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The Economics of Adaptation

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Description of adaptation options and their costs and benefits

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Executive Summary

What is the aim of this deliverable?

Work Package 6 of the ECONADAPT project is concerned with two “real-world” economic appraisals of investments in climate change adaptation, in the European context. The two selected cases deal with adaptation to higher risk of floods: in the Czech Republic, centred on the Vltava river impacts on Prague, and in Spain, centred at a the sea-level rise-related impacts of the Nervión river in a district of Bilbao.

In this deliverable we explain how the two appraisals are carried out. We outline the methodological approach, stressing how cost-benefit analysis and real-option analysis can provide viable tools for appraisal of investments in adaptation to climate change. To support the exploration of the appropriate adaptation solutions, we provide a catalogue of adaptation *measures* (or *options*) that address increased flood risk.

Why is the work of this deliverable important?

This document sets therefore the work for the next WP6 deliverables, where the results of the appraisals are presented, and where generalized guidelines for the EU context are synthesized from the two case studies. In addition to this, the catalogue of measures of adaptation to floods can be used by other practitioners to support the exploration of the available adaptation options, and the selection of the most appropriate.

Which method was used/developed?

Here we describe the adaptation measures that are contemplated for each case. The choice of adaptation in each case study is done also with the aid of a catalogue of options for adaptation to increased risk of flooding, which is provided as Annex I to this document.
This is assembled based on a research of the specialized literature and on the project members’ expertise. To best enhance the usefulness of the catalogue within the case studies, and beyond the scopes of the project, we propose a classification of adaptation measures based on their characteristics. By sorting measures by their characteristics, operators can readily make a selection of the measures that are more relevant to their case.

Further, we indicate the approaches taken in the appraisals. Generally, we proceed from generating hazard (flood) datasets, for the present day and for scenarios of the future; then we employ a damage modeling framework to convert future changes in the hazards into changes in damages to assets and infrastructure. We therefore outline which economic tools are used to evaluate the economic aspects of the adapation investment, i.e., mainly its costs and benefits in the long run, and to informa the decision-making.

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1 Introduction

1.1 Aims and structure of the ECONADAPT project

The ECONADAPT FP7 project carries out research in the context of Europe's adaptation to man-made climate change. The economics to support decision-making about adaptation actions are examined, and particular attention is given to the aspects of uncertainty and multiplicity of scales inherent to the climate change predicament.

The project's aims are to provide decision-makers and stakeholders with economic methodologies, evidence and appraisal criteria to guide and coordinate adaptation action, at the various scales applicable in the European context. The climate change areas on which the project focuses range from the short-term effects of extreme weather events, to the long-term costs of climate-related risk, and from the macroeconomic consequences of impacts, to the assistance to developing countries in their response to expected climate developments.

To facilitate the project's scope, ECONADAPT is organized in three methodological Work Packages (WP) (WPs 2 to 4), that are meant to inform and provide operational input to five WPs (WPs 5 to 9) that are centred on policy-relevant case studies. Besides these, other work packages focus on the project-supporting aspects of the framing of the policy-focussed economic analysis (WP1), stakeholder engagement (WP11), the final set-up of a toolbox for economic assessment of adaptation (WP10), dissemination (WP11) and project management and integration (WP12).

1.2 Work package 6

Among the policy-relevant case studies WPs, WP6 is dedicated to the economic appraisal of projects related to adaptation to climate change. The aim here is "to provide illustrative examples of prototype appraisals in real-world contexts"[1]. To represent a variety of contexts, two case studies are selected:

- fluvial flood protection in the Vltava river basin in the Czech Republic (Vltava case study);
- the restructuring of a district, Zorrotzaurre, in the city of Bilbao, Spain (Bilbao case study).

The Vltava case study is led and conducted by Charles University of Prague (CUNI partner), and the Bilbao case study by the Basque Centre for Climate Change (BC3 partner).

The two case studies explicitly address the two main threats that climate change poses to Europe, namely increased hazard from river floods, originating from modifications in the precipitation patters in continental regions (Vltava case study), and increased pressure on coastal zones from rising sea levels and intensifying storm surges (Bilbao case study).

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[1] From the ECONADAPT project Description of Work.

The two case studies will present the evaluation of costs, benefits and related uncertainties of the two concrete projects of adaptation in the Czech and Spain contexts. Projections of the effects of climate change, in the form of altered rainfall, of and socioeconomic developments will be explicitly taken into account. The methodologies applied will at least partially be derived from work in the methodological WPs of the project.

1.3 Aims of this report

Deliverable 6.2 addresses a central aspect of ECONADAPT; that is the methodology of appraisal of economic and social costs and benefits of measures of adaptation to climate change. The two WP6 case studies, about the Vltava river basin and the city of Bilbao, deal with increased risk from flooding due to the impacts of climate change on precipitation and on river discharge.

The two case studies are meant to address the same research question (i.e., evaluating the economic and social costs and benefits of adaptation measures), performed for the same time future time horizons (near future: 2021-2050; and far future: 2071-2100), and for the same emission scenarios (Representative Concentration Pathways (RCPs) 4.5 and 8.5; Moss et al., 2010). By keeping these factors constant, we use the two case studies to confront real-world situations that present differences at multiple levels:

1. contingencies, such as: geographic scale; legislative, policy and stakeholder domain (see Deliverable 6.1); climate; economic use of the resources at risk;
2. approaches of adaptation to climate change impacts;
3. assessment methodologies.

While Deliverable 6.1 focused on the first of the above points, in the present Deliverable 6.2, we give an account of points 2 and 3, treating how each case deals with adaptation, and how each case structures its method of evaluating costs and benefits of adaptation.

Contents

This document contains a general catalogue of options for adaptation to increased flood-risk, presents the methodological approach that is taken in these two appraisal exercises, and then examines adaptation measures that are currently in place, that are planned for the future, and that can be envisioned and assessed in our exercise, for the two case studies. The initial catalogue of options is meant to provide guidance to the case studies as to which options could be suited to the case context. More in detail:

In **section 2** the general topic of flood adaptation measures is addressed, and a catalogue is presented of general flood protection options. Options are classified according to their characteristics, which enables their selection on the basis of the case specific context.

Section 3 (Vltava) and **4** (Bilbao case study) have two scopes:

- Illustrating adaptation measures for the case. First, adaptation measures that are currently in place are presented, then those that institutions have planned to enforce in the future, and therefore measures will be examined that are envisioned within the case study exercise, that are selected from the catalogue in section 1 and are considered suitable to the case context.

- Presenting the materials and methodology that are used in the appraisal, including details about climatological and flood-risk datasets, future scenarios, and a comprehensive description of the methods applied.

1.4 Appraisal methods: Cost-Benefit and Real Option analyses

In their assessments, the Vltava case study will apply Cost-Benefit Analysis (CBA), and the Bilbao case study will apply Real Option Analysis (ROA). In the following the general features of these methodologies are presented. The information presented below on CBA and ROA is taken from MEDIATION (2013).

CBA is the commonly-used economic evaluation method for public decisions at different scales (local, regional, national). The approach allows to (1) analyse whether a decision is sound, and (2) to compare different alternatives, such as investment options. The used approach includes all relevant costs and benefits of the options to society in monetary terms. This method is called social CBA. Based on the different cost and benefit components, it estimates a net present value or a benefit-cost ratio per option. CBA provides justification for interventions and support for decision making. But uncertainties are included due to difficulties to estimate all the costs and benefits of a project or investment.

For the evaluation of climate adaptation measures, CBA has been implemented, mainly as part of the impact assessment of the adaptation activities. Actually a CBA is only suited to partially reflect the complexity of climate adaptation, e.g. by including climate uncertainties, distributional impacts and equity (UNFCCC, 2009). The technique will only be appropriate for some of the adaptation decision-making contexts, but it can be used in combination with new methods such as ROA or robust decision making.

ROA is an economic decision support tool specifically suited for decision making under uncertainties. It estimates the risk for the implementation of activities or investments for which the future outcomes are uncertain. The method was originally used for the evaluation of financial options and the transfer of risk on the financial markets. The technique was then transferred to the valuation of investments in physical assests, the “real options”, that are characterized by considerable uncertainty or risk. The method includes the evaluation of the flexibility of an investment: the flexibility over time and the flexibility for adjustments to the investment project This means that a flexible measure can be adjusted as a consequence of new climatic information becoming available, or of new information deriving from other experiences with the investment: it can be expanded - e.g., heightening of dike - or dismantled easily. The technique enables evaluation about the optimal timing of realization of a measure, and the evaluation of alternative measures which might yield more flexiblility. The common implementation of the ROA develops decision trees, defines possible outcomes and indicates probabilities. For the comparison of alternative measures estimated expected values are used.

ROA has been discussed in the literature as a suitable decision tool for climate adaptation. The underlying concept aligns with other approaches, such as adaptive management and iterative decision making. ROA shows advantages as the estimation of information in quantitative and economic terms and first applications. Nevertheless, its usage is limited by its technical complexity and its resource intensiveness. Indeed, one of the main difficulties is the need of probabilistic (or probabilistic-like) information on outcomes. The approach is best used for investments which have large upfront costs and are irreversible, such as coastal dikes, which are flexible in timing and for which relevant new information may emerge in the years after initial realization. The technique tends to support measures or investment options which have short-term benefits and the flexibility to be adjusted in the future.

The following table summarizes strengths and weaknesses of CBA and ROA.

Table 1: Summary Cost Benefit Analysis (CBA) and Real Option Analysis (ROA).

	CBA	**ROA**
Potential use as decision-supporting tools for adaptation	- Short-term assessment of low- and no-regret options. - Combined with iterative risk management.	- Large investments such as flood protection, water storage. - Especially where necessity or potential for flexibility within the project.
Advantages	- Provides direct analysis of economic benefits, justification for action, and optimal solutions. - The method is well known and widely applied.	- Flexibility is valued in quantitative and economic terms. - Interlinked with concept of adaptive management
Disadvantages	- Difficult to include non-monetary values (without market price) and soft adaptation measures. - Uncertainty usually limited to probabilistic risks.	- High complexity, data and resource intensive. - Identification of decision points often complex.

Source: Based on MEDIATION (2013).

2 A catalogue of flood adaptation measures

To assist the choice of adaptation in the two ECONADAPT WP6 case studies, a catalogue of adaptation *measures* (or *options*) that address increased flood risk has been put together. This is assembled based on research of the specialized literature and on the project members' expertise. The sources of data were mainly: UNISDR (2013); ISDR (2004); UNFCCC (2011); IPCC (1990; 2012; 2013); European Commission (2003); EEA (2013).

To best enhance the usefulness of the catalogue within the case studies, and beyond the scope of the project, we propose a classification of adaptation measures based on their characteristics. By sorting measures by their characteristics, operators can readily make a selection of the measures that are more relevant to their case. In the following section the characteristics are described. The catalogue of adaptation measures is included as Annex I of this report.

2.1 Characteristics

Because of the differences among the contexts where adaptation action is planned, the catalogue of adaptation measures needs to include measures with a wide range of characteristics. Depending on a case study's context, policy objectives, and modelling approach, the focus would be on different aspects of the adaptation option, and would thus require information about different characteristics. Also, characteristics might have different relevance in the eyes of different stakeholders. By including multiple characteristics, multiple categorisations can be made of the adaptation options, thereby permitting their use within different cases, by different stakeholders, etc., making the catalogue useful for operators in a variety of coastal and continental contexts. The following classifications of the adaptation options are included in the catalogue.

Coastal storm surge / river flood / general hazard. This classification of adaptation options distinguishes the type of hazard they address, i.e., whether options are designed to respond to coastal storm surge, to river flood, or whether they are suited to a range of climate hazards. Within the first three classes, the options are further separated on the basis of the specific type of hydro-meteorological risk they are designed to address:

- For coastal storm surge: **inundation / erosion / salinization**
- For river flood: **inundation**

Reduce hazard / exposure / vulnerability. This classification reflects the so-called "risk framework" (Kron, 2005). The risk framework reflects the stress on a risk management perspective proposed by the EU (2007). It provides a comprehensive characterization of adaptation options and has been used in other coastal zone studies (e.g., Nicholls et al., 2008; Kreibich and Thieken, 2009; Aerts and Botzen, 2011; Lasage et al., 2014). It allows for a process-wise schematization of the adaptation subject, which enables a prompt use of the catalogue in the context of management and decision making. It is also advantageous in the context of scientific research that is aimed at the calculation of risk, specifically at the evaluation of the effect of specific adaptation measures on the total risk (e.g. Lasage et al., 2014), which falls within the scopes of the ECONADAPT project. For example, physical barriers, such as dykes and seawalls are *hazard* (flood)-limiting strategies. Zoning and elevating roads and houses reduce the *exposure* of people and assets. Flood-proofing of buildings, like evacuation and early warning, are examples of reducing *vulnerability*, in the sense specified in the IPCC's AR5 (IPCC, 2013), i.e., "the propensity or predisposition [of a system] to be adversely affected; Vulnerability encompasses […] sensitivity, susceptibility to harm and lack of capacity to cope and adapt".

For this classification, a clear definition of what precisely constitutes the hazard is necessary. For example, considering the phenomenon of river floods, a *flood* can be defined as: 1) the extra-ordinary inundation of land by a riverine water body (akin to the definition in the EU Floods Directive, 2007/60/EC): in this case the *hazard* is the area covered by water, the *exposure* is the number of people/assets located in that area, and the *vulnerability* is the susceptibility of those people/assets to suffer damage; 2) the extra-ordinary height reached by a riverine water body: in this case the *hazard* is the anomalously large flow rate within the water body, the *exposure* is the number of people/assets located in the "proximity" of the water body, and the vulnerability is the same as in the former case.

Protect / retreat / accommodate. This is a classic classification for adaptation options, which was first proposed by the IPCC (1990) (cf. also Dronkers et al., 1990; Nicholls, 2011). It gives insight into the approach taken in the response. It has close analogies with the "risk framework", described above, and to some extent overlaps with it.

- Measures that aim to *protect* function by inserting a physical structure - commonly a dyke, levee, or a seawall - between the water body that can generate the hazard (the sea, a river) and the area at risk.
- *Retreat* measures either (i) relocate population or assets at risk to areas that are less threatened by flood (typically to higher ground, or further from a river or the coast), or (ii) deliberately breach land (i.e., managed realignment or regulated tidal exchange) and at times, move defences landward, to allow space for water or increase biodiversity, thus offsetting risk elsewhere (Esteves, 2014).
- *Accommodate* measures function by adapting the area, people, and assets to the likely occurrence of the flood, e.g. by elevating households and goods, or by impeding water access to buildings.

In general terms, this classification of measures represent a gradient of intensiveness of alteration of the natural system, where *protect* represents the deepest interventions, and *accommodate* the lightest. It must be noted that appointing of measures to these categories is not universal, and can be scale-dependent. The option of "managed realignment" (i.e., either removing physical protection from or evacuating some areas to better manage the hazard posed by the water body) can be viewed as *retreat* at a small scale, but as *protect* from a wider point of view.

Grey / soft / green. This classification reflects the recent shift of focus away from the classic, infrastructural, cement-based approach, towards more sustainable courses of institutional and environmental-friendly adaptation (EEA, 2013).

- *Grey* adaptation options include physical solutions that consist of *hard* infrastructure (thus the often-used term *hard measures*), and/or require a continuous input of energy. Classic examples are dykes, and pumping water from a polder.
- *Soft* options are non-structural, or "non-engineering", and are often referred to as "institutional". They consist of *economic* (e.g. insurance), *spatial* (e.g. spatial

planning, zoning of functions), *legislative* (e.g. building code), and *physical* options (i.e., those that imply mechanical interventions, albeit less construction-intensive than the classic *grey* measures).

- *Green* options consist of physical solutions that are considered apart from *grey* ones, because they are based on natural processes, and are specifically meant to perform positively in terms of environmental sustainability and/or climate mitigation (i.e., the reduction of greenhouse gas emissions). Instances include using vegetation to protect the coastal zone, or supplementing sand to the beach (beach nourishment) so as to enhance the natural sedimentary processes.

The example of beach nourishment also serves to illustrate a point of controversy inherent in this classification. In fact, counteracting sea level rise-induced beach erosion might require considerable amounts of offshore sand dredging, which in turn – depending on the location - might severely impact the offshore marine ecosystem. On the other hand, if a physical protection is favoured, such as an artificial reef, commonly classified as *grey*, a more environmental-friendly, *green* effect could be obtained. We note, therefore, that a correct classification of *grey* vs *green* measures necessarily depends on several circumstances inherent to the particular case, which therefore has to be duly examined.

Water / agriculture / energy & transport / nature / housing & infrastructure sectors (de Bruin et al., 2009). This classification refers to the economic sectors upon which an adaptation option impinges, and is therefore of explicit interest to the type of economic analysis that is carried out in the two case studies of ECONADAPT WP6.

Reactive vs anticipatory. This classification divides the adaptation options into anticipatory actions and reactive actions (Bosello, 2007). The former may be in response to a sudden or unexpected extreme event, opening a policy window (Kingdon, 1995), thus allowing adaptation to occur. It has been shown that anticipatory actions are often less expensive and more effective than reactive actions (e.g., Smith and Lenhart, 1996; Fankhauser et al., 1999). This distinction is exemplified by adaptation measures in urban flood management: if an action is taken *in anticipation* of expected climate change, such as by creating wetlands upstream to prevent urban inundation, it would provide a greater benefit than the same action taken *in reaction* to occurred climate change, as when urban damage has already occurred due to intervening climate change. The degree to which anticipatory actions are preferred over reactive actions depends in large part on the resilience of the system being examined (e.g., Linkov et al., 2014): the less a system is able to return to its original state after a shock, the larger are the advantages of anticipatory adaptation.

Short vs long term. This classification divides the adaptation options according to whether an option is more suitable to tackle the effects of climate change in the short or in the long term. Avoiding the specification of an arbitrary and necessarily non-universal time-threshold for this distinction, we propose, after Prenger-Berninghoff et al. (2014), that *short-term* measures correspond to “emergency management (preparedness and response) aimed to minimize the impact of a disaster” and “to immediately respond”, whereas *long-term* measures “include permanent technical (structural/non-structural) measures as well as spatial planning, which is inherently a future-oriented activity”.

Autonomous vs planned/policy-driven. This classification separates options that arise from community/household/private-enterprise initiatives, from those that result from any level of governmental/institutional (local, regional, national, international) policymaking

(Satterthwaite et al., 2007). Often, the first class of measures is identified with the term “private”, while the second with “public” adaptation (Tompkins and Eakin, 2012). Although case studies within ECONADAPT do not contemplate autonomous adaptation per se, autonomous action can be stimulated and incentivized by policy decisions, and is therefore of interest for the project.

Local / regional / national. This classification refers to the spatial scale of the implementation of a measure. The *local* level may be further subdivided into *district*, *building,* and *household*-scale adaptation (Shaw et al., 2007).

National or regional governments / international institutions / private households / NGOs / private businesses as the cost bearer. This classification distinguishes who pays (entirely, or partially) for the implementation of the adaptation measure. This aspect is central to the economic analyses conducted in WP6, and is directly connected to the research on stakeholders’ involvement that is realized in other WP1 of ECONADAPT.

3 Assessing adaptation costs and benefits - The Vltava case study

This case study focuses on flood risks in the Czech Republic, in the study site of Vltava river basin. The study aims at the appraisal of several strategies/measures of adaptation to flood, for which the corresponding social costs and benefits will be calculated, comparing adaptation to the reference case of business as usual. The impacts of these adaptation measures will be analyzed using cost-benefit analysis. We will investigate the impacts on different stakeholders groups, including the trade-offs among various uses of the study area. Key to the assessment is to incorporate uncertainties in the economic appraisals.

3.1 Adaptation measures

In general terms, according to Flood control strategy of the Czech Republic (MoE, 2000), the flood control system in the Czech Republic is composed of:

- stream-channel regulation and enhancement of the flow capacity of water courses,
- structural flood measures in water courses and in inundation areas ensuring fast effluence,
- prediction and warning systems,
- flood plans.

Technically, the system involves structural and non-structural measures. Structural protection comprises retention basins, with the possibility of enhancing the capacity of the watershed and of riverside reinforcement, levees and regulation of activities in floodplain areas. In active zones (the most vulnerable areas within floodplain zones), urban planning does not allow new building, and restrictions are placed also upon agriculture also in the aim of reducing the risk of flash flooding. Non-structural protection includes administrative definition of floodplains (Q5, Q20, Q100; corresponding to the 5-, 20-, and 100-year floods) and prediction and warning systems (Čamrová and Jílková, 2006).

CGS, IH AS CR (2011) stress the importance of measures offsetting the decreases in discharges and the yields of water resources, and also of measures minimising the impacts of flash floods, especially in mountain and foothill areas. Although several subsidy programmes exist that focus on flash flood-related problems, most programmes are used to co-finance the reduction of flood damage and the measures to adapt to the risk of flash flooding are still underdeveloped in the Czech Republic.

Since 2000, a new modern flood control system has been built in Prague, composed of structural protection measures. Construction of flood-reduction works reduced the flood risk in the city, but on the other hand, as Čamrová and Jílková (2006) pointed out, those may have lead to increases of flood risks in areas downstream the Vltava.

More in detail, the flood protection adaptation measures under consideration for the case study in the Vltava river basin are the following:

- **Increasing the safety of water works against overflowing.** This consists in the reconstruction and modification of existing water reservoirs. This measure is at present suggested for 346 water works. For 80 of these the cost has been already estimated, amounting to 5.3 B CZK in total.
- **Reconstruction and renewal** of polders, reservoirs and dykes, increasing the flow capacity of the channels of water courses. During the period 2007-2012, 10.5 B CZK have been allocated from public budgets to these measures.
- **Retention and restoration measures,** such as increasing the water retention ability of the landscape, creation of new retention areas along water courses, protection of the landscape against erosion. In 2006, 1.2 B CZK have been allocated to this scope from public budgets.
- **Water management measurements** centred on changing water runoffs in time, especially in the case of multifunctional reservoirs (accumulation, hydro-energy, flood protection or recreation) that imply adjustment of manipulation regulations.

Ongoing adaptation measures

The adaptation measures in water management in the Czech Republic that are relevant to counter flood are based either on reducing requirements from water resources, land use etc., or on compensating for water shortages. The adaptation measures related to flood risks include (CHMI et al., 2011):

- **measures in the landscape focusing on organisational approaches**, such as promoting widespread diversity within the framework of comprehensive land consolidation, promotion of afforestation and grassing, limiting the cultivation of crops below which an impermeable crust is formed (e.g. maize), agricultural approaches (cropping patterns supporting infiltration) and biotech approaches (contour furrows, drainage ditches etc.);

- **measures carried out on watercourses and floodplains focusing on watercourse revitalization**, such as modifications of riverbeds to slow down runoff and to improve communication with near-surface aquifers, removing obstructions on floodplains for floodwater flows;

- **measures in urban areas focused on improving rainwater infiltration** (retention and drainage facilities), collection and use of storm water;

- **renovation of old reservoirs or the establishment of new reservoirs**;

- **raising the efficiency of water resource management** (transfers of water between river basins and water supply systems, reverse transfers of water within basins, temporary use of static groundwater supplies, artificial recharge, multiple use of water, improvement and reallocation of the capacities of water resources);

- **reduction of water consumption** (minimising losses in water supply systems, rationalising the determination of minimum flows, setting priorities for critical water shortage situations).

At present, the priority is set on dry polders and water reservoirs - for example the new subsidy measure for the period 2014-2019 “Support for flood prevention III” (financed by Ministry of Agriculture) focuses particularly on increasing retention in river basins - if it is possible, with the use of newly installed accumulation areas in polders and water reservoirs. In existing water reservoirs, the subsidized measures are adjustments of control systems of the hydraulic structures.

The cost of the adaptation measures differs vastly from project to project. Adaptation measures are in most cases financed from the budget of the state, regions or municipalities, and are mostly subsidized on EU, state or regional level. That means, for almost all measures that have been implemented, that the total cost is known by the subsidy provider and the information on the budget is accessible and reported in the official documents that are produced by the main investors, which are the state enterprises Povodí and the municipalities. Larger projects are also subject to Environmental Impact Assessment (EIA) and the reports on the results of the EIA are publicly available at Czech Environmental Information Agency website (CENIA, 2014).

Overview of planned measures

All the flood protection measures that are planned within the area of the Czech Republic (mostly defined within the Plans of each river basin district) are based on a thorough planning procedure, which pays great attention to the climate change scenarios. The measures are designed after consideration of the climate change effects and are meant to cope with the predicted extremization of the hydrological cycle.

The plans of the Upper and Lower Vltava river basin districts include a Summary of flood control measures that are planned by the Povodí Vltavy or the municipalities in the districts, including the estimates of investment costs for each measure (Povodí Vltavy 2007a; 2007b). 130 measures are described for the Upper Vltava and another 42 measures are suggested for the Lower Vltava. Most of the measures are structural ones, such as dyke constructions around the streams in the river basin districts, or stream regulations, and the vast majority is designed for particular cities and villages around the streams. The plan of the Lower Vltava designs also specific measures in the priority area Štěchovice-Mělník that is defined in Czech National Flood Protection Strategy.

The overview of areas where these measures are proposed for both river basin districts is depicted in the following figures 1 and 2.

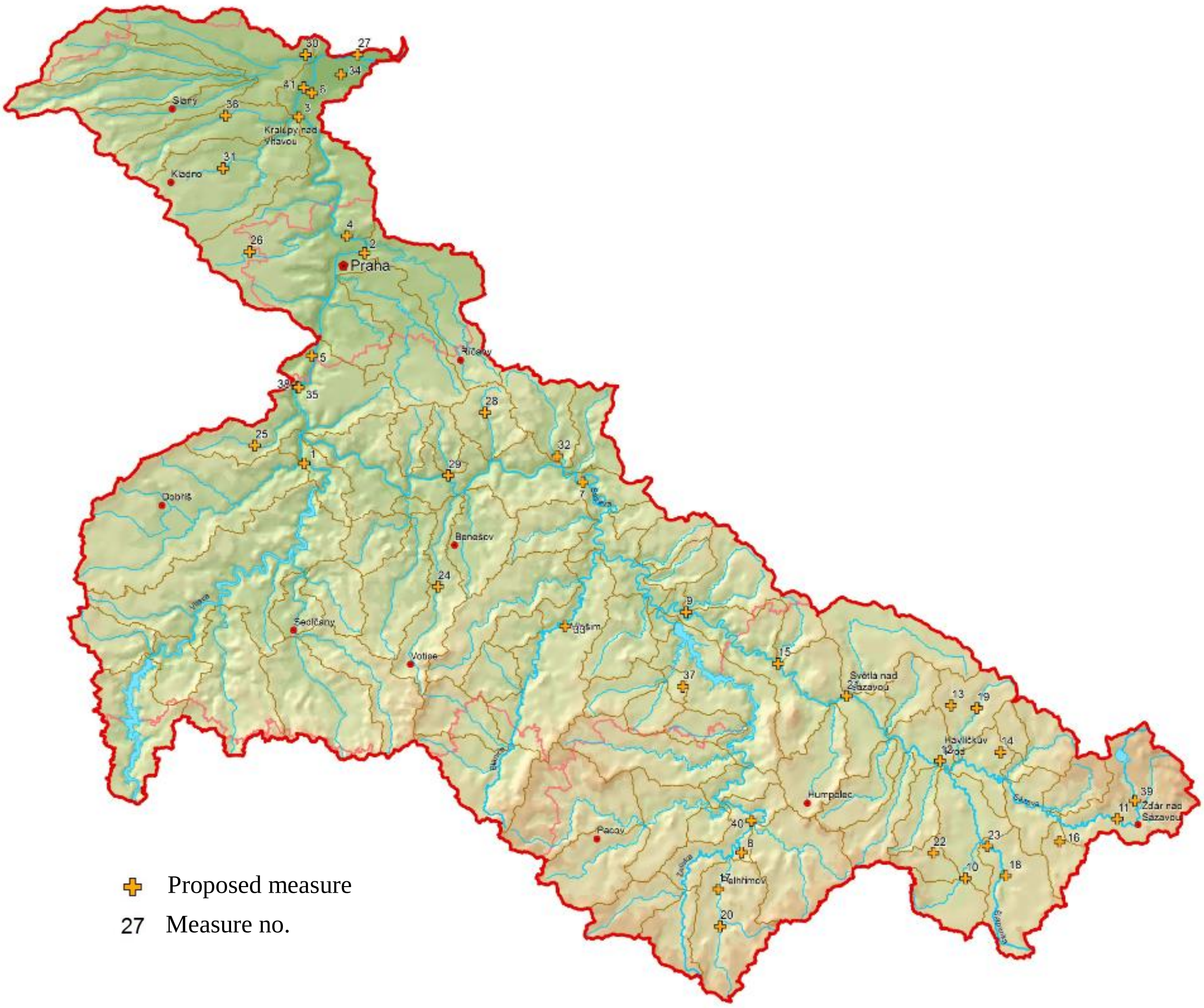

Figure 1: Overview of areas with proposed measures in the Upper Vltava river basin district. Source: Povodí Vltavy (2007a).

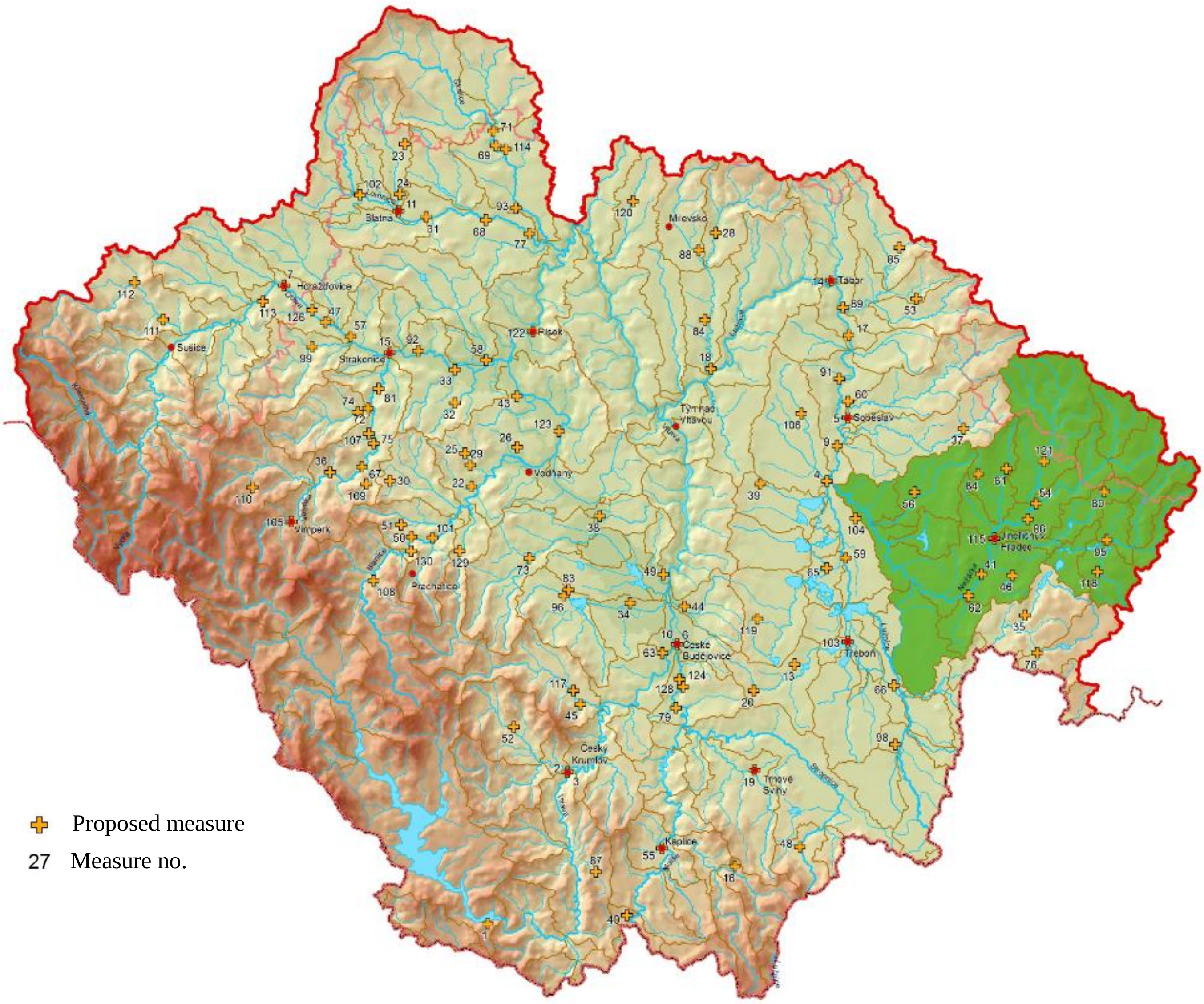

Figure 2: Overview of areas with proposed measures in the Lower Vltava river basin district. Source: Povodí Vltavy (2007a).

The following table 2 shows the measures that are to be applied in the stretch Štěchovice - Mělník (lower Vltava) by Povodí Vltavy, which is set as priority area in the Vltava river basin by the National Flood Protection Strategy. However, new actual planning documents are being prepared and it is likely that current policies will change considerably after new discussions on these documents (Flood risk management plans, actualisation of Plans of the river basin districts).

Table 2: Overview of measures proposed in the Plan of the Lower Vltava river basin districts, part Summary of flood control measures. Source: Povodí Vltavy, s. e. (2007b).

Measure	Type of measure	Proposer	Cost *(millions CZK)*	Finish date	Planned efficiency
Flood control in municipality Štěchovice	Damming of the stream, mobile barriers	Municipality	73.2	No	From Q_{10} to Q_{50} at Vltava river, from Q_{min} to Q_{20} river Kocába, decrease of area under flood risk by 7.5 ha
Vltava in Prague - increasing the capacity of the riverbed in the area of Rohanský island	Relief river branches	Povodí Vltavy, s. e.	1,043.0	No	*No information available*
Flood control in town Kralupy nad Vltavou	Adjustment of the stream, solid constructions (damming of the stream), mobile barriers	Town	190.0	No	From Q_{min} to Q_{20} river Vltava; decrease of area under flood risk by 57.3 ha
Flood control in Prague - Troja	Solid constructions (damming of the stream), mobile barriers	Povodí Vltavy, s. e.	455.0	Yes	From Q_{20} to $Q_{2002+30\ cm}$
Flood control in Prague - Zbraslav	Solid constructions (damming of the stream), mobile barriers	Povodí Vltavy, s. e.	208.2	No	From Q_{5-20} to $Q_{100+30\ cm}$
Flood control in municipality Veltrusy	Solid constructions (damming of the stream)	Municipality	30.5	Yes	From Q_5 to Q_{20}
Flood control in municipality Vrané nad Vltavou	Solid constructions (damming of the stream)	N/A	5.0	No	*No information available*

Another adaptation measure is set by the spatial development policy of the Czech Republic, which defines areas geologically and hydrologically suitable for accumulation of surface water. The set of protected areas is further specified in the General plan of surface water accumulation protected areas that is developed by the Ministry of Agriculture and the Ministry of Environment (2011). These areas are located without exception on smaller streams, none of which is planned directly on the Vltava River.

Apart from the measures stated above, also operational water management measures are applied. Recently, the most discussed operational measure in the Vltava river basin has been the increase of retention capacity of dykes by means of setting maximum water levels, to more efficiently transform (lower) high flood flow rates. This measure is set in each dam’s manipulation code. The latter is a set of rules on the operation and water management in the dam that is approved by the state or regional water authority, taking into account the opinion of river basin administrator. For example, in 2014 the operational water level on the Lipno water reservoir was decreased by 40 cm (Povodí Vltavy, 2014a); by the end of 2014, Povodí Vltavy changed the manipulation code also for the Orlík water reservoir, to permanently increase its retention capacity by 13%. For the assessment of other operational water management measures, the Czech Technical University is preparing a report for Povodí Vltavy that evaluates several variants of water management of the Vltava cascade and its effects on flood risks. Among the considered variants are lowering of water level in Orlík water reservoir, and also an extreme scenario of discharge of Orlík (Povodí Vltavy, 2014b).

Adaptation simulated in this study

Considering the adaptation measures that are most discussed to be applied by Czech stakeholders in the river basin area (see section 3.2.1), and accounting for the data available and the capabilities of the modelling techniques (see section 3.2.4), the present study will focus on flood hazard-limiting measures applied to water dams, such as:

- management of water level and accumulation capacity of the dam. This is defined as “Source control (upstream management)” in the catalogue of adaptation measures (section 2);
- improvement of dams, to reduce the risks of overflow and risks of dam failure. This is defined as “Improve and maintain waterways, dams, ponds” in the catalogue of adaptation measures.

The following section explains the datasets and methods with which the simulation of impacts and of the effect of adaptation is carried out.

3.2 Datasets and methods

Hazard data

All GIS maps on hydrologic situation of the Czech Republic and the study site created by the T. G. Masaryk Water Research Institute (TGM WRI) are freely downloadable at the DIBAVOD database (TGM WRI, 2014). This database contains relatively extensive hydrologic data. In contrast, the information on water ecosystems is relatively scarce, as confirmed by CGS and IH AS CR (2011). Basically, these data are available for the whole hydrologic units and not for specific ecosystems in the river basins.

The information on the value of assets that are subject to flood risk stems from national statistic surveys and evidence from insurance companies. Detailed geo-referenced data on the asset value are generally not available due to data protection concerns, but the aggregated data for territorial units are utilizable for analyses (Langhammer, 2007).

Detailed data from the census of the Czech Statistical Office “Counting of people, houses and flats”, which occurs every 10 years (the latest available data are from year 2011) are available on demand, and have been used in hedonic pricing analysis of the Prague housing market, for example by Kaprová (2014). However, these data only cover housing units and do not bear any information on the price of the properties - the information covered is mainly on the technical and structural characteristics of the house/flat.

For some areas in the Czech Republic, the Law on Property Pricing enables the local authorities to develop price maps of building sites that are approved through a generally binding regulation. In the study site, such a map exists only for Prague.

The other GIS information needed for the analysis (such as location of the municipalities, constructions, number of citizens in municipalities, location of transport infrastructure) is available from the Czech Office for Surveying, Mapping and Cadastre.

Also needed are data on basic climatological characteristics (air temperature, precipitation, humidity), which could be used as monthly averages.

Information on water use that is needed to assess the effect of adaptation measures on the household, industrial and agricultural use of Vltava surface water, is collected by Povodí, state enterprises in water management balances. The data are divided into three groups: withdrawal of surface water, withdrawal of underground water, and waste water discharge (including the volume and quality of discharged water). This information is collected only for larger withdrawals and discharges that exceed 6,000 m^3 per year or 500 m^3 per month.

Hazard simulation

Current hazards

The information on flood risk is available in the form of GIS maps of administratively-defined floodplain areas and active zones of floodplain areas. Also, based on the EU Flood Directive requirements, maps of flood danger and maps of flood risks have been created by Povodí state enterprises. For the study site, these maps are owned by Povodí Vltavy, s. e., and cover areas with substantial flood risk that have been identified in its territorial scope. The maps are available in the Central data warehouse, the owner of which is the Ministry of Environment (MoE, 2014).

The Czech Association of Insurance Companies (2014) runs the application “Flood maps”, which exists from year 2003 and whose main purpose is the identification of flood areas for the use of insurance companies. All member insurance companies employ this map to determine the flood risks for the setting of insurance price for property close to watercourses. The system of risk zones has been actualised in 2012 using the digital model of terrain NEXTMap Europe - Czech Republic belonging to the company Intermap Technologies, Inc. The new topologic-statistical model Risk zones of flood 2012 is included in the application and contains updated information on the river risk zones and risk zones of inundation from flash floods, both including water depth. The modelling of river/fluvial risk has been done in software Aquarius.NET by the company Intermap Technologies, Inc., and modelling of flash/pluvial flood risks in software Flowroute by the company Ambiental. All streams with a river basin at least of 10 km^2 (i.e., ca 30,000 river km) are mapped in this system (Ibid.). The information for specific locations is publicly available in the application on-line ; the underlying GIS map is not publicly available.

Future hazards

The focus in the estimation of future hazards is to simulate and relate spatially the potential losses, i.e., damage in each location. We will assess several flood return periods (10-, 100-, 1000-year).

To simulate the future hazards, the catastrophe risk management Integrated model (CRIM) is provided by the International Institute for Applied Systems Analysis (IIASA). CRIM combines a High-water Information System – Damage and Casualties Module (HIS-SSM) and stochastic quantile-based optimization procedures to generate flood losses and quantify robust insurance policies for flood-prone locations outside of the main flood defense system, i.e. outside dike rings. The model comprises four main GIS-based modules: hazard simulation, vulnerability estimation, a multi-agent accounting system, and decision-making stochastic optimization procedures. The model addresses the specifics of catastrophic risks: highly mutually dependent and spatially distributed endogenous risks, the lack of historical location-specific observations (unknown risks), the need for long-term perspectives and robust strategies, and the explicit treatment of spatial and temporal heterogeneities of the involved agents such as farmers, producers, households, local and central governments, land use planners, water authorities, insurers, and investors.

The physical data on the hazards will be related to corresponding “social” non-marketed benefits, e. g. for flood risk reduction or recreation value. This step is needed for the finalisation of the social cost-benefit analysis of the case study. The social benefits will be based on the benefit transfer technique.

Future scenarios

We have performed a survey on climate change scenarios available in the Czech Republic, which is presented in the text below. The scenarios on socio-economic trends will be acquired as input from ECONADAPT WP1.d and as such are not presented in the text.

Scenarios of climate change have been developed within the project "Assessment of the effect of climate change on the water budget, and proposed practical measures to mitigate its impacts" by climatologists lead by the CHMI (CHMI et al., 2012) using the regional climatic model ALADIN-CLIMATE/CZ for three time horizons: 2010-2039, 2040-2069 and 2070-2099, and for three emission scenarios (A2, A1B, B1). The model predicts basic climate variables such as air temperature, precipitation and relative humidity; the results suggest that climate change in Central Europe in terms of frequency increase of "100-year-like" flood events will be less than 10 %. The comparison of these predictions of climate change variables with other regional climate models is analyzed in Crhová et al. (2013).

Novický et al. (2007) from TGM WRI simulated the effects of climate change in years 2071-2100 on the whole Vltava river basin, using a static simulation model for water management balance with one-month step. The estimated climatic effects include significant increase and prolonging of periods with low runoffs. Yearly runoffs will decrease by 10-15%, and for the worst-case scenario by up to 40% (depending on the model and emission scenario employed). The suggested adaptation measures generally focus on increasing water accumulation in local dams.

Dankers et al. (2007) estimated future changes in flood hazard in Europe as a map of percentage changes in the flow rate Q100 to the horizon of year 2080. The study builds on preliminary results of PESETA EU project (Feyen et al., 2006), the main inputs into which were air temperature and precipitation, modelled by the HIRLAM model, and simulations of the outflow using the LISFLOOD model. The results show significant increase of probability of outflow at the Q100 level in all main European river basins.

The "National programme to abate the climate change impacts in the Czech Republic" of 2004 works with climate change scenarios that are outputs of two global circulation models: HadCM2 (Global circulation model of the atmosphere and ocean, developed at Hadley Centre, Bracknell) and ECHAM4 (Global circulation model of the atmosphere and ocean, developed at Max-Planck-Institut für Meteorologie, Hamburg). The projections extend to year 2050 and, through application of a hydrological model, indicate a decrease in average flow rates of 15 to 40% for the country. The projections are described in the following way: "higher temperatures in the winter months will lead to a reduction or disappearance of water supplies from snow and greater evaporation from the ground. This will further lead to a shift of elevated flow rates and addition to groundwater supplies from the spring to the end of winter and to a significant reduction in their amounts. Flow rates will mostly decrease as a consequence of greater evaporation from the ground from spring to autumn. Because of reduced flow rates and increased evaporation, water reservoirs will have reduced ability to provide for and balance withdrawals. Water courses with large accumulation areas in the form of groundwater stocks or artificial reservoirs are more resistant to the impacts of climate change. The danger of eutrophication of water courses increases with a decrease in flow rates and warming of the water. In connection with the increased variability of the distribution of precipitation and extreme weather events, there will be an increasing risk of floods and periods of drought.” (National programme to abate the climate change impacts in the Czech Republic, 2004, p. 33).

The Ministry of Environment stresses that predicted increased winter runoffs will lead to increased risk of spring floods, while intense precipitation that is projected to occur during summer will present a greater risk of flash floods even if the long-term total precipitation will not change much (MoE, 2009). Reduced creation of stocks of water from snow-cover and other consequences of changes in the climatic regime will substantially affect the size of the storage spaces in water reservoirs that will be necessary to preserve the existing levels of water withdrawal. These scenarios are not very favourable for energy generation either, both in terms of availability of water required for cooling in thermal power plants, and of required water levels in reservoirs for reliable hydro-energy production.

The most recently developed climate change scenarios for the Czech Republic (CHMI et al., 2012) show that there will be a hydrological imbalance in both the short- and long-term. An increase in temperature by approximately 1° C is expected in the short term, up to year 2039. That will lead to augmented potential evapotranspiration by 5-10 % as an annual average; the same increase (by 5-10 %) is expected in spring and summer. In winter, the increase in evapotranspiration will be the most significant (more than 20 %), which is the result of occurrence of more days with temperature above zero. In autumn, no increase in air temperature and no major changes in potential evapotranspiration are expected. The changes in potential evapotranspiration will be to a large degree offset by precipitation in most of the Czech Republic. South Bohemia, south of the study site, will however suffer from significant increase in autumn precipitation (by 20 %), while north of the study site, Central Bohemia is likely to see decreases in spring precipitation by 20 %.

In the medium-term outlook (years 2040-2069), the simulated warming is even more significant (in summer, the temperature will increase the most, by 2.7° C). In all areas of the Czech Republic and over the whole time period there will also be a decrease in relative humidity. The long-term outlook (years 2070-2099) will be characterised by decreases in summer and winter precipitation and increase in autumn precipitation.

Assessment methods

The impacts of climate change on floods, and the costs and benefits of flood protection adaptation measures in the Vltava river basin will be simulated using models that overarch hydrologic and economic aspects. The hydrological and economical impacts of potential adaptation measures will be assessed by the Catastrophic Risk Integrated Management model (CRIM; Ermoliev et al., 2013) (Fig. 3) and by a model for multi-user reservoir management under uncertainties (STO; Ermoliev et al., 2015) (Fig. 4). Both model are provided by the International Institute for Applied Systems Analysis (IIASA; www.iiasa.ac.at). The projection of climate data and flood risks in the case study area is performed with regional climate models (RCMs) and hydrologic models. Both models, CRIM and STO, also enable to evaluate and compare the deterministic scenario assessment with robust management based on stochastic optimization procedures using flood/precipitation scenarios (forecasts).

CRIM model

The CRIM model will be used and adjusted for the modelling and assessment of adaptation measures. Measures will correspond to physical and economic adaptation, mainly for flood protection (increasing the safety of water works, flood protection measures realized by municipalities, households).

The catastrophe model CRIM adjusted for the Vltava river basin study consists of four modules: the Hydrologic, Vulnerability, Multi-agent accounting system (MAAS) and the Variability modules (climate data are processed outside CRIM). The structure of modules and the flow of data is outlined in figure 3.

The Precipitation-runoff models elaborates meteorological forecast from Regional climate model, and topographic data to simulate hydrologic predictions in terms of total runoff volume, peak flow for each river segment and water inflows. The River hydraulic model based on water inflows from precipitation-runoff model and geo-physical data maps water released from the river into level of standing water, produces flood inundatin maps, floodplain depths and boundary.

The Vulnerability module translates spatial patterns of released water into economic losses. This module calculates direct losses and reflects the damages for a particular land use at a particular water level and flood wave speed. Location specific economic damages (losses) for the specified flood risk are estimated in the MAAS combining the data from the Hydrologic and Vulnerability modules. Specifically, the damage functions and categories for residential buildings, agriculture and natural areas are captured in the CRIM model. The MAAS module maps spatial economic losses into gains and losses of stakeholders. These stakeholders are the central government, a mandatory catastrophe insurance fund, an investor, and households.

The Variability module - a Monte Carlo model – transforms spatial scenarios of losses and gains among stakeholders into probability distributions. It derives histograms of direct losses at a given location or sub-basin (Ermoliev et al., 2013).

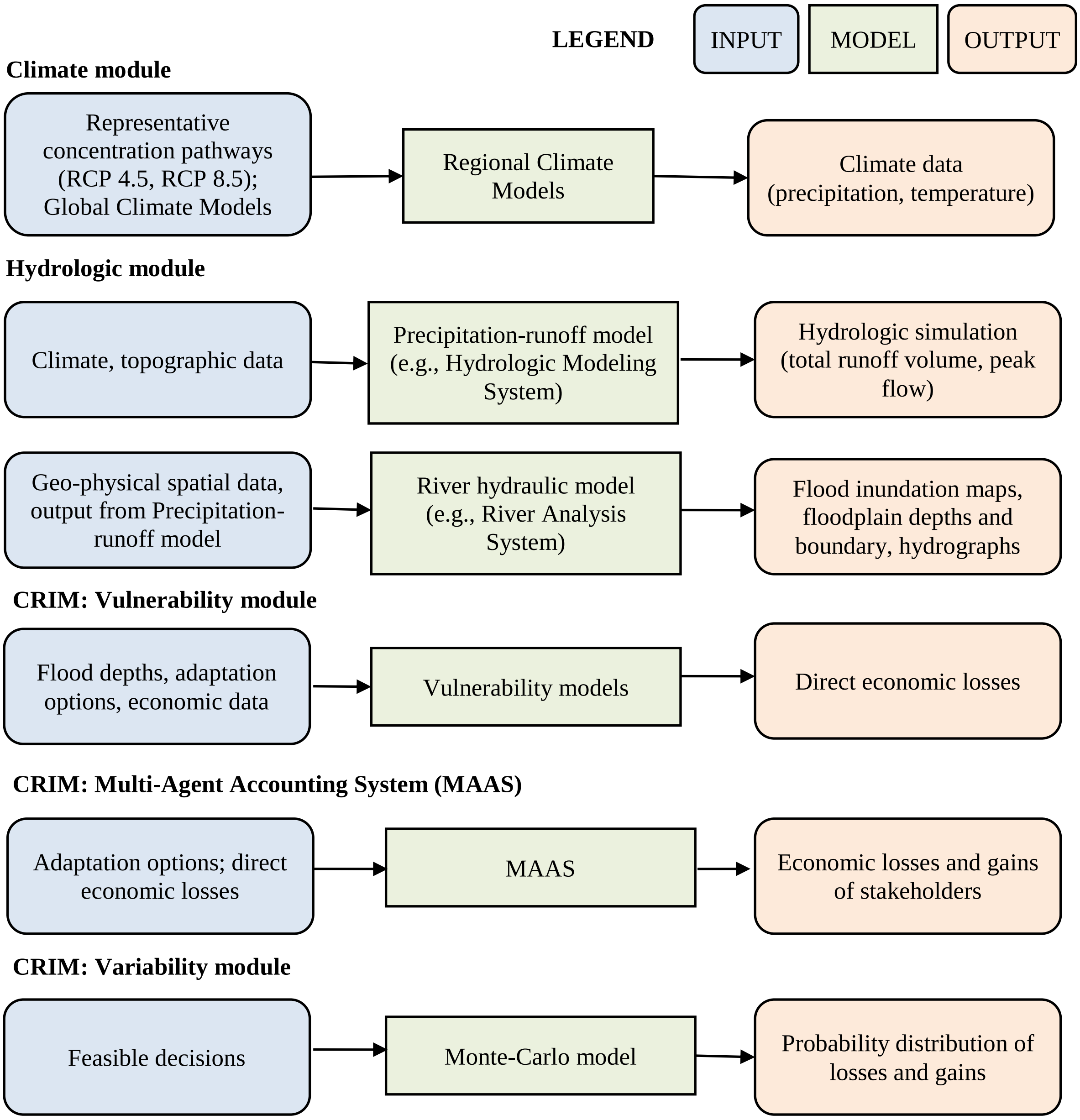

Figure 3: Diagram of modules and data flows of the catastrophe model. Source: adapted from Ermoliev, Ermolieva, Galambos (2013).

Regarding adaptation, the options that CRIM model enables to assess within the scope of the Vltava case study include:

- physical measures: reinforcing/upgrading of existing dams (decreasing probability of flood/dam's failure). Potentially deriving optimal scheme of investments into dams' reinforcement/maintenance;
- financial measures: creating / supporting initial catastrophe fund reserve (and/or subsidies to premium payments to the fund);
- operational measures: daily-scale choices on water management, to manage water levels.

STO model

The STO model for multi-user reservoir management under uncertainties will be used for the evaluation of the trade-offs – competitions – between different water functions of reservoirs which are part of Vltava cascade. Water management measures – such as changing of water runoffs in time and their economic impacts – and the competitiveness between different water requirements – reservoir storage, hydroenergy production, agriculture, flood protection and recreation deman - will potentially be investigated.

STO is a stochastic dynamic optimization model for controlling the water mass balances in the river basin influenced by the reservoir water management. The stochastic optimization technique enables including water requirements for: agriculture, hydroenergy production, flood protection, fishery production, recreation and water accumulation. The goal of the model is to achieve of a proposed water management regime under defined safety levels for each of the specified users. The structure of modules and data flows of the STO model is outlined in figure 4.

The climate and hydrologic modules consist of two main parts processed outside of STO: the precipitation forecast and the rainfall-runoff model. These parts form the meteorological and hydrological forecast. The precipitation forecast is based on the Regional climate model, which enables projection of global weather variables as temperature, precipitation, wind strength, evaporation, etc. Water inflow forecast will be based on rainfall-runoff modelling, which is part of the hydrologic module.

The stochastic optimization model is solved by fast linear programming methods and treats multiple-period reservoir operations as two-stage optimizations to obtain optimal solution. Reservoir discharges in this model are used as control variables. Additional objectives concerning physical characteristics of the reservoir – maximum and minimum storage and discharge – are also implemented in the model as control variables. The model selects several different criteria, or water requirements, for agricultural, energy production, flood protection, recreation and reservoir storage. The goal of the optimization is to achive robust solutions with a specified safety level for each of the specified users (Ermoliev et al., 2015).

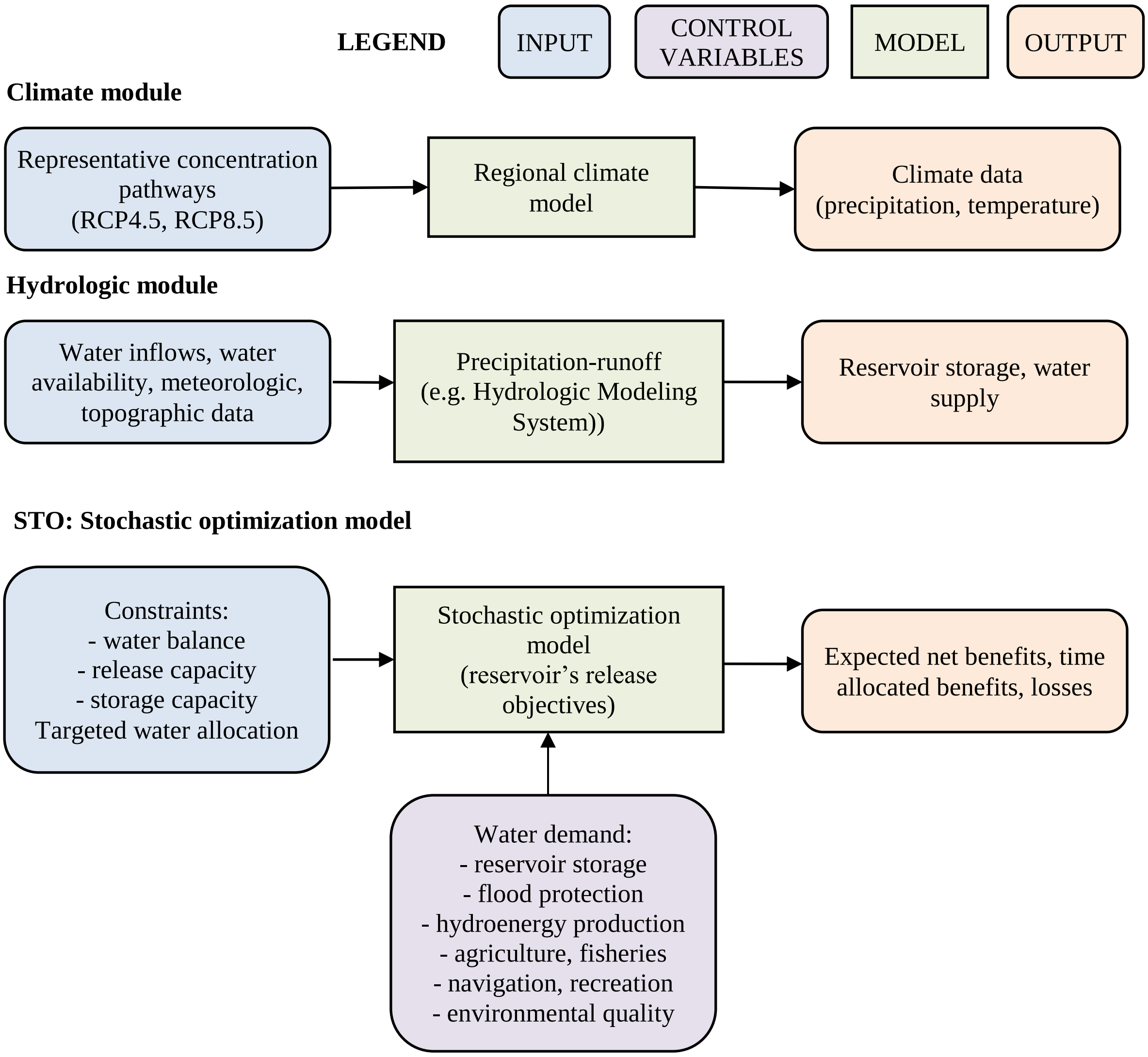

Figure 4: Diagram of modules and data flows of the multi-user reservoir management model (STO).

Climate change impacts will challenge water managers, so that flood protection might need to be be enhanced, depending on climate projections. Each user will therefore have its own adaptation possibilities and limits. Particularly, foreseen interdependent adaptation options that can be assessed by STO include, by economic sector:

1) agriculture: more irrigation; drought-proof cultivars;
2) hydropower: creating more water storage; switching to alternative energy sources;
3) drinking water: storage waters may be used for drinking purposes, which implies treatment of waters prior to their distribution.

4 Assessing adaptation costs and benefits - The Bilbao case study

This case study focuses on analysing, from an economic perspective and considering uncertainty, measures of adaptation to climate change-induced increased flood risk in the new urban development of the Zorrotzaurre district of Bilbao (Spain). From a climate change perspective, the new urban design needs to consider mainly the risk of river flooding, but the impacts of flood imply a great degree of uncertainty regarding their timing in the future, and their spatial extent.

4.1 Adaptation measures

As explained in section 2, many approaches to the classification of adaptation measures have been proposed, e.g., according to timing of implementation (anticipatory vs. reactive), the spatial and time scope (regional vs. local; short vs. long-term), the risk framework (protect vs. accommodate/retreat), purpose (hard vs. soft), the adapting entity (private vs. public) or the adapting mode (autonomous vs. planned).

Importantly, while climate change adaptation is thought to respond to future climate patterns, it is closely linked to disaster risk management, in that the two disciplines share similar characteristics and the common focus of reducing vulnerabilities and developing disaster-resilient communities in the face of current and future climate variability and extremes. As adaptation measures might serve disaster risk management and vice versa, it is crucial to link the two approaches, particularly to address the adaptation deficit.

The Flood Risk Management Plan (PGRI) is the main framework for disaster risk management for the Basque Country. Indeed, floods are considered as the most important climate hazard for the region. The plan elaborates prevention, protection, preparation and recovery activities, identifies high priority areas and potential interventions. While it is planned for the region, the PGRI impacts on the local level. The studied area of Zorrotzaurre represents a small district of the municipality of Bilbao. In this context, the Basque PGRI is a crucial building block for adaptation implementation, together with the Special Urban Plan of Zorrotzaurre developed and approved by the Bilbao city council. These two plans are the main source of information screened for relevant flood risk reduction measures, existing or planned, in Zorrotzaurre.

In the following sections, existing and planned flood risk reduction measures are first enumerated and classified according to the EEA adaptation characterisation (4.1.1; see section 2.1). Second, a quick analysis identifies opportunities in already existing adaptation options, and weaknesses that potentially lead to maladaptation (4.1.2). Third, some additional potentially relevant measures for flood risk reduction are suggested (4.1.3).

Existing and planned adaptation measures

Assuming that it is important to link disaster risk management and climate change adaptation policies and interventions, this section presents flood risk management activities that are either already deployed or planned within:

- the Flood Risk Management Plan of the Basque Autonomous Community (following section A), and
- the Urban plan of Zorrotzaurre (following section B).

Measures are classified according EEA as grey (hard measures implying infrastructural interventions), green (measures that integrate flood risk and natural resource management) and soft measures (management tools and policy instruments to incentivise adaptation) (EEA, 2013).

A. Adaptation in the Flood Risk Management Plan

The PGRI of the Basque Autonomous Community is the main framework for prevention, protection, preparation and recovery of flood events. It will impact flood risk reduction in Zorrotzaurre through normative developments, and via defined priority areas. Indeed, the Bilbao-Erandio priority area (Code ES17-BIZ-IBA-01) is one of the most flood-prone areas of the Basque Country. The PGRI project is currently being reviewed for approval as the last phase of the European Directive 2007/60/CE on regional implementation and will have a validity period of 6 years, from 2015 to 2021.

Measures range from infrastructural protection such as the projected deviation tunnel for river waters and defence wall in the city centre of Bilbao, for which implementation is not yet stated, to institutional measures such as risk mapping, improvement of early warning systems, land use regulation and raising the awareness of the civil society. Table 3 summarises the measures and gives details on their costs, benefits, responsible agents and possible opportunities and weaknesses. In the sections below, details of each measure are provided.

La Peña – Olabeaga tunnel and protection wall

A tunnel for flood water deviation that short-cuts the river loop within the Bilbao city centre had been on the table of decision makers for decades (Fig. 5). The tunnel is considered a project of general interest because, besides the great autonomy of the Basque Country, this specific project will be carried out and financed by the Spanish government. However, even if the tunnel is mentioned and budgeted in the Bilbao-Erandio priority area, its implementation should not be taken for granted. Yet, this investment, together with the opening of the Deusto channel, would represent a step forward regarding flood prevention in Bilbao and surrounding areas.

In addition, a 1 m high protection wall is planned in the city centre of Bilbao between Atxuri and the city hall, along the deviated river loop. It is supposed to complement the tunnel, consolidate the right river bank and protect the city centre, specifically the old part of Bilbao, increasing the protection to face 500-years return period floods. Together, the costs of these two infrastructural measures are estimated at 210 M EUR by 2027, overstretching through the PGRI's subsequent validity period. The tunnel implies a considerable bulk of this investment from the Spanish Ministry of the Environment (MAGRAMA) and the Basque Water Agency (URA).

Technical guidelines for construction norms

Within the urban spatial planning, prevention measures range from limiting urban development in flood-prone areas to encourage resistant construction criteria. For the period 2015-2021 the elaboration of technical guidelines for construction norms are being planned within the PGRI. These are supposed to diminish the vulnerability of exposed goods in flood areas. The costs of developing the guidelines are estimated at 70 thousand EUR.

Table 3. Adaptation measures in the Flood Management Plan of the Basque Autonomous Community, grouped into grey and soft measures.

	Measure	Proposer	Cost	Threats	Operational
Grey	La Peña-Olabeaga tunnel and protection wall	MAGRAMA/ URA	210M EUR 2021 and 2027;	Compression of waters at Olabeaga by Zorrotzaurre	No
Soft	Technical guidelines on construction norms	MAGRAMA	0.07M EUR		
	Knowledge improvement on risk	URA (with collaboration DAEM)	10M EUR	Implies infrastructural measures	Partly
	Hydrological conservation program	URA	3.5M EUR	Implies infrastructural measures	
	Norms for improved urban drainage systems	MAGRAMA (DGA) and URA	0.03M EUR		
	New hydrological control stations and modern forecast system	DAEM, URA	1M EUR		

Note: there are no identified green measures that have been affected financial resources to, for current PGRI project validity period.

Knowledge improvement on risk

Current flood risk management plans are developed on the basis of the actual state of knowledge about meteorological and hydrological phenomena. About 10M EUR are planned to be invested to improve knowledge including: update of available studies on flood frequencies and magnitudes, evaluation of risk and risk mapping, and the current FRM plan.

The current version of the Flood Risk Management Plan (PGRI 2015-2021), which is at this stage under public information, does not pay sufficient focus to the effects of climate change on flood risk. Nevertheless, we are currently working together with URA in providing them with the latest information on RCP scenarios, so they can use this inputs to estimate future flood risk under climate change. This new information is to be introduced in the final version of the Plan, before its approval in December 2015.

Figure 5. Plan of the tunnel that would deviate river waters from La Peña (upstream, south-east) to Olabeaga (downstream, north-west). Source: ARPSI, Proyecto PGRI 2015-2021.

Hydrological conservation program

Within the program for maintenance and conservation of river basins, relatively low cost interventions are undertaken to punctually prevent flood occurrences. These include small structural defences, clearing stream debris, improvement of river bank vegetation and intervention in the river bed. Within the current PGRI project, 3.5M EUR are budgeted for the development of the conservation plan.

Improved drainage systems

The increase of impermeable urban zones limits water infiltration and drainage. Interventions to face this problem usually range from integration of vegetative areas, permeable pavements and retention ponds. Within the PGRI, 30 thousand EUR are directed to sustainable urban drainage systems that reduce superficial water flows. Yet, it is not clear which locations and which particular intervention will benefit from the initiative.

Hydrological control stations and improved forecast system

The Basque Country has a well-established early warning system, based on continuous weather monitoring, estimation of flood intensities in various control points with 72 hours of anticipation and on three alert levels assigned according to the severity of flood estimations. Measures in the PGRI suggest the instalment of new weather control stations (0.5 M EUR) and the improvement of hydrological predictions using new models, improved algorithms for hydrodynamic simulation and potentially flooded areas (0.5 M EUR). It is not clear where control stations will be situated, yet we believe this measure will benefit the region as a whole.

B. Adaptation in the Special Urban Plan for Zorrotzaurre

The Special Urban Plan for Zorrotzaurre is the grounding stone of what will be a significant urban development for the Bilbao area. Because of its strategic location, it had already caught attention in the 50s when urban planners suggested the opening of the canal in order to develop industrial activities by facilitating harbour logistics. However, the canal had never been completely opened and the option was neglected for many years.

It is only with the new plan approved in 2007 and which started implementation in 2014 that this breach is being operationalised. To approve the project, the Management Commission of Zorrotzaurre needed to come up with a solution to reduce flood risks, to respond to URA's concerns about flooding in the area. This is when the initial plan to open the Deusto channel came back on the agenda.

Table 4. Adaptation measures in the Special Urban Plan for Zorrotzaurre.

Measure		Proposer	Operational
Grey	Deusto channel	URA Zorrotzaurre Management Commission	Yes
	Elevation of ground level	Zorrotzaurre Management Commission	No
	Permeable pavements		No
	Gravity based measures		No
	Two platforms leaving "room to the river"		No
Green	Rainwater harvesting /reuse	Zorrotzaurre Management Commission	No
	Tree plantation		No

Because of its history, and more so for its infrastructural implications, its flood prevention capacity and its engaged investments, the opening of the Deusto channel is the major adaptation measure of the Special Plan. In addition, other flood prevention measures are mainstreamed into the urban design of the future island. Table 4 above summarises measures identified as relevant for adaptation in the plan and a short detail of those is added below.

Opening of the Deusto Channel

The opening of the Deusto channel will turn Zorrotzaure into an island. The excavation already started and is planned to finish in 2016. It is estimated to significantly reduce flood risk not only on the island, but also in several other areas of Bilbao as it would increase the drainage capacity of the estuary. Available information on the intervention depict a 75 m wide opening, which would reduce the water level by an average of 0.87 m for the 500-years return period. In some areas (e.g. the Euskalduna bridge) the difference of the water level with or without the intervention could be as high as 1.43 m (SAITEC, 2007). Figure 6 shows how the flood-risk area would change with the opening of the Deusto channel.

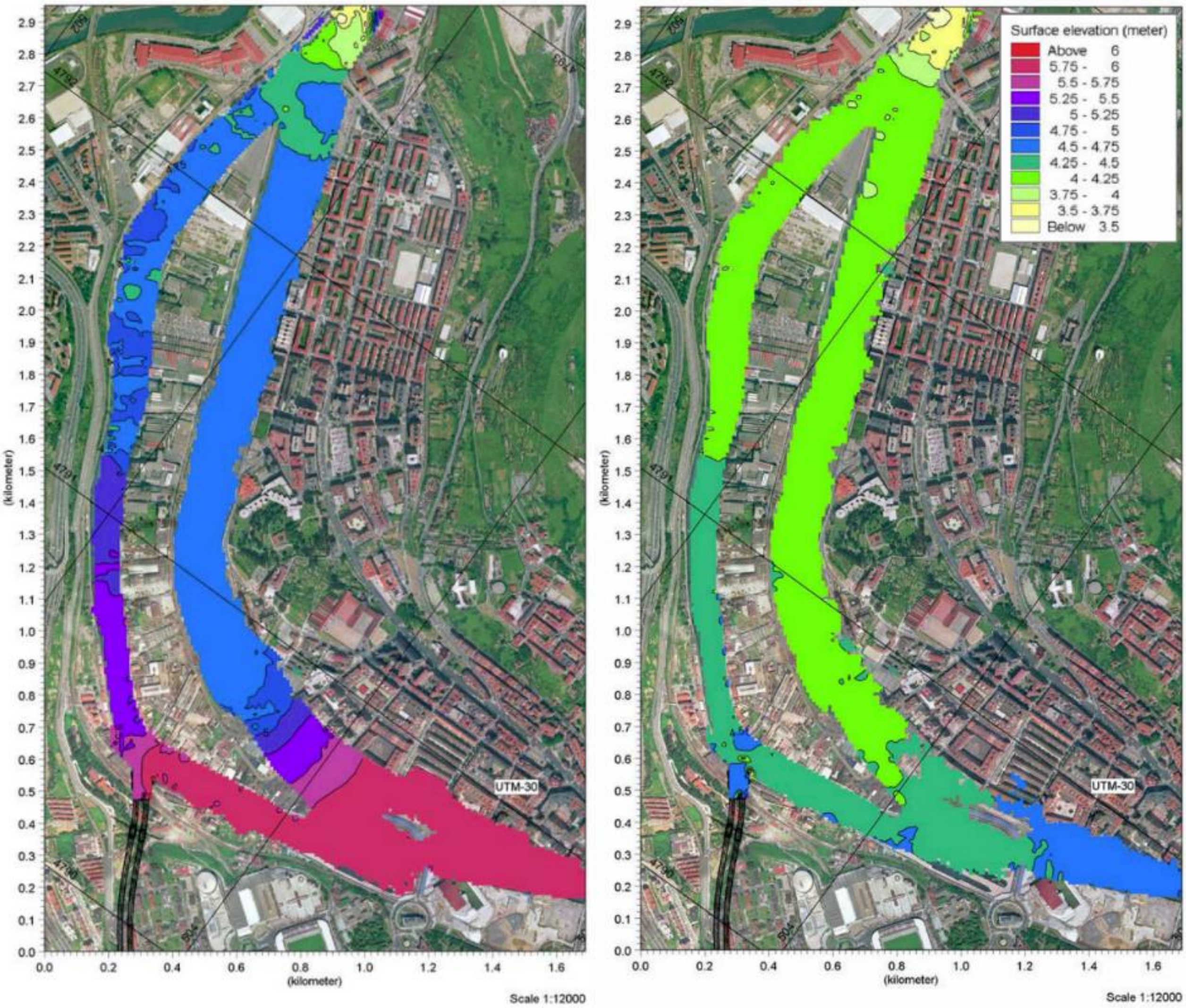

Figure 6 (previous page). Flood-risk area for the 500-years return period with the current Deusto Channel (left) and a 75 m wide opening of the Channel (right). Source: Saitec (2007).

The cost of this measure is estimated at 12.1 M EUR and it will be financed entirely by the Bilbao City Council. Benefits shall be significant, and Osés Eraso et al. (2012) estimated considerable annual damage reduction represented by a retraction of the damage-probability curve for Bilbao compared to the reference case (Fig. 7). For 100-years return period flood events, expected damages decrease by 67.4% (from 241.3 M EUR to 78.6 M EUR). The reduction for the most severe flood events (those with a 500-year return period) is lower, 30.7%, but still significant (from 444 M to 308 M EUR for the most conservative estimates). This analysis was carried out considering a 50 m width channel instead of the 75 m width finally adopted by the City Council, so the reduction of damages is expected to be even greater.

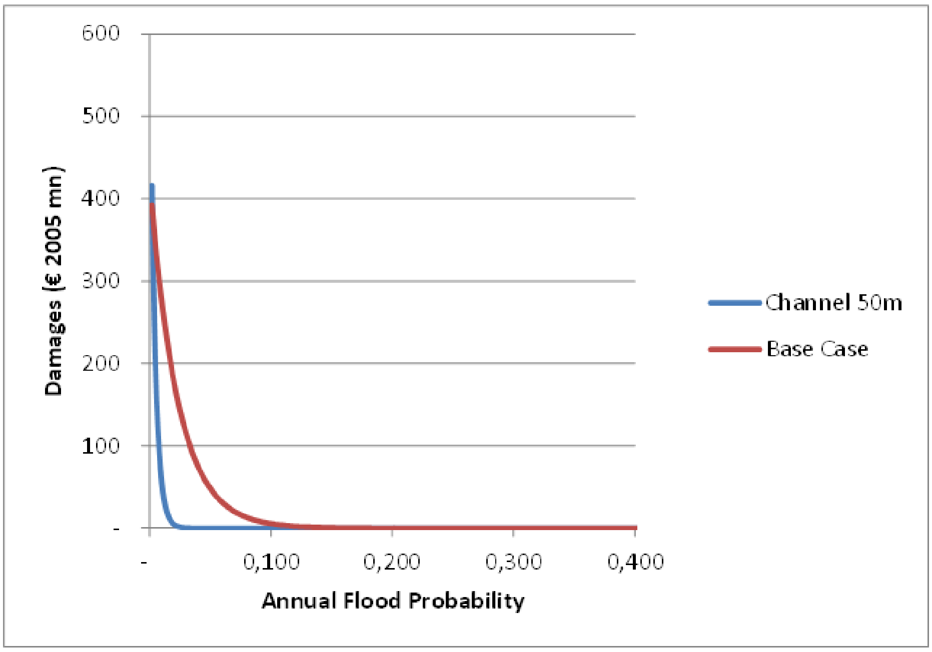

Figure 7. New damage-probability curve for Bilbao with the 50 m-wide opening of the Deusto Channel (blue), compared to the base case (red). Source: Osés Eraso et al. (2012).

Other measures

There are a number of other measures within the Special Urban Plan for Zorrotzaurrethat are directly or indirectly limiting superficial water flooding. Although less capital intensive, these measures imply considerable structural design and have true potential for draining flood waters. Firstly, the augmentation of the ground level from its current height up to 5 m above Alicante ordnance datum will elevate the island about 1.2 m from the current urban level. Secondly, a low platform is envisaged at 3.8 m height below the maximum 5 m. This will provide “room to the river” in case of flooding events while it will be a usable area under moderate climatic conditions. Thirdly, permeable pavements are planned. Together with tree plantation at a rate of 1 tree per 100 constructed m^2 (which totals about 5800 trees) this measure will enhance the infiltration of flood waters into the soils. Finally, measures for water harvesting for direct reuse or channelled towards green areas – possibly for irrigation – are envisaged. Yet, it is not clear whether these will be implemented.

Opportunities and weaknesses of existing adaptation measures

During the review of adaptation measures in the FRM plan of the Basque Autonomous Community and the special plan , we identified main tendencies as well as some potential bottlenecks in discrete adaptation initiatives.

General tendencies

Total costs of the measures that are both relevant to Zorrotzaurre and available, amount to about 237 M EUR. Out of this total, 200 M EUR are related to the tunnel which investment has remained improbable by now. Considering only 2015-2021 planned investments and according to our classification, around 40% of the investment is planned for soft measures (14 out of 37 M EUR). Notwithstanding, many “soft” measures imply structural transformation. For example elaboration of norms relate to construction or drainage systems. Thus, infrastructural protection measures remain the bulk of planned investments. This suggests the persistence of traditional trends towards structural protection despite a theoretical paradigm change for “living with floods” and integrated risk reduction approaches reconceptualising the interaction between society and environment (McLaughlin, 2011).

Within this context, it is worth mentioning that most measures relevant to Zorrotzaurre are protection interventions, if looked at through the lens of the disaster risk management cycle. While protection is relevant to anticipatory adaptation, it does less consider preventive and preparation action. It therefore might not be flexible enough to accommodate to extreme events under increasing uncertainty.

Specific adaptation measures and potential weaknesses

In the flood risk management plan of the Basque Autonomous Community

First, insurance policies play a relevant role not only in risk spreading among various bearers, but also for the sensitisation of the civil population to risks. In this sense it might be considered beyond simple insurance use or compensation, as it is by now in the FRM plan. As reiterated below under potential adaptation measures, insurance can be a potent preventive tool if properly designed (Ward et al., 2008).

Second, and without further technical knowledge, one of the water mouths of the tunnel is planned to be situated in front of the future Zorrotzaurre island which might put additional stress on the flood prone area. This suggests that in case of flooding, deviated water flows would be discharged on the left bank of Zorrotzaurre, which might put pressure on the island’s river bank defences.

Third, climate change effects are not yet included in estimation of flood risks. Neither is it included in the budget for the next PGRI validity periods. Yet, taking climate change and/or uncertainties of climate change into account within planning is crucial, especially when infrastructural works lock in huge financial resources in the long term. Currently, there is ongoing work together with URA to integrate climate change scenarios and variables into meteorological and hydrological models. These will be valuable inputs on the economic assessment to be carried out within this Work Package.

Finally and related to the above, the FRM only considers development of guidelines for cost benefit analysis. In reality, other complementary valuation methods exist that can help decision making for effective investment. The Real Option Analysis (ROA) developed in this study is one of them (see section on Assessment Methods).

In the Special Urban Plan for Zorrotzaurre

Although the opening of the canal and the elevation of the ground level is estimated to drastically reduce damages by up to 60% relative to the no channel case, sea level rise is a missing variable that might mitigate this benefit. The integration of sea-level rise with hydrological and economic models is still to be specified.

Also, by elevating the future island by more than 1 m above current ground levels the project responds to a flood protection concern by elevating the inundation quota. However, existing houses and buildings conserved as historical heritage sites remain vulnerable at current levels.

The waste management infrastructure and parking lots below ground as well as ground floor commercial activities might be at risk too. In the special urban plan the building design is planned in H shapes, while technical guidelines suggest square ground buildings are more resistant to flood waters (URA, 2015).

The elaboration of vulnerability assessments are desirable to build better, and still remains a priority for the future urban area.

Finally, and reaching beyond the purpose of this analysis, it may be of interest to note that in such an important urban transformation, planners might be keen on proofing a much wider panorama of impacts and interactions, such as for example potential wind dynamics that might change with the height of new skyscrapers.

Potential adaptation measures

Within the disaster risk management / climate change adaptation community there is a global recognition of the need to shift from protection towards accommodation to extreme events under highly uncertain contexts, especially as many countries are already innovating: “living with waters” in Hamburg, participative approaches for adaptation to floods in Riga (Schmidt-Thomé and Klein, 2013) and Netherland’s showcase for adaptation to floods. Recent extreme events also motivated the emergence of creative initiatives such as the “rebuild by design” competition on the aftermath of 2012 super storm Sandy in the USA[2].

In the context of Zorrotzaurre, planned interventions can be redesigned for more resilience to extreme events and uncertainties. In addition, new adaptation measures are suggested referring where possible to what is done in other parts of the world facing similar hazards. Table 5 shows a classification of these measures. As they will closely interact, it is probable

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[2] See further information at www.rebuildbydesign.org

that a judicious combination of all might provide more adequate adaptation. Adaptation options for the Bilbao area and Zorrotzaurre are also analysed under the RAMSES project (Landa Mendez, 2014).

Table 5. New potential adaptation measures for Zorrotzaurre

Grey measures	Green measures	Soft measures
Room to the river platform	Green roofs	Risk based insurance and PPP
Water squares	Rain gardens	Volunteering FRM committees
Elevated housing for basic services	Green facades	Evacuation plans
Parking lots flood proofed and/or used as temporary water tanks		Social and health support systems
Storm tanks		IT initiatives
Dry-flood and wet-proofing buildings		Adaptation support programme
Design for flood resistant building		Zorrotzaurre Vulnerability Assessment
		Emergency assessments

A. Soft measures

As structural measures are already the focus of flood protection in Zorrotzaurre, we would like to focus on soft actions that we consider more flexible and important to raise awareness among the general population, incentivise adaptation, reconsider social vulnerabilities and build capacity of potentially affected communities and reshape the interactions between communities and natural hazards.

Risk based insurance and PPP

Insurance policies play a relevant role not only in risk spreading among various bearers, but also to raise awareness in the civil population about risks associated with climate change and extremes. This has also various benefits in terms of avoided damages both material and psychological. In this sense, insurance use has additional use beyond compensation, as it is by now in the FRM plan. Insurance can be a potent preventive tool if properly designed, i.e., developing flood risk based insurance policies and public private partnerships to incentivise autonomous adaptation (Ward et al., 2008).

FRM committees

It is recognised that the intensity with which disasters affect communities depends on their exposure and vulnerabilities. Potential impact depend not only on spatial but also on social vulnerabilities and access to knowledge (Koks et al., 2015). While citizen association have been successful in responding to disasters in developing countries such as South America, we think FRM committees could be equally beneficial in the case of Zorrotzaurre: such structures will be able to tailor responses to local needs and knowledge and promote local participation and awareness raising. They could also act as an intermediate between municipal or regional governance levels and local neighbourhoods for example in informing flood alerts, through radios or phone applications and other IT initiatives. They would be able to promote systems for social supports both ahead of extreme events such as family flood plans and during the recovery process (WHO, 2002).

Environment and climate in school curricula

The introduction of environment and climate related lectures within the school curricula would raise awareness amongst children from the youngest age not only of the need to protect the environment, but also of how to live more harmoniously with nature and natural hazards.

Vulnerability Assessment, Evacuation and Recovery plans

The vulnerability assessment (VA) of Zorrotzaurre is desirable as it identifies potential damages, population at risk and propose adequate responses. Outcomes of the VA would also facilitate the definition of evacuation and recovery plans for Zorrotzaurre, though we recommend the elaboration of specific evacuation and recovery plans at building level, especially for schools, houses for elderly and medical centres.

B. Green Measures

Green roofs, rain gardens and green façades

Beyond capturing rainwaters avoiding additional superficial flooding, green roofs, rain gardens, urban gardens and green façades represent also win-win options as they usually generate co-benefits in terms of heat mitigation, recreational, environmental as well as esthetical values.

C. Grey Measures

Room for the river, water squares and flood proofing

The lower lying platform of the right river bank is expected to leave more room for the river in case of flooding. Its level could be fixed at minimum possible height to maximise the space to river floods and the pressure on other structural defences. It could also be further exploited by integrating water ponds and squares, combining outdoor activity area with temporary water harvesting facilities. The potential of making room for the river could be further developed by taking advantage of the different levels that will coexist in the island. This option would require water-proofing existing buildings, by combining flood-proof designs and technologies, for instance dry flood proof and wet proof systems (Rotterdam Climate Initiative, 2013).

Parking lots and storm tanks

Storm tanks are not mentioned in the special plan of Zorrotzaurre, however they are suggested in this research in order to avoid additional risk due to the height difference between existing buildings and the new urbanised areas (Otaola, 2014). We suggest to take advantage of below ground parking lots planned in the urban plan to either dry flood proof them and/or to flood proof and turn them into temporary water tanks.

Elevated housing and design for resistant buildings

Elevated housing has been a strategy to cope with floods around the world both in developed and developing countries. Together with the necessity of protecting basic services such as provision of medical healthcare, electricity/energy, access to schools, buildings elevated on pylons might be a valuable option for Zorrotzaurre. The totality of buildings could be concerned; alternatively the measure could focus on basic infrastructures that should not fail during flood events. In addition to preserving assets and favor normal conditions of work during floods, elevated houses can also serve as shelter during sever events.

Also, while Zorrotzaurre plans H shaped buildings, it could be interesting to consider square based edifices that appear to be more flood resistant (URA, 2015).

4.2 Datasets and methods

Hazard data

The Basque Water Agency (URA), in the context of the European Floods Directive 2007/60/CE, has conducted a study to determine and map more than 400 risk areas in the Atlantic area of the Basque Country, amongst which Bilbao is one of the main risk points (URA, 2013).

In this process of adapting to the requirements of the EU Floods Directive, URA updated the flood risk maps for 10-, 100- and 500-year return periods (Fig. 8). An approximation to *exposure* has also been developed based on the following factors: population, economic activity, and areas of environmental interest potentially affected. Table 6 summarises the main information sources. This analysis has included estimates of potential annual economic damages for each flood-risk area (URA, 2013). This information on flooding is public and available in different formats (reference documents, applicable legislation, datasets and GIS maps) on the webpage of URA.

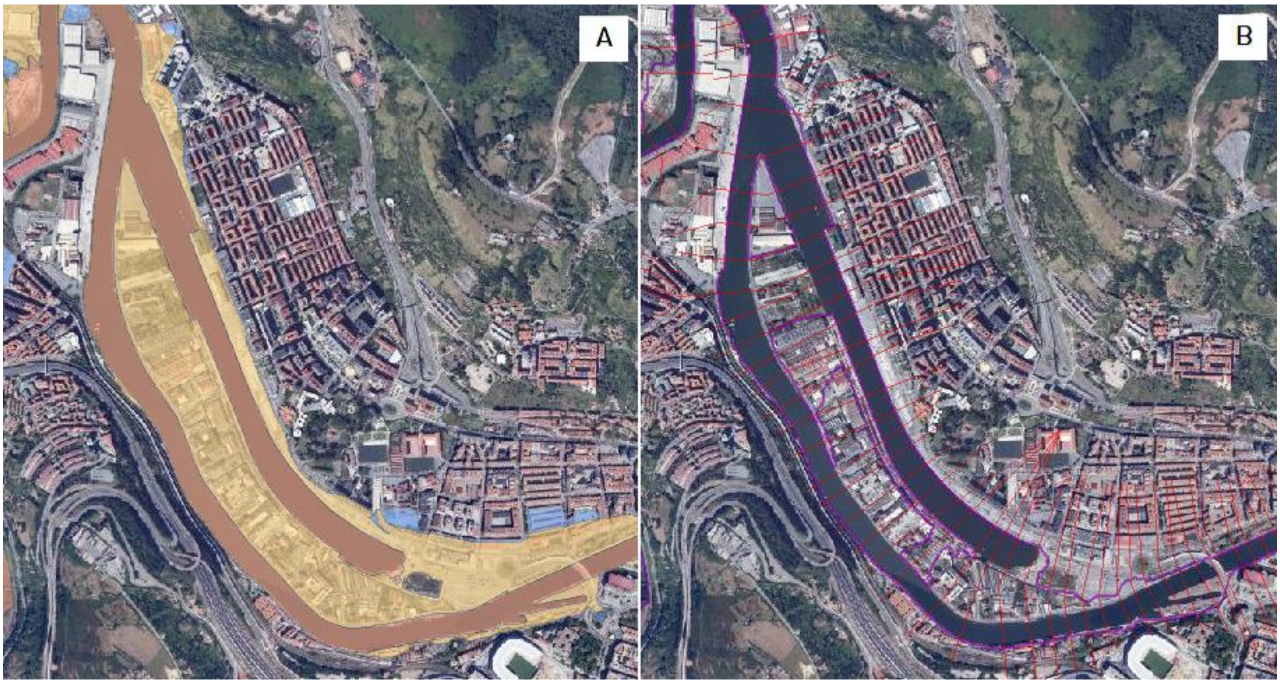

Figure 8. A. Flood risk map of Zorrotzaurre. The yellow area represents the area at risk of the 100-year return period flood. Blue areas represent the additional areas at risk of a 500-year return period flood event. B. Profiles of the depths of water, available under different return periods. Source: Basque Water Agency - URA (2013).

The Basque Institute of Statistics (EUSTAT) offers a wide range of services to access municipal indicators. Two are the sources we have used in this case study. The first is Udalmap, a web-accesible platform that combines geographical information with historic data series for several sustainability indicators and urban planning. The second tool is KALEGIS, a territorial information system through which economic activities at risk can be identified. Table 6 lists the information that has been derived from each platform.

Further, the Special Urban Plan for Zorrotzaurre (2012) includes detailed information of the urban design of Zorrotzaurre and it has been especially relevant for the identification of planned, as well as additional adaptation measures.

Future scenarios

In 2012 the Spanish Ministry of Environment published a report about the impacts of climate change on water resources (CEDEX, 2012). The study found a general reduction in precipitation in Spain, a decline in evapotranspiration and a decrease in runoff, but with is significant regional variability. However, differences among the results of various models are also significant, and the results cannot therefore be consider conclusive.

Regional (sub-national) scale climatic models[3] suggest a 14% increase of extreme precipitation in the Basque Autonomous Community from 2001 to 2050. In the upper Ibaizabal River, Mendizabal et al. (2010) estimated an increase in peak flow for the 50 year

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[3] Climate data from ENSEMBLES project, for emission scenario A1B with a horizontal resolution of 25x25km. Data were calibrated with measurements from local stations (Basque Government, 2011).

return period, but there are no specific data for the impact that these changes could have on Bilbao.

Table 6. Summary of information used in the Bilbao case study.

Data		Description	Scale	Available information
Flood risk data				
Hazard	Flood risk	Areas at risk of flooding for return periods 10, 100 and 500 have been identified by the BWA. Flood depth maps and profiles are also public.	Local	- Flood risk maps: publicly available at the Water Information System webpage: www.uragentzia.euskadi.net/appcont/gisura/
Exposure[1]	Population	BWA has identified the population (in terms of population density in each potentially affected area), economic activities and protected areas at risk	Local	- Reference documents: www.uragentzia.euskadi.eus/mapas-de-peligrosidad-y-riesgo/demarcacion-cantabrico-oriental/u81-0003421/es/ - Cartographic information: www.uragentzia.euskadi.net/appcont/gisura/
	Economic activities			
	Protected areas			
Additional data				
Municipal Statistics		The Basque Statistics Institute provides several tools to acces information at the municipal level.	Local	- Municipal indicators available at Eustat - Kalegis, local registry of land and economic activities
Land planning		The Basque Government (BG)offers detailed information on the land planning at different scales: regional, county and local levels.	Regional to local	- Basque Government: www.ingurumena.ejgv.euskadi.eus/r49-578/es/ - Cartographic information: www.geoeuskadi.eus
Urban planning		The detailed urban information on Bilbao and the new development in Zorrotzaurre is also publicly available.	Local	- Bilbao: www.udalmap.es - Zorrotzaurre: www.zorrotzaurre.com
Climate information		Available from the Basque and Spanish Metheorologic Agencies	Regional (Subnational)	- Euskalmet: www.euskalmet.eus - AEMET: www.aemet.es

[1] This information is currently available only for the Atlantic area of the Basque Country. The Meditarrean area is managed in coordination between the BWA and the Ebro Basin Confederation (Spanish Ministry of Environment).

With the aim of producing the most reliable and updated output for our study, we decided to make use of climate forcing data from the downscaling of a suite of state-of-the-art Regional Climate Models, and we are working with URA (see upcoming Deliverable 6.3) towards the definition of flood hazard probabilities under the new IPCC emission scenarios, RCPs 4.5 and 8.5 (Moss et al., 2010).

Flood risk and associated economic impacts

The Basque Country is an area with a long history of flood events (see Deliverable 6.1). However, most of the studies carried out so far have focused on the hydrological component and only very recently, during the last decade, economic assessments have been performed (Osés Eraso, 2009; Galarraga et al., 2011).

In the case of Bilbao, two reference studies assessed the costs of river flooding. The first was produced by the Basque Government in 2007, coinciding with the drafting of the Basque Plan to Combat Climate Change 2008-2012 (Basque Government, 2007). In this study a methodology to estimate the costs of climate change impacts in the Basque Country was developed and applied to the city of Bilbao. The methodology follows two steps: in the first step, the impacts of flooding in Bilbao were identified and quantified in terms of physical damage. Damages were measured for three different return periods (10, 100 and 500 years) and according to three scenarios: *baseline*, *reference* scenario (future, accounting for socioeconomic development but without climate change) and *climate change* scenario. In the second step, the physical units at risk previously identified were translated into monetary units. For doing so, information from reference studies from the United Kingdom was adapted and transferred to the socio-economic characteristics of the Basque Country. The results from this two-step process were used to build a loss-damage curve for Bilbao, which shows the relationship between flood risk probability and associated economic impacts. To estimate damages under climate change, the loss-damage curve was projected considering population growth (0.2% annually) and increase in the number of households (also 0.2% annually). This projected curve was then recalculated based on estimated climate change impacts. However, there were no downscaled estimates of changes in flood risk for the Basque Country, so the Basque Government followed the approach previously defined by Evans et al. (2004) for the UK. This way, an increase in precipitation of 25 mm per month (Moreno et al., 2005) is assumed to have a direct proportional impact on flood risk. In the case of Bilbao, a multiplier of 1.25 was used to estimate the new loss-damage curve under climate change. Table 7 summarises the economic impacts obtained in this study. The annual average damage costs on the *baseline* scenario range between 225 and 275 millions of (2005) euros. For the *reference* scenario, the increase on the number of household and its associated population growth increment annual damage costs by 2.05% and 2.24%, respectively. Finally, in the *climate change* scenario annual costs would rise by 56%.

Table 7. Estimated total flood damages for the city of Bilbao. Costs are expressed in millions of euros (2005) per event (Basque Government, 2007).

Scenario	***Annual average damage costs (M€$_{2005}$)***	
	Low	**High**
Baseline	225	275
Reference scenario (2080)	229	281
Climate change scenario (2080)	359	440

Using the results from the study of the Basque Government for the current climate as a baseline scenario, Osés Eraso et al. (2012) estimated the economic benefits of the opening of the Deusto channel in terms of avoided damages. These authors found out that damages decrease by 67% and 31% for 100- and 500-years return period flood events, respectively. Further details have been provided in Section 4.1.1.A.

Nevertheless, we should stress the fact that, due to the lack of data, the approach taken in those studies was quite simplistic and therefore their results should be interpreted carefully. The work that is being carried out within ECONADAPT, including the development of new climate change and flood risk scenarios, represents a significant contribution both in the academic and the policy arena.

Assessment methods

When planning a new urban development in a flood prone area, uncertainty becomes a major issue, mainly due to the difficulty to quantify future climate impacts. In this context, cost-benefit analysis is not the most appropriate methodology to deal with uncertainty and other approaches are recommended, particularly robustness based approaches (Markandya, 2014).

From the methodological perspective, a robust analysis has three components (Markandya, 2014):

1. The first component consists on assessing the **robustness** of measures. Measures are defined robust when they are effective in a wide range of future scenarios. Typically, **low- and no-regret measures** grant robustness in situations of uncertainty about the future. However, some of these measures that are able to cope with a wide variety of scenarios can be too costly; others, such as early warning systems, while being cheaper, will not be enough to cope with some extreme situations, for example, the 500 years return period floods, and will likely not prevent all damage in the event of any flood.

2. The second component relates to **flexibility** in decision making. In this case, low- and no-regret options could be decided at the short term, waiting for more and better information or technologies to implement the most costly policies.

3. Finally, the third component analyses the **adaptability** of options in response to future information or needs. For example, building a dyke with foundations strong enough for a 2 m-high wall, that could be built in the future. In this last case **real options analysis** (ROA) can be applied.

Building robustness of adaptation measures: real options analysis

As previously stated, ROA can contribute to robustness offering flexibility in adaptation measures. There are many situations in which this can be very useful. A simple example would be a coastal area that can be protected against sea level rise by building a dyke of 1 meter high now or a 1 meter dyke with stronger foundations that allows raising the wall up to 2 or 3 meters should it becomes necessary (see Box 1).

Real options evolve from the financial economics and are meant to deal with future uncertainties of a project’s implementation (Zeng and Zhang, 2011). The concept of real option is relatively easy to understand, this is, when an investment decision is made, the entity doing it can obtain a right that can be used to buy or sell a physical asset or investment plan in the future (Myers, 1977).

In the context of adaptation economics, it can be said that Real Options Analysis quantifies the investment risk associated with uncertain future outcomes, being very useful when considering the value of flexibility of investments (Watkiss and Hunt, 2013). “This includes the flexibility over the timing of the capital investment, but also the flexibility to adjust the investment as it progresses over time, i.e. allowing a project to adapt, expand or scale-back in response to unfolding events. The approach can therefore assess whether it is better to invest now or to wait – or whether it is better to invest in options that offer greater flexibility in the future.” (Watkiss and Hunt, 2013).

This investment analysis tool has been gaining a lot of interest in the framework of adaptation economics as it “aligns with the concepts of iterative adaptive (risk) management, providing a means to undertake economic appraisal of future option values the value of information and learning, and the value of flexibility, under conditions of uncertainty. It can therefore justify options (or decisions) that would not be taken forward under a conventional economic analysis” (Watkiss and Hunt, 2013).

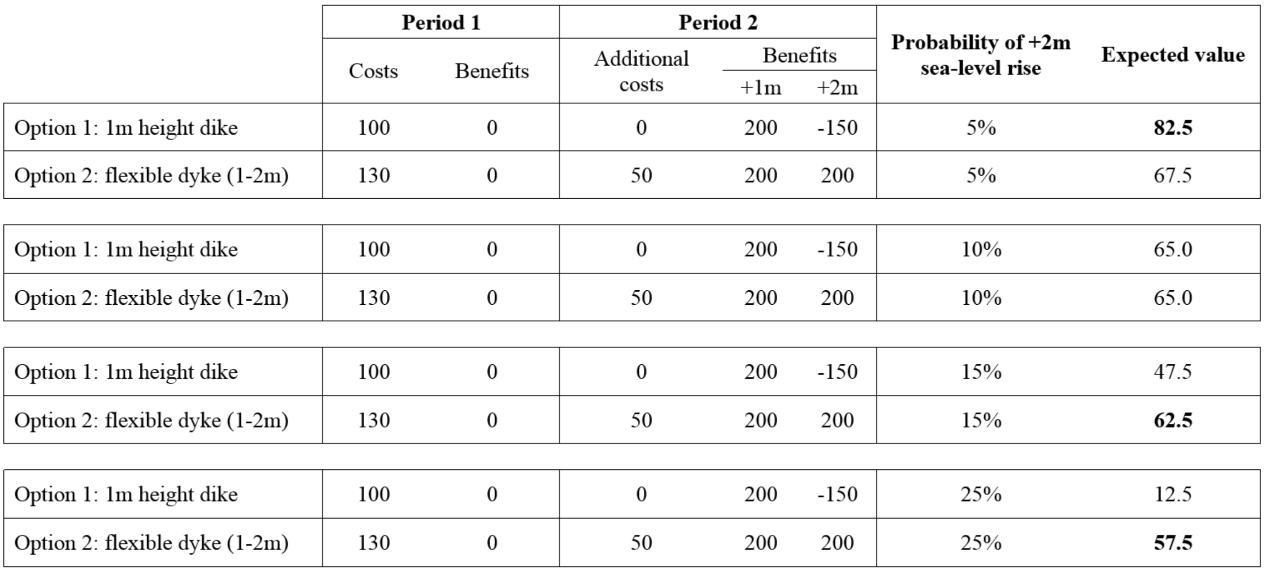
Relatively few applications exist for adaptation alternatives or investment projects. One of the exceptions is Kontogianni et al. (2014) where the alternatives to protect the Greek coast from sea level rise are analysed. The authors conclude that the analysis “through recognizing the uncertainty and keeping all the options open till uncertainty is resolved, provides an adaptation strategy that may be beneficial […] for the society”. Another interesting example can be found in Jeuland and Whittington (2013) with an application to water resource planning in Ethiopia for the construction of several large dams and operating strategy accounting for uncertainties due to climate change. And a third example is the work by Woodward et al. (2011) for flood risk management in the Thames Estuary. The authors conclude that “the results obtained demonstrate the potential for substantial cost savings under future uncertainties when Real Options are used instead of more traditional, precautionary approaches”.

BOX 1. Applying real options analysis: an example

Markandya (2014) describes an example of the application of ROA to a context of sea-level rise. The analysis is carried out considering two adaptation options to protect a coastal area. The first options consists on building a 1 m-high seawall; the second is building a more expensive flexible wall whose height would initially be of 1 m, but which can be increased to 2 m because of its stronger foundations (Table 8).

In the following table 8, column Period 1 represents the baseline, i.e. the present time when the sea wall is to be constructed. In this period, Option 1 incurs in fewer costs and both options represent no benefits. Period 2 represents the future under climate change, with two hypothetic scenarios where sea level rises by either 1 or 2 m. In the first case, sea level rises 1 m and both options provide benefits (200 units), but Option 1 at a lower initial cost. In the second case, when sea-level rise reaches 2 m, then Option 1 would imply losses of 150 while Option 2 would have benefits of 200 with an additional cost of 50.

Table 8. Example of a real options analysis from Markandya (2014). Costs and benefits are expressed as dimensionless quantities.



	Period 1		Period 2			Probability of +2m sea-level rise	Expected value
	Costs	Benefits	Additional costs	Benefits			
				+1m	+2m		
Option 1: 1m height dike	100	0	0	200	-150	5%	**82.5**
Option 2: flexible dyke (1-2m)	130	0	50	200	200	5%	67.5
Option 1: 1m height dike	100	0	0	200	-150	10%	65.0
Option 2: flexible dyke (1-2m)	130	0	50	200	200	10%	65.0
Option 1: 1m height dike	100	0	0	200	-150	15%	47.5
Option 2: flexible dyke (1-2m)	130	0	50	200	200	15%	**62.5**
Option 1: 1m height dike	100	0	0	200	-150	25%	12.5
Option 2: flexible dyke (1-2m)	130	0	50	200	200	25%	**57.5**

However, the key issue is that applying ROA allows us to contemplate the possibility of sea levels rising by 2 m. If the probability of this higher rise is 5%, the expected value of Option 1 is greater, but for higher probabilities of sea levels rising by 2 m, the expected value of Option 2 grows in relation to Option 1. In fact, for probabilities equal or greater than 15% the expected value of Option 2 is greater.

Zorrotzaurre: an integrated assessment of flood-risk under climate change

The analysis that is being carried out in Zorrotzaurre is developed based on information generated in different steps that span the assessment process, as summarized in Figure 5. Thus, the starting point are several climatic variables, that are currently being estimated for scenarios RCP 4.5 and 8.5. The results from this first process will then be introduced into a downscaled meteorological model that will provide probabilistic peak flows. The new data will serve as input of the hydrologic model run by URA, that will estimate the changes in flood risk in Bilbao under climate change and next, geographical information systems will be used to demarcate the new flood prone areas.

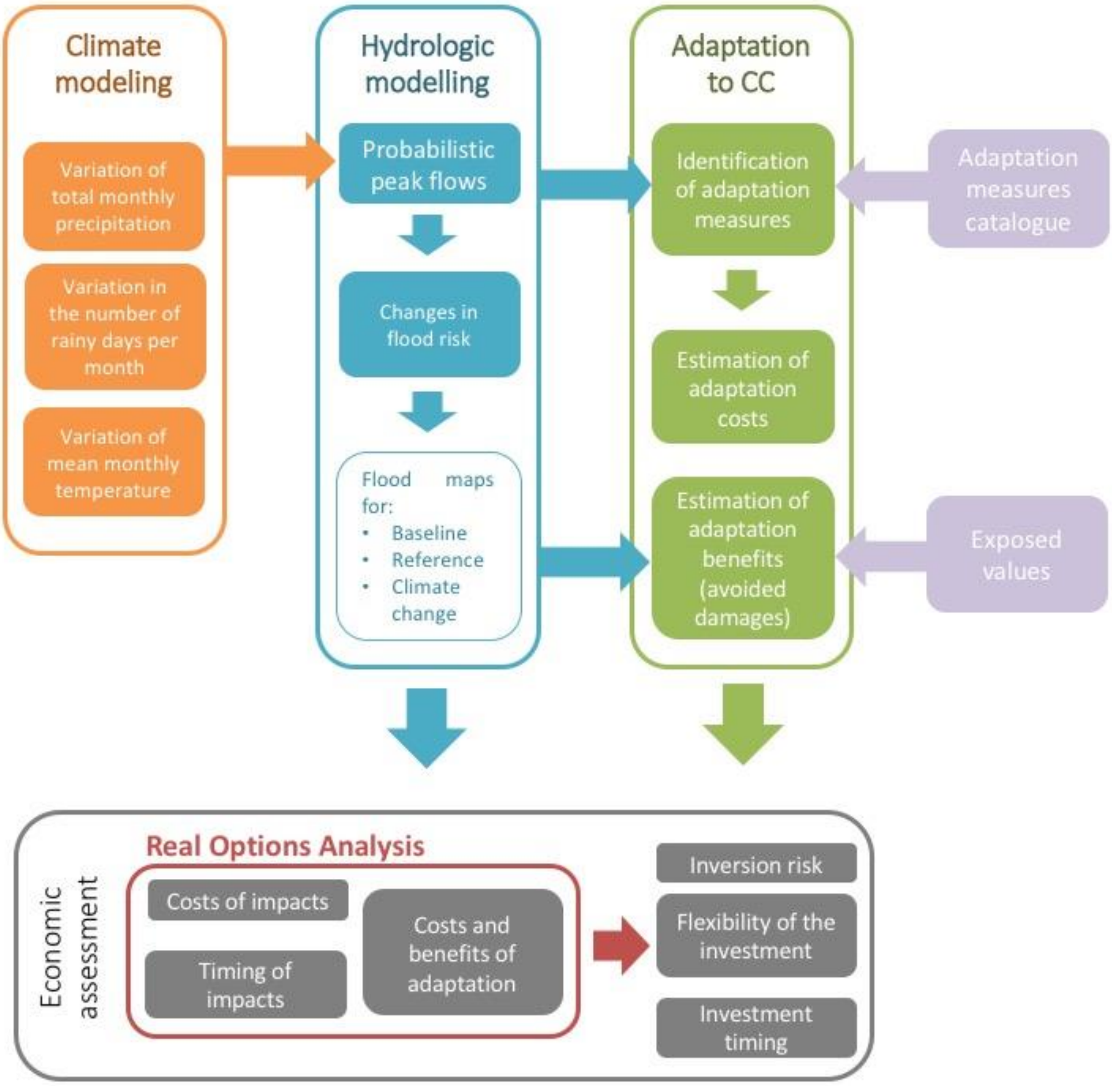


Figure 9. Flowchart summarising the different processes involved in the assessment of the Bilbao case study.

Parallel to this process, a literature review and a benchmark analysis of potential measures for adapting to flood-risk has been performed (Section 4.1) and the main cost estimates have already been identified. The benefits of adaptation will be calculated in terms of the avoided impacts once the new flood-risk maps for Zorrotzaurre are available. At the same time, a theoretical real options model is being defined to estimate the economic impacts of adaptation to flood risk at the global scale.

The final step of the assessments involves introducing all the date produced previously into a ROA model specifically designed for Bilbao. The outcome of the ROA is expected to provide useful information about inversion risk, flexibility of the investments as well as the most appropriate timing to perform different adaptation alternatives.

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Annex I – Inventory of adaptation measures

The current catalogue is contained in an excel table that accompanies this document. It is developed on the basis of literature and of experience.

Each adaptation measure is classified according to the categories described in section 2.1. It is possible to select measures according to one or multiple categories by using the filter buttons. As pointed out in section 2, often ambiguity persists about the category into which a given option falls, as this might depend on the scale, on the time frame, on other case-specific circumstances, and in cases even on the specific definition of the measure or of the category.