

Chapter 16

Assessing Flood Impacts, Wetland Changes and Climate Adaptation in Europe: The CLIMSAVE Approach

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Chapter Highlights

Approach: A meta-modeling approach is used to develop a continental (European) scale integrated assessment methodology. The method allows dynamic and cross-sectoral simulations of flood impacts and wetlands change/loss to be developed under varying conditions including climate and socio-economic changes.

Participant Engagement: A series of six professionally facilitated, participatory scenario development workshops involving stakeholders and scientists were carried out during the project period in order to: (1) develop plausible socio-economic scenarios, and (2) test and provide feedback on the design and functionality of the CLIMSAVE Integrated Assessment Platform (IAP) for Europe.

Models/Outcomes: A user-friendly and interactive web-based tool was developed to allow stakeholders to assess climate change impacts, adaptations, and vulnerabilities for a range of sectors including coastal and fluvial flooding, and wetlands.

Challenges: The dynamic link and feedback of adaptation plans over a long time span is challenging to simulate. Incorporating adaptation responses into scenarios is planned for future work and is an important frontier for participatory modeling.

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16.1 Introduction

Floods have already had significant socio-economic impacts in Europe (EEA 2010). These impacts are expected to be exacerbated due to future changes in climate and sea-level rise (IPCC 2013). Several studies have already developed methods for assessing flood impacts and analyzed the implications of future climate and socio-economic conditions at global (Jongman et al. 2014; Hinkel et al. 2014; Hallegatte et al. 2013; Hirabayashi et al. 2013), continental (Mokrech et al. 2015; Rojas et al. 2013; Meyer et al. 2013; Jongman et al. 2012; Feyen et al. 2012; Hinkel et al. 2010), and national/sub-national scales (Dawson et al. 2009; Mokrech et al. 2008; Richards et al. 2008; Evans et al. 2004a; Evans et al. 2004b). For example, at the European scale, Feyen et al. (2012) investigated the implications of future climate on fluvial flooding under current socio-economic conditions; and Rojas et al. (2013) accounted for future climate and population changes and investigated the effect of adaptation by increasing protection levels. The Dynamic Interactive Vulnerability Assessment (DIVA) integrated model of coastal systems, developed by the DINAS-COAST (Dynamic and interactive assessment of national, regional and global vulnerability of coastal zones to climate change and sea-level rise) project, is capable of assessing biophysical and socio-economic impacts of sea-level rise and socio-economic development as well as analyzing selected adaptation options. The DIVA model has been used (Hinkel et al. 2010) to investigate flood impacts and adaptation in Europe due to sea-level rise and storm surges for the A2 and B1 IPCC SRES scenarios (IPCC 2007). The analysis highlights the role of socio-economic pressures (population and GDP) in driving coastal flood impacts during the first half of the current century; while in the second half, the consequences of sea-level rise become more significant. No studies have yet assessed the combined impacts of coastal and inland flooding at regional-to-continental scale in view of climate and socio-economic changes, except Mokrech et al. (2015). In this chapter, we present the overall methodology that was developed within the CLIMSAVE project for assessing the socio-economic impacts of flooding as well as the environmental impacts on wetland habitats under future conditions.

Projections of future climate and socio-economic conditions can be uncertain (Berkhout et al. 2014). Investigating flood impacts under these uncertain conditions can be ineffective for planning adaptation. The use of a dynamic and interactive model allows the assessment of various scenarios under user-defined socio-economic and climate conditions leading to a better understating of the implications of future conditions. Many studies to date investigate only a limited number of predefined scenarios, often for multiple climate realizations under a given scenario. Thus, any changes in climate, socio-economic conditions, and/or adaptation options require a major research effort to analyze possible changing and interacting impacts. Holman et al. (2008) have suggested integrated assessment methodologies to address this limitation, where an integrated platform can be developed and the concept of meta-modeling can be used to overcome modeling complexity and to allow dynamic links between sectors and user interactions. Achieving this, however, requires that the modeling process involves scientists as well as stakeholders to

inform the development of alternative socio-economic scenarios and to design and assess the usability of the integrated platform. This approach has already been implemented at the regional scale by developing the Regional Impact Simulator (RegIS) for assessing the socio-economic and environmental impacts under future climate and socio-economic conditions in the UK (Holman et al. 2008) and more recently has been extended to the European continental scale in the CLIMSAVE (Climate Change Integrated Assessment Methodology for Cross-Sectoral Adaptation and Vulnerability in Europe) project (Harrison et al. 2013, 2015). The aim of this project is to develop a broad-scale model that combines coastal and fluvial flood impact assessment models for Europe that can be integrated into the CLIMSAVE IAP (Integrated Assessment Platform) with rapid simulations that allow users to interactively examine flood impacts under varying climates, socio-economic conditions, and adaptation options.

As part of this effort, this chapter presents the CFFloodmeta-model and describes briefly the participatory modeling activities that have been conducted to design socio-economic scenarios for Europe, to quantify socio-economic parameters, to identify relevant adaptation choices, and to design and assess the CLIMSAVE IAP. The chapter is structured to present the methodology in the CLIMSAVE approach section including the integrated assessment framework, datasets, scenario development, flood meta-model, and adaptation options. The flood impact assessment section discusses illustrative model results for Europe. Finally, key findings and future work are included that relate not only to our work, but also the field of participatory modeling at large.

16.2 The CLIMSAVE Approach

Five main design principles can be used to characterize the modeling approach adopted in the overall CLIMSAVE project including the CFFlood meta-model:

- 1) **Interdisciplinary:** climate change impacts, adaptation, and vulnerability for a range of sectors including agriculture, forests, biodiversity, coasts, water resources, and urban growth can be assessed;
- 2) **Integration:** the Driver-Pressure-State-Impact-Response (DPSIR) framework (Harrison et al. 2013; Holman et al. 2008) is used to integrate sectoral assessment models, establish the needed links, and facilitate interactions between models;
- 3) **Interactivity:** users of the CLIMSAVE IAP can interact with the platform to explore impacts attributed to climate and socio-economic changes as well as examine predefined scenarios and exploratory scenarios that they can create to reflect the uncertainty associated with climate and socio-economic projections;
- 4) **Effective user engagement:** achieved via simulations and visualizations on the CLIMSAVE IAP based on rapid, but credible meta-models. The use of computationally simpler but efficient modeling techniques (e.g., simplified

process-based models, multiple regression on model outputs, artificial neural network models), so called “meta-models” can be effective in allowing much greater complexity of model linkages and feedbacks (Holman et al. 2008; Carmichael et al. 2004).

- 5) Participatory: stakeholder involvement is needed to develop alternative socio-economic futures, quantify key models’ parameters (e.g., population, GDP), provide guidelines on feasible adaptation choices under different futures, and assess the CLIMSAVE IAP for constructive feedback on its design, functionality, and overall social validity. The following sections explain the methodologies used with a focus on the CFFloodmeta-model for the European case study.

16.2.1 Model Data

The data inputs for the CFFloodmeta-model are acquired mainly from available European datasets, such as the “coordination of information on the environment”(i.e. CORINE) land cover data, but also global datasets such as the enhanced Shuttle Radar Topography Mission (SRTM) topographical dataset. Table 16.1 describes the key datasets and the necessary processing for the model.

Table 16.1 Key datasets used in the development of the CFFlood model

Name	Description
Fluvial flood maps	Derived from LISFLOOD (i.e. a two-dimensional hydrodynamic model designed to simulate floodplain inundation) simulations for 2-, 5-, 10-, 20-, 50-, 100-, 250- and 500-year flood events at 100 m spatial resolution (Feyen et al. 2012). Data is gridded at 10’ spatial resolution
CORINE land cover	2006 dataset— version 12/2009 at 100 m spatial resolution. Data is tabulated in the fluvial flood zones and at 25 cm elevation bands in coastal areas and then gridded at 10’ spatial resolution
The ESRI enhanced global SRTM elevation data	SRTM dataset at 90 m spatial resolution; Void filled SRTM elevation data using the United States Geological Survey (USGS) Global 30 Arc-Second Elevation (GTOPO30) dataset. Data is tabulated at 25 cm elevation interval and gridded at 10’ spatial resolution
Population density, GDP of the Nomenclature of Territorial Units for Statistics (NUTS) dataset	The NUTS data of EUROSTAT at the NUTS3 statistical regions (~1–10 ⁶ km ²). Data is statistically summarized at the 25 cm elevation bands and at 10’ spatial resolution.
Extreme sea-levels (astronomical tides and storm surges)	Water depth for 1-, 10-, 100- and 1000-year events (DIVA database, Vafeidis et al. 2008) with an average segment length of 70 km. Data is gridded at 10’ spatial resolution
Land uplift/subsidence	Annual rate of change (DIVA database, Vafeidis et al. 2008) with an average segment length of 70 km. Data is gridded at 10’ spatial resolution

16.2.1.1 Indicative Flood Protection Data for Europe

Flood protection levels are essential for assessing flood impacts. Currently in Europe there is little information about these protection levels in coastal and river flood zones. Studies, such as those cited in Feyen et al. (2012) and Jongman et al. (2014) used economic indicators and modeling approaches to estimate flood protection standards. In the CFFlood model, an indicative flood protection dataset at the European level is constructed following the UK (Department for Environment Food and Rural Affairs) DEFRA methodology (MAFF 1999), where ranges of Standard of Protection (SoP) of coastal and fluvial flood defenses are determined based on land use/cover classes and the economic value of the land. Table 16.2 shows the minimum and maximum indicative standards of protection that are implemented for six land use categories in fluvial and coastal flood zones based on the CORINE land use/cover dataset. The resulting flood protection dataset has been revised using published data on flood protection in individual regions/nations including Belgium, the Netherlands, Northern Germany, and London (Mokrech et al. 2015). For example, up to 10,000- and 1000-year flood protection levels are included for the Netherlands and London (UK), respectively. This method is seen to be consistent for establishing a European baseline dataset on flood protection for exploratory purposes.

Table 16.2 Ranges of indicative standards of protection associated with land use classes (from CORINE), (following MAFF 1999)

Land use band	Description	Land use (CORINE classes—third level)	Indicative standard of protection	
			Fluvial	Coastal
			Return period (years)	Return period (years)
A	Intensively developed urban areas	111	50–200	100–300
B	Less intensive urban areas with some high grade agricultural land and/or environmental assets	112, 121, 122, 123, 124, 131, 141, 142, 211, 212, 213, 221, 222, 223	25–100	50–200
C	Large areas of high-grade agricultural land and/or environmental assets with some properties	132, 133	5–50	10–100
D	Mixed agricultural land with occasional properties at risk of flooding	241, 242, 243, 244	1.25–10	2.5–20
E	Low-grade agricultural land (often grass) or seasonally occupied properties at risk	31, 311, 312, 313, 321, 322, 323, 324, 333	0–2.5	0–5
F		All other classes	0	0

16.2.2 CLIMSAVE IAP

The development of the CLIMSAVE IAP has been iterative; it has undergone modifications throughout the duration of the project in response to progressive stakeholder feedback over three sets of workshops held over the course of 2 years. The IAP includes a collection of mathematical models that together provide quantitative estimates of sectoral impacts due to climate and socio-economic changes in the form of maps and graphs. The effect of a range of adaptation options on reducing impacts and vulnerability can be simulated, as well as estimates of their cost-effectiveness. The fundamental concept underpinning the specification of the IAP is to deliver rapid interactivity for the user utilizing the World Wide Web (available at www.CLIMSAVE.eu). This approach is designed to broaden accessibility and participation of stakeholders, thereby increasing impact in research communities.

16.2.3 Scenarios

16.2.3.1 Climate Change Scenarios

An ensemble of climate change scenarios were developed to represent alternative emissions and climate sensitivity that are consistent with the Intergovernmental Panel on Climate Change (IPCC 2007) climate scenarios. Thus, climate pressures (e.g., temperature, precipitation, sea-level rise) are available for four emissions scenarios (i.e., A1B, A2, B1, or B2) at three climate sensitivity levels (low, medium, or high) as well as for credible designed ranges. For example, the CFFloodmeta-model allows the exploration of up to 2 m of sea-level rise by 2100 (following current guidance by Nicholls et al. 2014).

16.2.3.2 Socio-Economic Scenarios

Four qualitative socio-economic scenarios are developed using participatory methods; mainly based on a “story-and-simulation” approach in an iterative procedure (Gramberger et al. 2015). Scientific methods and stakeholder knowledge are brought together to develop storylines that cover a range of aspects including social and economic developments, but also cultural, institutional, and political aspects in a set of integrated future outlooks (Linham et al. 2010). Stories are developed during a set of three stakeholder workshops. Additional to the stories, flow-charts, graphs depicting temporal developments, and quantitative estimates of main drivers of future changes (e.g., population and GDP) are produced as inputs for the mathematical models within the CLIMSAVE IAP. The four socio-economic scenarios for Europe are developed with extensive stakeholder input at two specific future time periods: the 2020s and the 2050s. Collectively, they show both population and GDP changes (increases and decreases) under the following conditions:

1. **We Are the World (WAW) Scenario:** Effective government change with a focus from GDP to welfare; less inequality and global cooperation. GDP change is +26 % by 2020s and +94 % by 2050s, while population change is +1 % by 2020s and +5 % by 2050s.
2. **Should I Stay or should I Go (SISOG) Scenario:** Failure to address economic crisis leads to increased gaps between rich and poor, political instability and conflicts, people live in an insecure and instable world. No change in GDP by 2020s and then -36 % by 2050s, while population changes +5 % by 2020s and +23 % by 2050s.
3. **Icarus Scenario:** Short-term policy planning and a stagnating economy lead to disintegration of social fabric and shortage of goods and services. No change in GDP, while population change is +5 % by 2020s and the -9 % by 2050s.
4. **Riders on the Storm (ROS) Scenario:** Strong economic recessions but successively countered with renewable and green technologies. No change in GDP by 2020s and then +54 % by 2050s, while population change is +5 % by 2020s and 16 % by 2050s.

In regards to the CFFloodmeta-model, change in GDP is used to reflect the change in economic conditions and how flood damage is influenced by such changes. Change in population density is used to estimate the number of people in flood zones.

16.2.4 Adaptation

Based on an extensive literature review, a list of adaptation options were generated and discussed by stakeholders and CLIMSAVE experts (Mokrech et al. 2015). The designed options, partly based on stakeholder opinions, were associated with the socio-economic scenarios and made as default choices. However, non-default options can also be explored. In regard to flooding, the following adaptation options can be examined in the CLIMSAVE IAP:

- a) Flood protection upgrade by 50, 100, 500, and 1000 %: this is applied directly to the present indicative protection and uniformly across Europe.
- b) Resilience measures: new properties are not affected by flooding due to the resilience measure applied (e.g., raising them above ground levels) up to a pre-defined threshold of flood event (e.g., 100-year event), while old properties continue to suffer from flood damage.
- c) Mixed response: this provides a more realistic adaptation approach, where a plausible combination of flood protection improvement (i.e., 100 % upgrade) and realignment of flood defenses are implemented.
- d) Retreat from rural areas in floodplains with the aim to generate accommodation space for creating habitats with the aim of maintaining or doubling stocks.

16.3 Flood Modeling

The CFFloodmeta-model is a two-dimensional simplified process-based model that consists of three main components: (1) coastal flood impacts, (2) fluvial flood impacts, and (3) wetland change/loss. These three components are coupled with a range of adaptation measures for reducing adverse flood impacts (socio-economic as well as environmental) under future conditions. Figure 16.1 shows the main modeling steps with data inputs and outputs at the 2010 baseline year as well as at the 2020s and 2050s time slices. Other models within the IAP that provide inputs into the flood model include the RUG (Regional Urban Growth) model and the WaterGAP meta-model. The modeling is nested at multiple spatial scales, where input data is resampled from high resolution data sets (e.g., 100 m resolution CORINE land use data and 100 m fluvial flood maps) and the results are communicated to the IAP at 10' resolution.

The notion of the meta-model is to determine the flood zones and the land cover classes within these zones in each 10' grid cell, and then use them to build detailed databases so this information can be retrieved quickly for computational algorithms within an integrated assessment framework. This approach allows interactions with other models and provides rapid dynamic assessments of flood impacts, adaptation to impacts, and sensitivity analysis. The meta-model is developed around the Driver-Pressure-State-Impact-Response (DPSIR) integrated assessment framework (Holman et al. 2005a, b; Rapport and Friend 1979) in order to establish dynamic links between the various models in the CLIMSAVE IAP (Harrison et al. 2013, 2015) as well as to build a consistent structure for the modeling elements.

The concept of “overlay analysis” is used to outline coastal flood zones by examining the regional extreme sea level relative to topography (Mokrech et al. 2015). Future regional extreme sea levels are obtained by combining present-day extreme sea levels and future relative sea-level rise (i.e., absolute rise in sea level and varying vertical land movement around the European coastline), as appropriate. Thus, flood zones are calculated and estimates of the people living in these zones are calculated using local population density. The method uses the Standard of Protection (SoP) parameter for analyzing the effect of relative sea-level rise on the protection level provided by flood defenses. It assumes that SoP decreases and flood frequency increases with a rise of extreme sea level (Lowe et al. 2001; Mokrech et al. 2015, 2008). This effect will vary along the European coastline as the vertical land movement and the slope of the exceedance curve varies spatially.

The fluvial flood component uses fluvial flood maps for Europe that are produced at 100 m resolution with a similar planar approximation approach based on LISFLOOD extreme river water level simulations (Feyen et al. 2012). The flood maps represent fluvial catchments across Europe including the extent and water depth at 2-, 5-, 10-, 20-, 50-, 100-, 250-, and 500-year return periods, assuming no flood defenses. These maps have been used to define the fluvial flood zones in the CLIMSAVE project. They are analyzed in conjunction with the CORINE land use and the socio-economic data (i.e., population and GDP) from the NUTS3 statistical datasets. The estimated SoP parameter is used to analyze the effect of change in peak river flows on flood

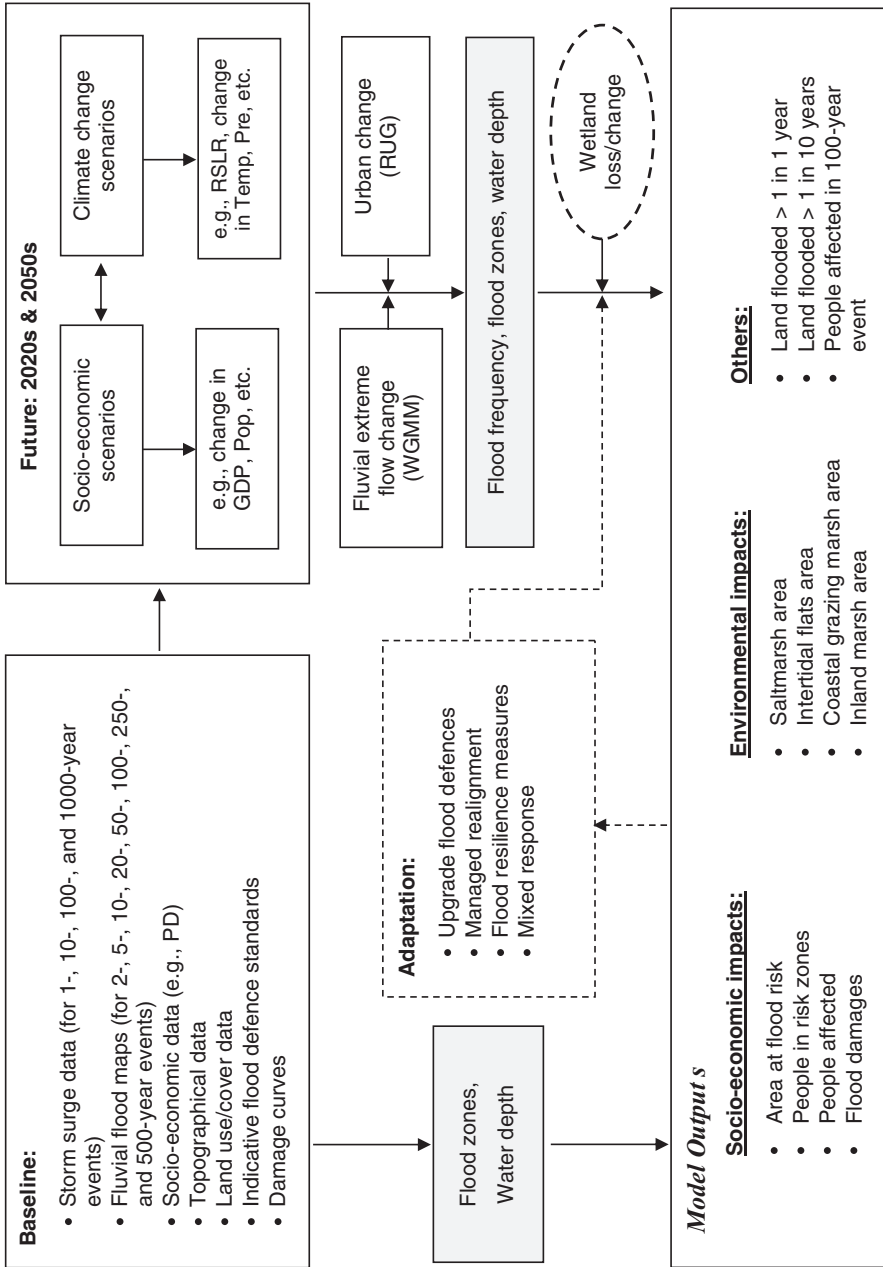


Fig. 16.1 Overview of the main steps, inputs, and outputs of the CFFLOOD meta-model. *PD* population density, *GDP* gross domestic product, *Temp* temperature, *Pre* precipitation, *RSLR* relative sea-level rise

protection following Mokrech et al. (2008). The changes in the peak river flow are derived from the WaterGAP meta-model (WGMM) (Wimmer et al. 2015), which emulates the performance of the WaterGAP3 model (Alcamo et al. 2003; Döll et al. 2003; Verzano 2009) on hydrology and water use. To reduce model runtime and input data requirements, the spatial resolution of WaterGAP3 (5 arc minute) has been aggregated to 92 European river basins greater than 10,000 km². Each river basin represents either a large natural river catchment or a cluster of several smaller catchments with similar hydro-geographic conditions. The climate change impacts on peak river flow is represented by the changes in the median of the annual maximum river discharge (Q_{med}), where the latter are derived from catchment-specific response surfaces that relate changes in Q_{med} with changes in temperature and precipitation. Response surfaces were derived from pre-run WaterGAP3 simulations for the period 1971–2000, in which spatio-temporal patterns in the baseline climate dataset were incrementally modified with respect to temperature ([0,0.5,...,6 °C]) and precipitation ([−50, −45,..., +50 %]) (Mitchell and Jones 2005). When WGMM is run with scenario input data of gridded mean annual air temperature and mean annual precipitation, it first computes the relative change in temperature and precipitation compared to the baseline in each river basin. In a second step, scenario Q_{med} is interpolated by inverse distance weighting of Q_{med} at the four neighboring grid points in the response surface. Finally, the relative change in Q_{med} compared to the baseline value is computed and passed to CFFLOOD as an estimate of changes in peak river discharge (see S6 for model performance). Thus, protection levels of flood defenses are degraded with the increases in peak river flows (e.g., a 10 % increase in peak river flow may degrade the 100-year flood defense to the 60-year level).

By comparing the investigated flood event with the degraded level of flood protection due to relative sea-level rise and/or change in peak river flow, the meta-model determines whether or not the flood zones are flooded. Thus, the number of people affected by flooding is estimated using local population density and urban land use classes. Considering the 10' cell size and the meta-modeling approach, the failing mechanisms of flood defenses (e.g., breaching and overtopping) are not investigated—the assumption here is that the flood risk zones will be flooded if the flood defense's SoP is exceeded.

Structural and content flood damages are calculated for residential and non-residential properties based on the broad assessment methodology outlined by Linham et al. (2010). The method uses the notion that the value of physical losses from a flood is no more than the value of the assets exposed to this hazard. For developed economies such as in Europe, the net capital asset is approximated to be three times the GDP. The proportions of structural assets are considered at 36 and 42 % for residential and non-residential properties respectively. Only a proportion of those assets located in a risk area are considered to be exposed to flooding; in densely populated urban areas a significant proportion of buildings are multi-storied and a large part of the assets are above any conceivable flood level. Hence, classes of population density are used to determine the proportions of assets at risk of flooding. Then, the Dutch Depth-Damage curve (Linham et al. 2010) is used to estimate structural and content losses caused by flooding.

Flood constraints on agricultural production are also calculated and provided to the agricultural model in the CLIMSAVE IAP. These include: (1) land flooded more than once a year is considered not suitable for any type of farming; (2) land flooded more than once each 10 years is considered not suitable for arable farming (Mokrech et al. 2008). In addition, the number of people affected by flooding in a 100-year event is calculated as a vulnerability indicator and communicated to the IAP.

Wetland changes and losses in floodplain are assessed following the broad scale model of McFadden et al.(2007). The investigated habitats comprise “saltmarsh,” “intertidal flats,” and what we term as “coastal grazing marsh” in coastal floodplains and “inland marshes” in fluvial floodplains. Saltmarsh and intertidal flats exist seaward of coastal defenses and are subjected to tides, while coastal grazing marshes are largely artificial habitats that exist landward of coastal defenses in areas that would otherwise be intertidal habitats. The wetland change/loss component accounts for both habitat loss and change using a standardized index, where the three influencing factors of *accommodation space*, *sediment supply*, and *rate of relative sea-level rise* are considered. Consequently, habitats such as saltmarsh, coastal grazing marsh, and intertidal flat can be either lost under high forcing conditions or can experience transition under the low-to-moderate forcing conditions as shown in Fig. 16.2. The direct effects of sea-level rise and the effects of defense abandonment due to managed realignment are also included. In river valleys, change in inland marshes is a function of change in river flows where existing marshes can increase or decrease as a function of change in floodplains.

The CORINE land cover data is used to establish the baseline of the intertidal habitats: saltmarsh and intertidal flats, and fluvial habitats (inland marshes). However, the designated habitats landward of coastal flood defenses are not defined in the CORINE

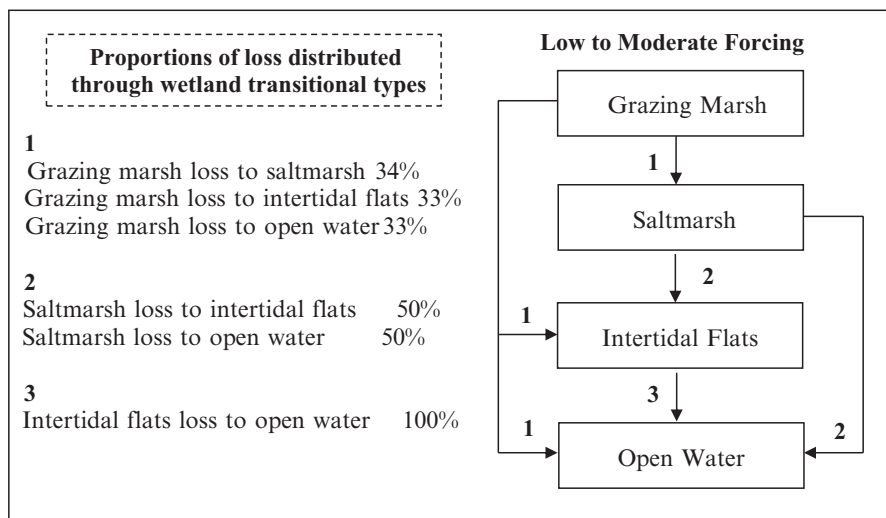


Fig. 16.2 Example of modeling wetlands loss/change for coastal areas. Adapted from McFadden et al. (2007)

land cover dataset. There is no standard European nomenclature for these areas and they are variously termed as: “coastal grazing marsh” (in the UK), or “summer polders” (in the Netherlands/Germany), to give two examples. They are also widely designated under the Habitats Directive for their environmental value. To develop a generic European methodology, pasture areas located within the coastal floodplain are assumed to be potential areas for “coastal grazing marsh” and this term is used for all such habitats in CLIMSAVE. If defenses are abandoned or realigned, the new intertidal land experiences a transition to saltmarsh and intertidal flats.

16.4 Impact Assessment

The coastal and fluvial flood impact analysis without flood protection indicates that almost 28 million people (i.e., 6% of the total population of the European Union) live within a 100-year flood inundation area. The economic damage is estimated to be €236 billion if this area is flooded. If flood protection is considered at the two designed levels (see Table 16.2), the number of people impacted will range from 0.24 to 17.4 million, while economic loss is estimated at €0.6 to €79 billion for the maximum and minimum protection standards respectively. These numbers demonstrate the benefits of flood protection, especially for the maximum protection level in reducing impacts without accounting for climate change and sea-level rise. In essence, the analysis suggests that Europe has adapted to a large degree to current flood risks, but these risks will grow with climate change and sea-level rise, and with economic growth in the floodplain if this occurs.

The CFFlood model within the IAP is capable of exploring impacts under pre-defined climate and socio-economic scenarios as well as under a wide range of exploratory scenario combinations that online users can define by varying climate, sea-level rise, socio-economic parameters, flood protection, and adaptation options. The people affected under the A1B climate scenario and the four pre-defined socio-economic scenarios for four events (i.e., 10-, 50-, 100-, and 200-year) are summarized in Fig. 16.3. The general trend of impact reflects the differences in population density under the four socio-economic futures. For example, the number of people affected under the minimum protection level (i.e., the default option on the IAP) for the very extreme flood event of 200 years is the highest under the SISOG scenario with the highest population change of +23% from baseline, while it is the least under the Icarus scenario with population change of -9% from baseline. Similarly, the economic impact of flooding is affected by change in economic conditions (i.e., change in GDP).

By isolating coastal flooding from fluvial flooding and exploring a range of conditions and flood events, we found that increases in socio-economic impacts of flooding can be mainly attributed to the effects of sea-level rise and to changes in future socio-economic conditions; the effect of change in temperature and precipitation on fluvial flood impact is small by comparison. When isolating the climate factor from the social factor, the quantitative and spatial distribution of the fluvial flooding shows

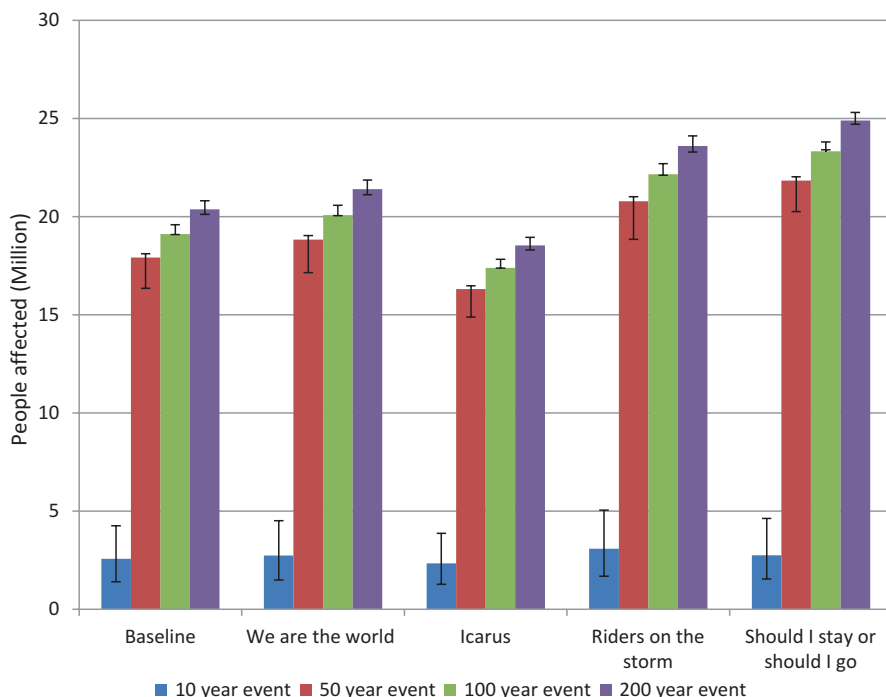


Fig. 16.3 People affected under different flood events in 2050s (i.e., 10-, 50-, 100-, and 200-year events) for future climate and socio-economic scenarios at the minimum level of flood protection at the middle climate variables; as well as sensitivity ranges that correspond to low to high climate variables

a general reduction in people at risk under both the WAW and ROS socio-economic scenarios by the 2050s. Under the Icarus socio-economic scenario, the number of people flooded reduces over almost the whole of Europe except in some areas in western and northern European regions. Under the SISOG scenario, there is a considerable spatial variation in people affected with some areas in Western Europe showing a reduction in people flooded while other areas show a clear opposite trend, for example Eastern regions of Europe. This can also be consistent with the fact that the increase in social pressure (e.g., +23% change in population by 2050s under the SISOG scenario) leads to larger flood impacts while a decrease in social pressure leads to a decrease in flood impacts. In this context, there is no significant difference in the number of people flooded in the 2020s under the low, medium, and high sensitivities of the investigated A1B emission scenario as well as across the socio-economic scenarios as minimal climate and social variations are expected by the 2020s under those scenarios. The economic damage follows a different pattern across the investigated scenarios as GDP is the primary parameter that influences damages in the implemented methodology. For example, the economic damage is the largest under the WAW scenario as the GDP increase is the highest (+94%).

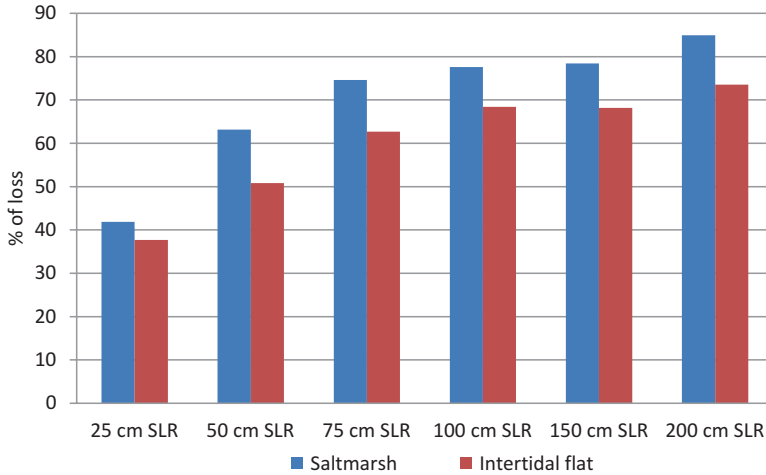


Fig. 16.4 Loss pattern of coastal wetlands under exploratory value of sea-level rise

The model indicates that environmental impacts due to sea-level rise can be significant. Figure 16.4 shows the systematic trend of loss in saltmarsh and intertidal flats. One meter of sea-level rise may lead to a loss of almost 80 % of saltmarsh and 70 % of intertidal flats in Europe. The area of coastal grazing marsh is mainly an indicative estimate of the potential of this habitat. It is mostly managed habitat and it will change into saltmarsh due to a change in salinity. On the other hand, in river valleys, change in inland marshes is a function of change in river flows where existing marshes can increase or decrease as a function of change in floodplains and management. The retreat options of maintaining habitats and doubling habitats have been analyzed using the CLIMSAVE IAP. It was found that habitats (e.g., saltmarsh) can be created but it will be very hard to maintain them at the baseline level under high-end climate scenarios.

To explore the potential benefits of the designed adaptation options, we examined an extreme climate and socio-economic scenario: one meter of sea-level rise, 25 % increase in winter and summer precipitation, 3 °C increase in temperature, 25 % increase in population, and 25 % increase in GDP; and evaluate flood consequences for the adaptation options. We found that the number of people at risk of flooding increases from almost 28 million (at the baseline) to 41 million people (i.e., +46 %). The minimum level of flood protection reduces the impact to almost 17 million at the baseline conditions and to 37 million under the extreme scenario (i.e., +32 %). Thus, while the performance of the current defense systems under current conditions can be effective, it is not effective under the investigated extreme scenario—more aggressive policies (e.g., 500 % or more upgrade of flood protection) are needed in order to reduce impacts of such extreme scenarios. These policies should also consider managed realignment of defenses in order to create the accommodation space needed for habitat creation. On the other hand, the resilience measures (e.g., elevated buildings) at the minimum level of flood protection may perform well, but they are not enough

on their own to reduce flood impacts to the baseline level. The economic damages under the investigated extreme scenario demonstrate a similar pattern as in the number of people flooded with the exception that even aggressive adaptation options such as upgrading defense by 500 % or more will not be effective in reducing economic damages to the baseline level, which can be mainly attributed to the increase in GDP. This shows that to maintain present risk levels under high-end scenarios, defenses will have to be raised even more than these upgrades imply; or, alternative measures will have to be considered such as landward realignment of defenses. A mixed response depending on land use and economic and environmental value looks most likely.

A sensitivity analysis of the sectoral and cross-sectoral effects of climate and socio-economic drivers on flood impacts has been conducted. Figure 16.5 shows the sensitivity of people flooded due to different sectoral (or direct) and/or cross-sectoral (or indirect) climate and socio-economic drivers. Out of the six drivers considered, the climatic drivers (temperature and precipitation) are identified as indirect drivers, while the socio-economic driver (population change) is identified as a combined (i.e., both direct and indirect) driver. Sea-level rise and change in flood protection are direct drivers; due to which the number of people flooded shows the highest sensitivity with a range greater than 17 million people.

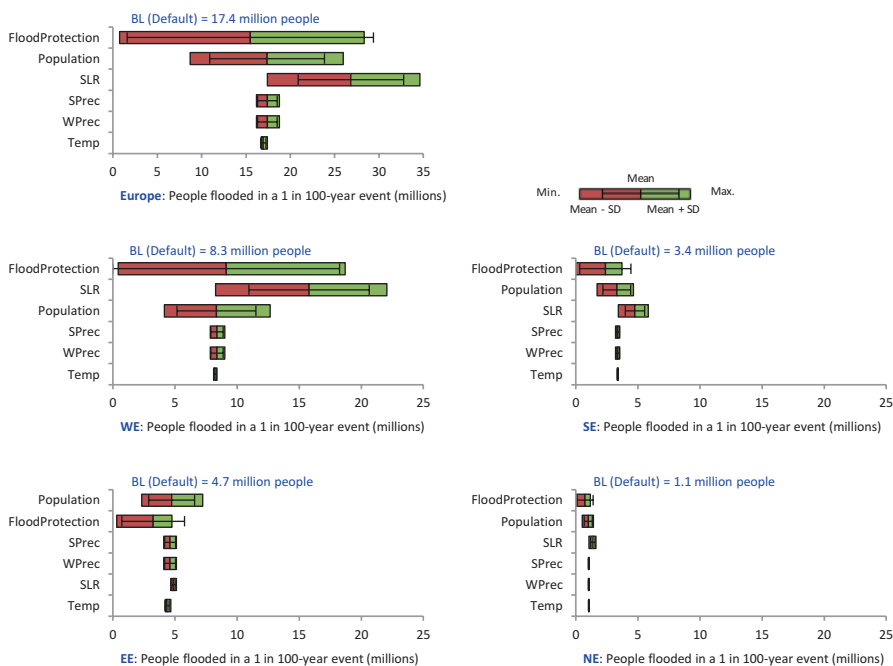


Fig. 16.5 Summary statistics (i.e., minimum, mean, maximum and standard deviation) of the sensitivity of people flooded in a 1 in 100 year flood event due to different climate and socio-economic change drivers for Europe and its four river-basin regions. *Note:* The drivers are sorted on the vertical axes based on the sensitivity range value. *BL* baseline, *WE* Western Europe, *EE* Eastern Europe, *SE*: Southern Europe, *NE* Northern Europe

16.5 Findings and Future Work

Participatory modeling led by scientists and stakeholders has been conducted to design the CLIMSAVE IAP and to develop alternative socio-economic futures where variations in economic development and innovation are realized in the qualitative storylines and the quantitative drivers of change (e.g., population and GDP growth). A range of adaptation options are also integrated within the socio-economic scenarios and the CLIMSAVE IAP.

The CFFlood flood meta-model within the CLIMSAVE IAP is capable of estimating coastal and fluvial flood impacts due to changes in climate and socio-economic conditions at the baseline year (i.e., 2010) and two time periods (i.e., the 2020s and the 2050s). The analysis of an illustrative set of results indicates that flood protection is very effective under baseline conditions. In the future, climate change may challenge this situation, especially under high-end scenarios in all coastal areas, and to a lesser extent in Northern European fluvial flood plains. Hence, there is a potentially large, but highly uncertain, need for adaptation. In terms of socio-economic changes, future socio-economic conditions have a major influence on the level of economic damage. Under socio-economic scenarios such as Icarus and SISOG with economic decline, the reduction in economic impact is significant and it is due to this cause. The highest economic damages are likely under the WAW scenario, reflecting the large economic growth. It is worth noting that economic growth gives a greater capacity to adapt, and vice versa, so the overall implications of these results need to be carefully considered. In addition, the impacts on coastal wetlands due to sea-level rise can also be assessed in the CFFlood meta-model. Incremental losses of salt-marsh and intertidal flats (70–80% from baseline) associated with high-end scenarios are simulated highlighting the need for corresponding adaptation efforts.

Although the CFFloodmeta-model offers a unique opportunity to quantify the socio-economic impacts of coastal and fluvial flooding across Europe for current as well as future conditions, there are a number of improvements that can be considered in future research. These include: (1) improving the flood protection dataset; (2) increasing flexibility for investigating time slices (ideally 10-year time steps until 2100); and (3) developing dynamic analysis of adaptation and feedbacks that may vary temporally and spatially in Europe reflecting regional and national policies for managing flood risk. Participatory modeling is seen as an appropriate approach for developing a multi-criteria indicator that feeds into the decision-making process with regards to adaptation.

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