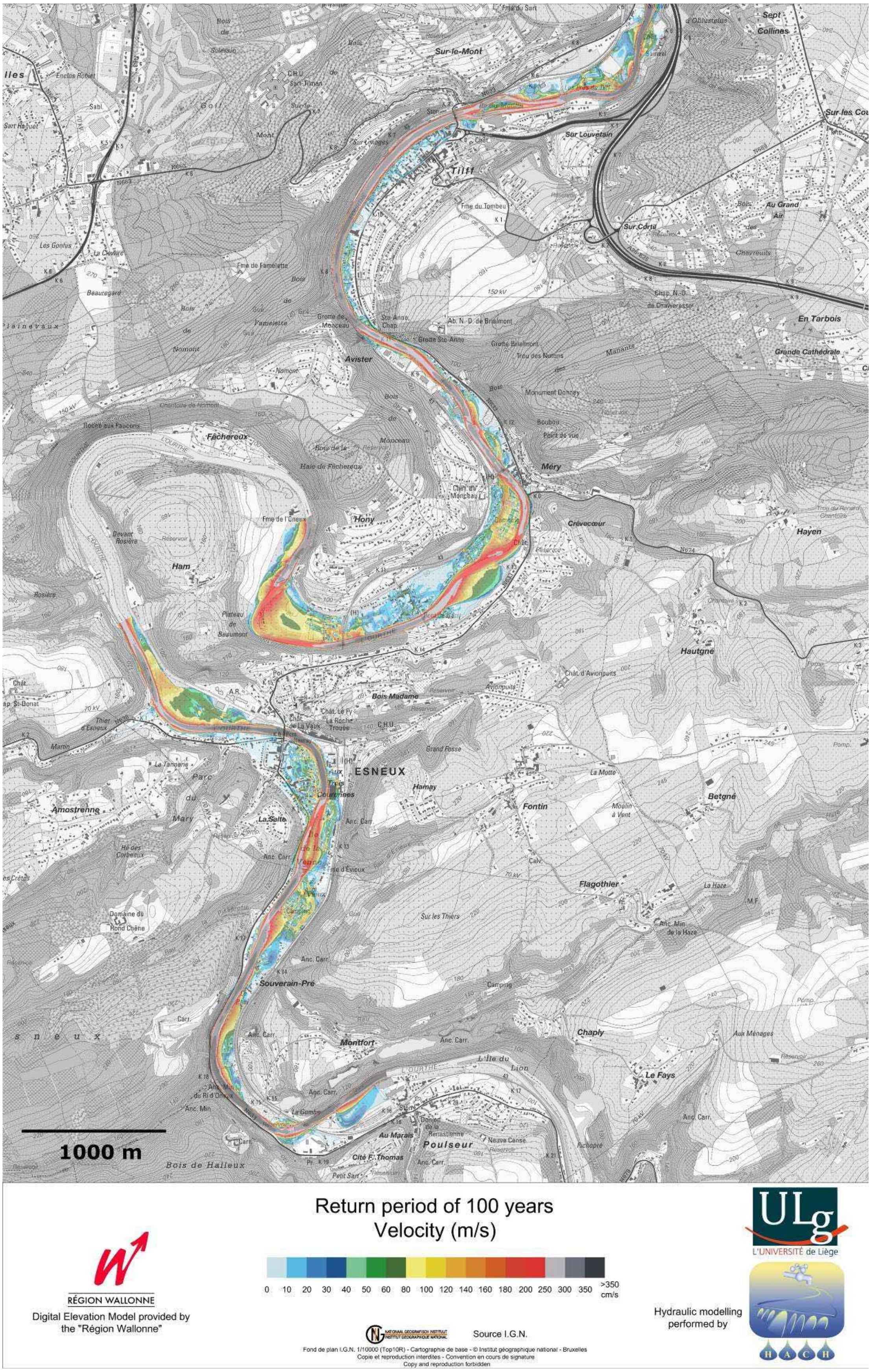
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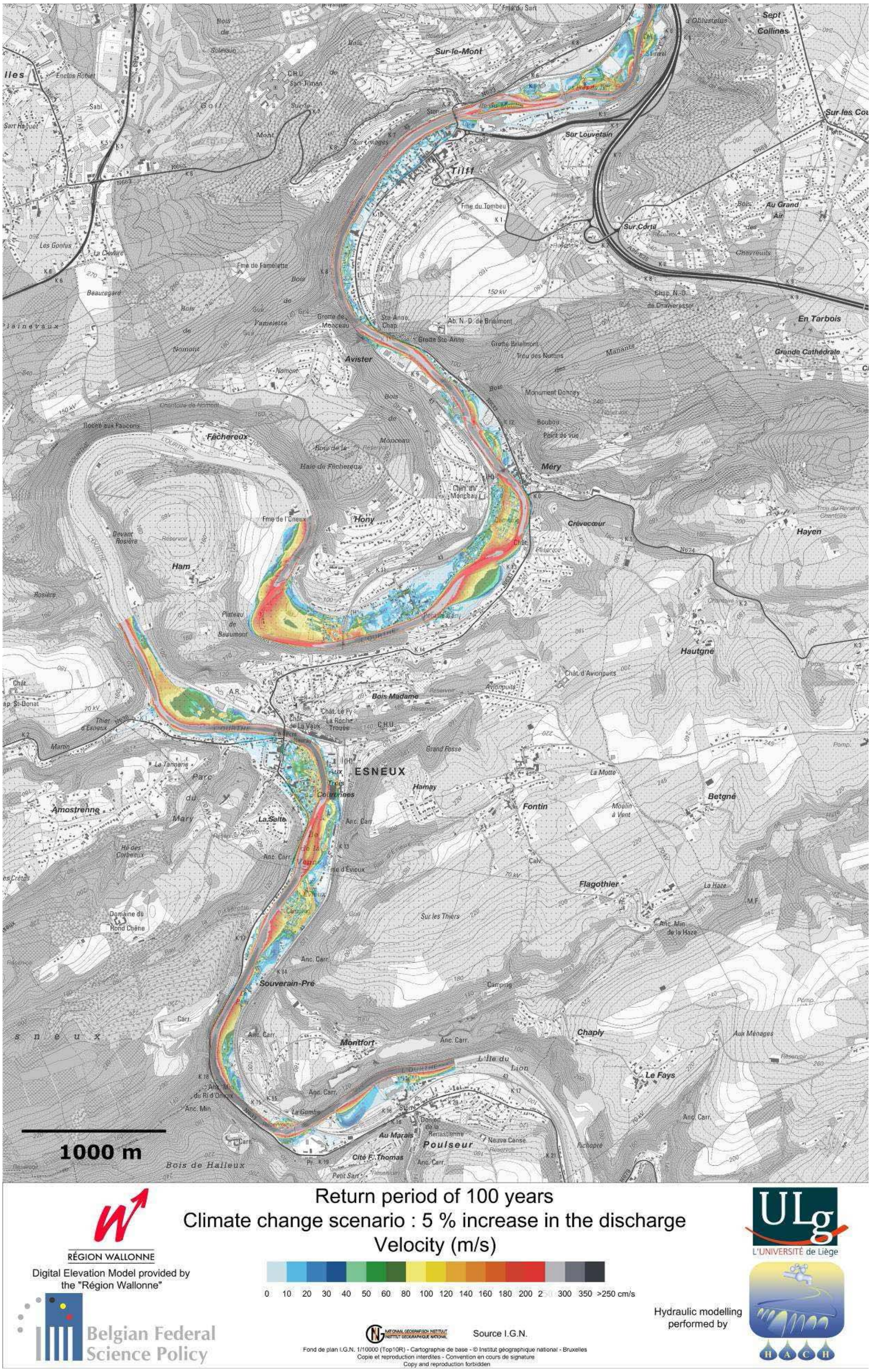
1000 m
Return period of 100 years
Climate change scenario : 5 % increase in the discharge
Velocity (m/s)
0 10 20 30 40 50 60 80 100 120 140 160 180 200 250 300 350 >250 cm/s
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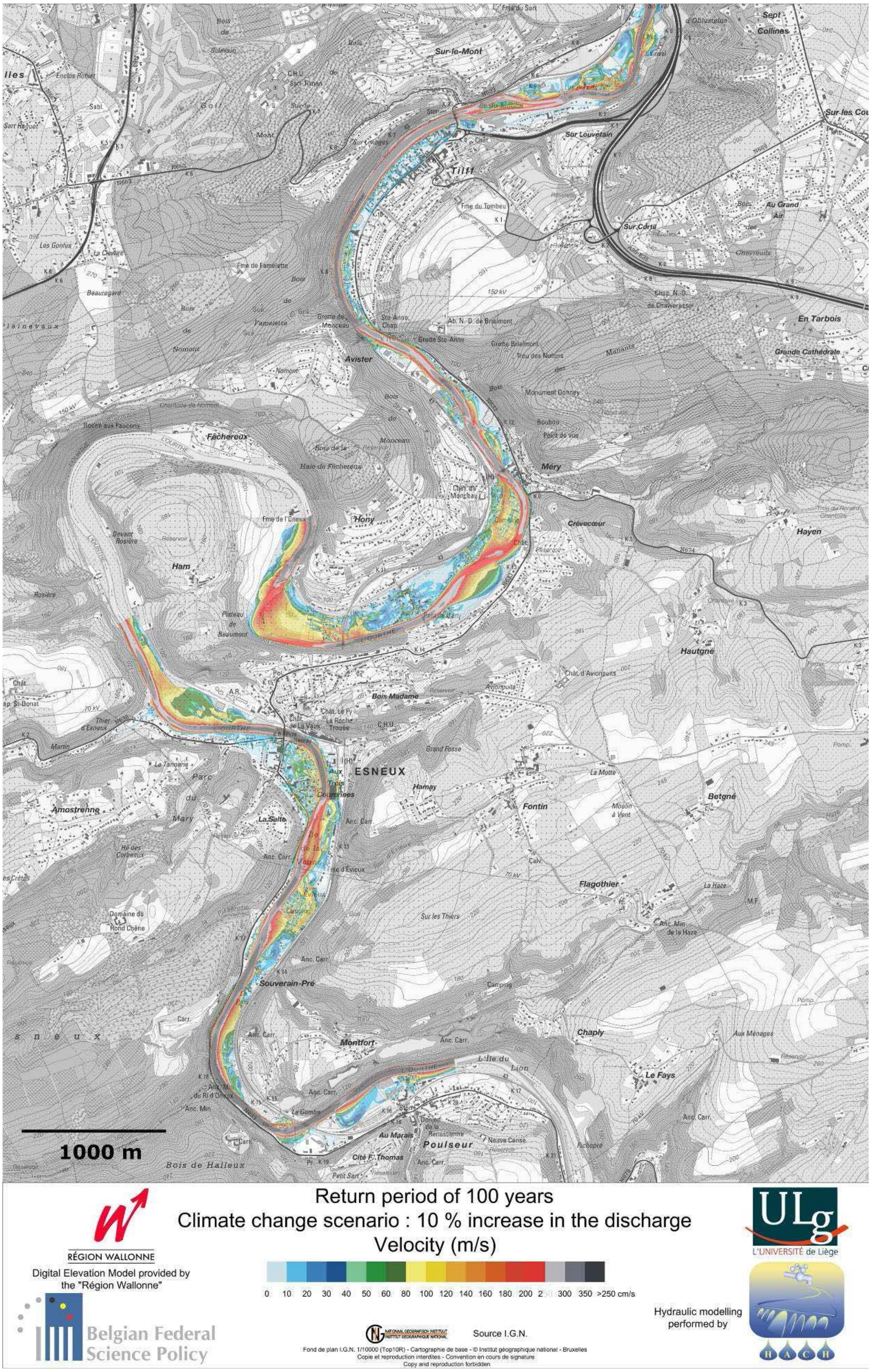
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Velocity (m/s)
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Annex 5 Overview of adaptation measures

Technical / non-technical	*Intervention in the DPSI-chain*	*Component risk assessment framework*				*Sort of measure*	
		Probability	*Exposue*	*value*	*vulenerability*		
Technical	Preventive	x	x			Renaturalisation of water bodies via the reconnection of riparian wetlands, restoration of rivers' natural floodplains and degraded wetlands	Physical engineering works
	Source oriented	x	x			Construction of areas for controlled flooding	
		x	x			Construction of dams	
		x	x			Installation of wells	
	Effect oriented	x	x			Construction of dikes and dike heightening	
		x	x			Construction of Walls	
		x	x			Use of mobile walls/closures	
		x	x			Construction and/or adaptation of weirs	
		x	x			Pumping	
		x	x			Canalisation	
		x	x			Cleaning of river beds (dredging)	
	Curative				x	Reinforcement of buildings	
Non-technical	Preventive	x	x	x		Limiting the use of flood plains via land use planning and/or economic disincentives	Obligations, prohibitions, economic stimuli, research, lessons learned and communication
		x	x			Enhancing the retention capacity of soils by agricultural policies stimulating a year-round vegetation cover and/or the prevention of soil compaction and sealing	
		x	x			Conservation and protection of wetlands and floodplains, preserving river roughness	
		x	x	x	x	Risk mapping and related communication measures and planning initiatives	
	Source oriented	x	x			Research on technical measures like the construction of controlled flooding areas	Research, lessons learned and communication
		x	x			Communication and knowledge dissimination on source oriented technical measures	
	Effect oriented	x	x			Research on technical measures like the dikes, walls, canals,...	
		x	x			Communication and knowledge dissimination on effect oriented technical measures	
	Curative				x	Flood forecasting and early warning systems	Training, rescue operations, relief aid, research, lessons learned, communication, and insurances
					x	Providing people / local authorities with directives of what to do	
					x	Training of actors taking part in rescue actions	
					x	Establishment of an emergency response plan	
					x	Establishment of a compensation system for supporting victims	
					x	Assistance in repairing damage an cleaning-up the dirt	
					x	Insurances	