RISC-KIT

Resilience-Increasing Strategies for Coasts – Toolkit

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Coastal Risk Assessment Framework

Guidance Document

Deliverable No: D.2.3 – Coastal Risk Assessment Framework Tool

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Publishable Summary

The Resilience-Increasing Strategies for Coasts – Toolkit (RISC-KIT) FP7 EU project (2013-2017) aims to produce a set of three innovative and EU-coherent open-source and open-access methods, tools and management approaches (the RISC-KIT) in support of coastal managers, decision-makers and policy makers to reduce risk and increase resilience to low-frequency, high impact hydro-meteorological events.

The Coastal Risk Assessment Framework (CRAF) is the first element of the risk assessment suite applied at a regional scale and permits a comprehensive and systematic approach to undertaking risk assessment at a variety of levels of detail. In particular, the approach reveals potential hotspots along the coasts. Hotspots are defined in the Toolkit as specific locations where high-resolution modelling and risk assessment are required to assess the coastal risk and to design and compare disaster risk reduction measures. As such, hotspots, or groups of hotspots, should be indicative of those areas where risk is highest.

To do so the CRAF consists of a 2-phase approach, Phase 1 is a coastal-index approach to identifying potential hotspots, whereas Phase 2 utilises a suite of more complex modelling processes to rank these hotpots. The coastal INtegrated DisRuption Assessment model (INDRA) has specifically been developed as an open-source and open-access model for this purpose.

This document provides guidance to CRAF users on both approaches, as well as explanations on the proposed methodologies. The CRAF is a prototype and will be trialled on the RISC-KIT case studies (WP5). Limitations in its application, the potential for a full application and the needs for further development will be discussed in Deliverable 5.1.

Executive Summary

The Resilience-Increasing Strategies for Coasts – Toolkit (RISC-KIT) EU FP7 project (2013-2017) aims to produce a set of three innovative and EU-coherent open-source and open-access methods, tools and management approaches (the RISC-KIT) in support of coastal managers, decision-makers and policy-makers to reduce risk and increase resilience to low-frequency, high impact hydro-meteorological events.

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- This Guidance Document, explaining the Coastal Risk Assessment Framework and the different methods and models developed within WP2, and;
- The INDRA model (INtegrated DisRuption Assessment model): an open-source and open-access model developed in NetLogo to assess direct and indirect impacts at regional scale following a coastal event.

<u>CRAF Phase1</u>

Phase 1 aims to screen the coastline sector by sector of about 1 km lengths in order to narrow down the risk analysis to a reduced number of sectors which are subsequently geographically grouped into potential hotspots. The approach facilitates the assessment of potential exposure through the calculation of a coastal index for each km considering hazard intensities, utilising simple hazard models, and the exposure of land use, population, transport, utilities and economic activities. The approach also allows for reporting on the availability and quality of the data, the indicator valuation, as well as the rationale and justification for identifying the hotspots.

<u>CRAF Phase2</u>

Phase 2 improves the regional assessment by increasing the number of transects considered per sector for the hazard calculation (and thus reducing the over- or underestimation of the hazard); by using 1D innovative modelling techniques; by including generic vulnerability indicators and the existence of DRR measures in the impact assessment; and by calculating regional systemic impact indicators related to different impacts (i.e. household displacement, household financial recovery, regional business disruption, business financial recovery, ecosystem recovery, risk to life, regional utilities service disruption, regional transport service disruption).

To assist the completion of Phase 2, this document explains how to integrate the various models and supporting documents available in an open-source and freeware format (XBeach 1D, a Library of Coastal Vulnerability Indicators, the INDRA model, a multi-criteria analysis and a visualisation interface).

CRAF Application

The CRAF is a prototype and will be trialled on the RISC-KIT case studies (WP5). Limitations in its application, the potential for a full application and the needs for further development will be discussed in another deliverable (5.1).

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1 Introduction

Recent and historic low-frequency, high-impact events such as Xynthia (impacting France in 2010), the 2011 Liguria (Italy) Flash Floods and the 1953 North Sea storm surge, which inundated parts of the Netherlands, Belgium and the UK, have demonstrated the flood risks faced by exposed coastal areas in Europe. Typhoons in Asia (such as Typhoon Haiyan in the Philippines in November 2013), hurricanes in the Caribbean and Gulf of Mexico, and Superstorm Sandy, impacting the northeastern USA in October 2012, have demonstrated how even larger flooding events pose a significant risk and can devastate and immobilise large cities and countries.

These coastal zone risks are likely to increase in the future[1] which requires a re-evaluation of coastal disaster risk reduction (DRR) strategies and a new mix of prevention (e.g. dike protection), mitigation (e.g. limiting construction in flood-prone areas; eco-system based solutions) and preparedness (e.g. Early Warning Systems, EWS) measures. Even without a change in risk due to climate or socio-economic changes, a re-evaluation is necessary in the light of a growing appreciation of ecological and natural values which drive ecosystem-based or nature-based flood defence approaches. In addition, as free space is becoming sparse, coastal DRR plans need to be spatially efficient, allowing for multi-functionality.

1.1 RISC-KIT Project objectives

In response to these challenges, the RISC-KIT project aims to deliver a set of open-source and open-access methods, tools and management approaches to reduce risk and increase resilience to low-frequency, high-impact hydro-meteorological events in the coastal zone[2]. These products will enhance forecasting, prediction and early warning capabilities, improve the assessment of long-term coastal risk and optimise the mix of PMP-measures. Specific objectives are:

1. Review and analysis of current-practice coastal risk management plans and lessons-learned of historical large-scale events;
2. Collection of local socio-cultural-economic and physical data at case study sites through end-user and stakeholder consultation to be stored in an impact-oriented coastal risk database;
3. **Development of a regional-scale coastal risk assessment framework (CRAF) to assess present and future risk due to multi-hazards ((Figure 1.1), top panel);**
4. Development of an impact-oriented Early Warning and Decision Support System (EWS/DSS) for hotspot areas consisting of: i) a free-ware system to predict hazard intensities using coupled hydro-meteo and morphological models and ii) a Bayesian-based Decision Support System which integrates hazards and socio-economic, cultural and environmental consequences

[1] IPCC (2015) Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. IPCC, Geneva, Switzerland.

[2] Van Dongeren, A., Ciavola, P., Viavattene, C., De Kleermaeker, S., Martinez, G., Ferreira, O., Costa, C. and McCall, R. (2014) RISC-KIT: Resilience-Increasing Strategies for Coasts – toolkit. In: Green, A.N. and Cooper, J.A.G. (eds.), Proceedings 13th International Coastal Symposium (Durban, South Africa), Journal of Coastal Research, Special Issue (66). ISSN 0749-0208. 6 p.

((Figure 1.1), centre panel);

5. Development of potential DRR measures and the design of ecosystem-based and cost-effective, (non-)technological DRR plans in close cooperation with end-users for a diverse set of case study sites on all European regional seas and on one tropical coast (Figure 1.1: bottom panel);
6. Application of CRAF and EWS/DSS tools at the case study sites to test the DRR plans for a combination of scenarios of climate-related hazard and socio-economic vulnerability change and demonstration of the operational mode;
7. Development of a web-based management guide for developing integrated DRR plans along Europe's coasts and beyond and provide a synthesis of lessons learned in RISC-KIT in the form of policy guidance and recommendations at the national and EU level.

The tools are to be demonstrated on case study sites on a range of EU coasts in the North- and Baltic Sea Region, Atlantic Ocean, Black Sea and Mediterranean Sea, and one site in Bangladesh, see Figure 1.2. These sites constitute diverse geomorphic settings, land use, forcing, hazard types and socio-economic, cultural and environmental characteristics. All selected regions are most frequently affected by storm surges and coastal erosion. A management guide of DRR measures and management approaches will be developed. The RISC-KIT Toolkit will benefit forecasting and civil protection agencies, coastal managers, local government, community members, NGOs, the general public and scientists.

1.2 Project structure

The project is structured into seven Work Packages (WP) starting with WP1 on 'Data collection, review and historical analysis'. WP2–4 will create the components of the RISC-KIT Toolkit containing an 'Improved method for regional scale vulnerability and risk assessment' (WP2), 'Enhanced early warning and scenario evaluation capabilities for hotspots' (WP3) as well as 'New management and policy approaches to increase coastal resilience' (WP4). The Toolkit will be tested through 'Application at case study sites' (WP5). WP6 will be responsible for 'Dissemination, knowledge transfer and exploitation' and 'Coordination and Management' are handled in WP7.

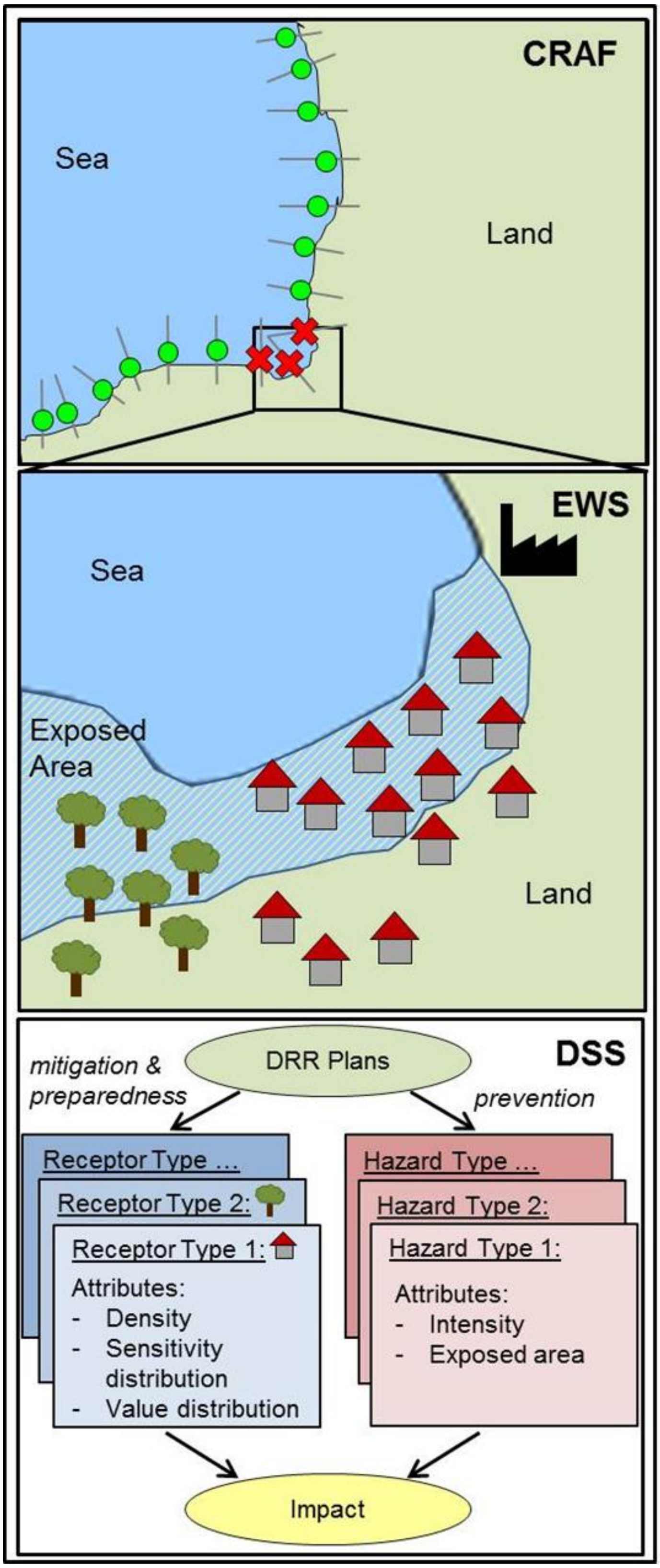

Figure 1.1: Conceptual drawing of the CRAF (top panel), the EWS (middle panel) and the DSS (bottom panel)

Figure 1.2: Case study sites (stars), RISC-KIT case study site partners (blue solid dots) and non-case study partners (red open circles)

1.3 Deliverable context and objective

The current Deliverable (D2.3) is a prototype. The objectives of WP2 are to develop a:

- Coastal Hazard Assessment module to assess the magnitude of hazards induced by the impact of extreme hydro-meteorological events in the coastal zone at a regional scale (O(100 km));
- Set of Coastal Vulnerability Indicators for the receptors exposed to coastal hazards;
- Coastal Risk Assessment Framework (CRAF) for extreme hydro-meteorological events which, integrating hazards and vulnerability inputs, can be used to assess potential impacts and identify hotspots where detailed models can be applied.

This deliverable is a framework that integrates Deliverable 2.1 and Deliverable 2.2 to calculate expected coastal impacts, by converting hazards into littoral impacts. The approach considers the potential ripple effects during an event to assess "indirect" impacts. A visual interface presents the results in a comprehensible and efficient way. This deliverable addresses the objective of WP2 and Project Objective 3 “Development of a regional-scale coastal risk assessment framework (CRAF) to assess present and future risk due to multi-hazards" by providing methodologies and indicators to assess coastal impact.

Description of Work:

***Verbatim* Text for Task 2.3 Coastal Risk Assessment Framework (CRAF)**

The CRAF (D2.3 and Milestone 7) will integrate the Coastal Hazard Assessment Module (Deliverable 2.1) and the Coastal Vulnerability Indicators (Deliverable 2.2) embedded into a data base library to calculate expected coastal impacts. To do this, a transfer function to convert hazards into real littoral impacts will be developed for the different coastal and hinterland typologies. This coupling between hazard and vulnerability will assess the shock of events by estimating the impact on the direct receptors at risk (probability and the sums of the consequences for receptors at risk). In addition to this, the CRAF will also consider the potential ripple effects during an event to assess "indirect" impacts. To do so, the CRAF will model the ripple effects and other services dependencies and the capacity of the system to respond to any drastic changes after the events, not only in the affected area but also outside it. The potential impacts will be expressed in terms of uniform indicators which independently score, or scale, economic, social, cultural and environmental aspects. The CRAF will provide different methods for weighting the indicators according to the preferences of the end users using a Multi-Criteria Analysis. Moreover, a visual interface will be developed to present the results in a comprehensible and efficient way.

1.4 Approach

Applying a suite of complex models at a full and detailed regional scale remains difficult and may not be efficient. Therefore a 2-phase approach is adopted for selecting the hotspots:

- The "identification of hotspots" by a screening process identifies several hotspots in alongshore length by assessing the potential exposure for every kilometre along the coast for different coastal settings;
- The "hotspot selection" phase uses a more complex modelling process to analyse and compare the risk between the identified hotspots in order to select one specific hotspot.

Both phases integrate elements of Deliverable 2.1 (*Coastal Hazard Assessment Module*) and of Deliverable 2.2 (*Library of Coastal Vulnerability Indicators*). For instance, various simple empirical hazard models are used in Phase 1 whereas the XBeach 1D model is used in Phase 2 in accordance with D2.1. The different impact categories presented in D2.2 are also analysed in both phases. Phase 1, focusing on exposure, mainly refers to the Social Vulnerability Indicator and some parts of the systemic analysis. Phase 2 requires the use of the vulnerability indicators presented in D2.2. In particular a specific impact assessment model, the INtegrated DisRuption Assessment model (henceforth INDRA) has been developed to assess the shock of events by estimating the impact on receptors, of variable vulnerability, that are directly exposed to hazards, as well as the potential ripple effects during an event in order to assess the "indirect" impacts. These indirect impacts occur outside the hazard area and/or continue after the event for all categories (households, businesses, ecosystems and critical infrastructures). The potential impacts are expressed in terms of uniform indicators, which independently score the indirect impacts of these categories. The CRAF also provides different methods for weighting the indicators according to the preferences of end users using a Multi-Criteria Analysis incorporated in the INDRA model. Moreover, a visual interface (map and charts) has been developed within the model to present the results in a comprehensible and efficient way. The user can also export the results for improved visualisation and further analysis on a desktop geographic information system (GIS) and a web viewer.

The deliverable comprises two elements:

- This Guidance Document, explaining the Coastal Risk Assessment Framework and the different methods and models developed within WP2, and;
- INDRA: a model developed in NetLogo to assess direct and indirect impacts at regional scale following a coastal event.

1.5 Outline of the report

The document is structured in 4 sections. Section 2 provides an overview of the Coastal Risk Assessment Framework (CRAF). Section 3 explains the different processes required to calculate a coastal index for Phase 1 in order to identify the hotspots. Section 4 provides detailed information on the methodologies used to develop Phase 2 and guidance on how to use the different tools. Yellow boxes are provided as a practical overview at the end of some sections to assist the reader in the application of the methodologies described.

Deliverable 2.3 is part of a suite of documents (D2.1: *Coastal Hazard Assessment Module*[3] and D2.2: *Library of Coastal Vulnerability Indicators* (including an Excel Library and an accompanying Guidance Document))[4]. It is assumed that the reader of this deliverable has an understanding of these aforementioned documents.

Deliverable 2.3 does not include information on the CRAF application. The CRAF will be trialled on the RISC-KIT case studies (WP5). Limitations in its application, the potential for a full application and the needs for further development will be discussed in another deliverable (5.1).

[3] Jiménez, J.A., Armaroli, C., Berenguer, M., Bosom, E., Ciavola, P., Ferreira, O., Plomaritis, H., Roelvink, D., Sanuy, M., Sempere, D. (2015) Coastal Hazard Assessment Module. RISC-KIT Deliverable, D2.1: http://www.risckit.eu/np4/file/23/RISCKIT_D.2.1_Coastal_Hazard_Asssessment.pdf (accessed 05.11.2015).

[4] Viavattene, C., Micou, A.P., Owen, D.J., Priest, S. and Parker, D.J. (2015) Library of Coastal Vulnerability Indicators. RISC-KIT Project Deliverable, D2.2: http://www.risckit.eu/np4/8/ (accessed 05.11.2015).

2 Introduction to the CRAF Framework

2.1 CRAF within the RISC-KIT Toolkit

The RISC-KIT Toolkit provides a set of innovative methods, tools and management approaches to reduce coastal risk and increase coastal resilience to hydro-meteorological events of low-frequency but high-impact.

The Coastal Risk Assessment Framework (CRAF) is the first element of the risk assessment suite applied at a regional scale and permits a comprehensive and systematic approach to undertaking risk assessment at a variety of levels of detail. One role is the identification and selection of hotspots to be further analysed (Figure 1.1). Hotspots are defined in the project as specific locations along the coast where high-resolution modelling and risk assessment are required to assess the coastal risk and to design and compare disaster risk reduction measures. As such, hotspots, or groups of hotspots, should be indicative of those areas where risk is highest. The last column in Table 2.1 indicates the level of detail required at the hotspots scale of analysis (third column Hotspots EWS/DSS). The Early Warning and Bayesian-based Decision Support System (EWS/DSS) is not part of the CRAF and will not be described in this document. However it needs to be highlighted that the EWS/DSS requires the use of complex-modelling techniques (2DH process-based, multi-hazard, 2DH flooding model, Bayesian Network analysis) and the demand in terms of data, time and resources is very high (e.g. 10m scale resolutions, thousands of simulation runs, detailed information on receptors, vulnerability and disaster reduction measures) to perform a strong and robust risk assessment. Therefore, decision-makers need to better define and prioritize where to spend their resources. The CRAF supports decision-makers by providing them with a framework, combining guidance documents and models, with which to screen the regional coast in the identification and selection of hotspots. Moreover, the CRAF has been designed in a way which integrates stakeholders directly into the process by not only taking account of their preferences and expertise, but also by initiating a discussion process. The narrative produced during the CRAF application is a critical part of the outcome of the framework.

2.2 CRAF Phase 1 and Phase 2

The CRAF provides two levels of analysis (2 phases) at the regional scale about 100 km of coastal length. The length is indicative and the term generic. The regional scale of assessment should be defined with the stakeholders' definition. The boundary could be based on an administrative unit (e.g. a region, a department), on a coastal risk management unit, on geographical considerations (e.g. fjords, bay).

Table 2.1: Level of analytical detail performed for CRAF Phase 1, CRAF Phase 2 and EWS/DSS

	CRAF Phase 1	CRAF Phase 2	Hotspot EWS/DSS
Assessment area	Entire regional coast (~100 km)	3–4 potential hotspots within the regional coast boundary	1 hotspot at local scale
Hazard pathway assessment model	Simple (empirical) model	1D, process-based, multi-hazard (XBeach transect-mode)	2DH process-based, multi-hazard
Hazard pathway assessment scale	Uniform hazard pathway per sector (~1 km)	Multiple hazard pathway computations per sector (between 5 or 10 transects per km, given the computational constraints)	At scale of numerical grid (~10 m)
Hazard model (inundation extent)	Simple bathtub/overwash extent model	LISFLOOD-type inundation model	2DH flooding model (e.g. XBeach)
Computation of hazard probability	Response approach (in the case of absence of long time series, event approach)	Response approach	n/a
Receptor and vulnerability information	Exposure only (receptor types and associated ranking values), can be at coarse CORINE-type scale	Receptor and vulnerability data, at individual or aggregated (neighbourhood) scale	Receptor and vulnerability at high resolution
Calculation of impact	Exposure indicators	Indicators of direct and indirect impacts	Quantitative impacts assessment

Phase 1 aims to screen the coastline sector by sector of about 1 km lengths in order to narrow down the risk analysis to a reduced number of sectors which are subsequently geographically grouped into potential hotspots (Figure 2.1). For a regional coast it would be difficult to complete an in-depth risk assessment analysis. Phase 1 facilitates the assessment of potential exposure through the calculation of a coastal index for each km utilising simple hazard models. The index considers the potential exposure of land use, population, transport, utilities and economic activities. Although considered to be a screening approach, this process is a significant and an important step within the CRAF which should not be overlooked. Whereas the techniques are simplified and the details required are few, the analysis supports a first review and a discussion about the level of information available to perform the regional scale assessment. Phase 1 also allows stakeholder input into the assessment by providing information on how they value the different exposed elements. Approaching various stakeholders (at a range of scales from the local to the regional) is therefore recommended for an exhaustive qualitative assessment of the coast. As such, beyond the simplicity of the Coastal Index calculation (see Section 3) a report detailing these data and the associated values, as well as the rationale and justification for their selection, is a key component of Phase 1 and an essential part of the screening process used to identify the potential hotspots.

However, Phase 1 is insufficient on its own, and is only the initial step towards the selection of specific hotspots for a more detailed risk analysis. Phase 2 provides the techniques and methods to fill the gap between the simplicity of a coastal index technique and the very complex modelling processes required at the hotspot level. Table 2.1 highlights how Phase 2 has been developed as an intermediary, but necessary, process between a coastal index screening approach and a detailed and complex modelling approach (WP3). Phase 2 improves the regional assessment by increasing the number of transects considered per sector for the hazard calculation (and thus reducing the over- or underestimation of the hazard); by using 1D innovative modelling techniques; by including generic vulnerability indicators and the existence of DRR measures in the impact assessment; and by calculating regional systemic impact indicators. To assist the completion of Phase 2, various models and supporting documents[5] are available in an open-source and freeware format (Figure 2.1: CRAF Overview): XBeach 1D, a Library of Coastal Vulnerability Indicators, the INDRA model, a multi-criteria analysis and a visualisation interface.

The involvement of stakeholders is also essential in CRAF Phase 2. Engaging with stakeholders will support the collection of information for evaluating potential direct and indirect impacts (e.g. land use and network information, development of vulnerability indicators, presence of DRR measures). Stakeholders do not have to be involved in the modelling component of the CRAF, but their involvement is a fundamental requirement in the multi-criteria analysis process. Only through such a learning process is a common understanding of the limitations possible and a critical analysis of the results achieved. The CRAF allows a comprehensive research and knowledge-based discussion on the selection of hotspots, in which the quantitative results and stakeholder engagement combine to provide impact outcomes. Furthermore, the CRAF also supports an evaluation of necessary efforts in future data collection.

[5] See Jiménez, J.A., Armaroli, C., Berenguer, M., Bosom, E., Ciavola, P., Ferreira, O., Plomaritis, H., Roelvink, D., Sanuy, M., Sempere, D. (2015) Coastal Hazard Assessment Module. RISC-KIT Deliverable, D2.1: http://www.risckit.eu/np4/file/23/RISCKIT_D.2.1_Coastal_Hazard_Asssessment.pdf (accessed 05.11.2015). *and* Viavattene, C., Micou, A.P., Owen, D.J., Priest, S. and Parker, D.J. (2015) Library of Coastal Vulnerability Indicators. RISC-KIT Project Deliverable D2.2: http://www.risckit.eu/np4/8/ (accessed 05.11.2015).

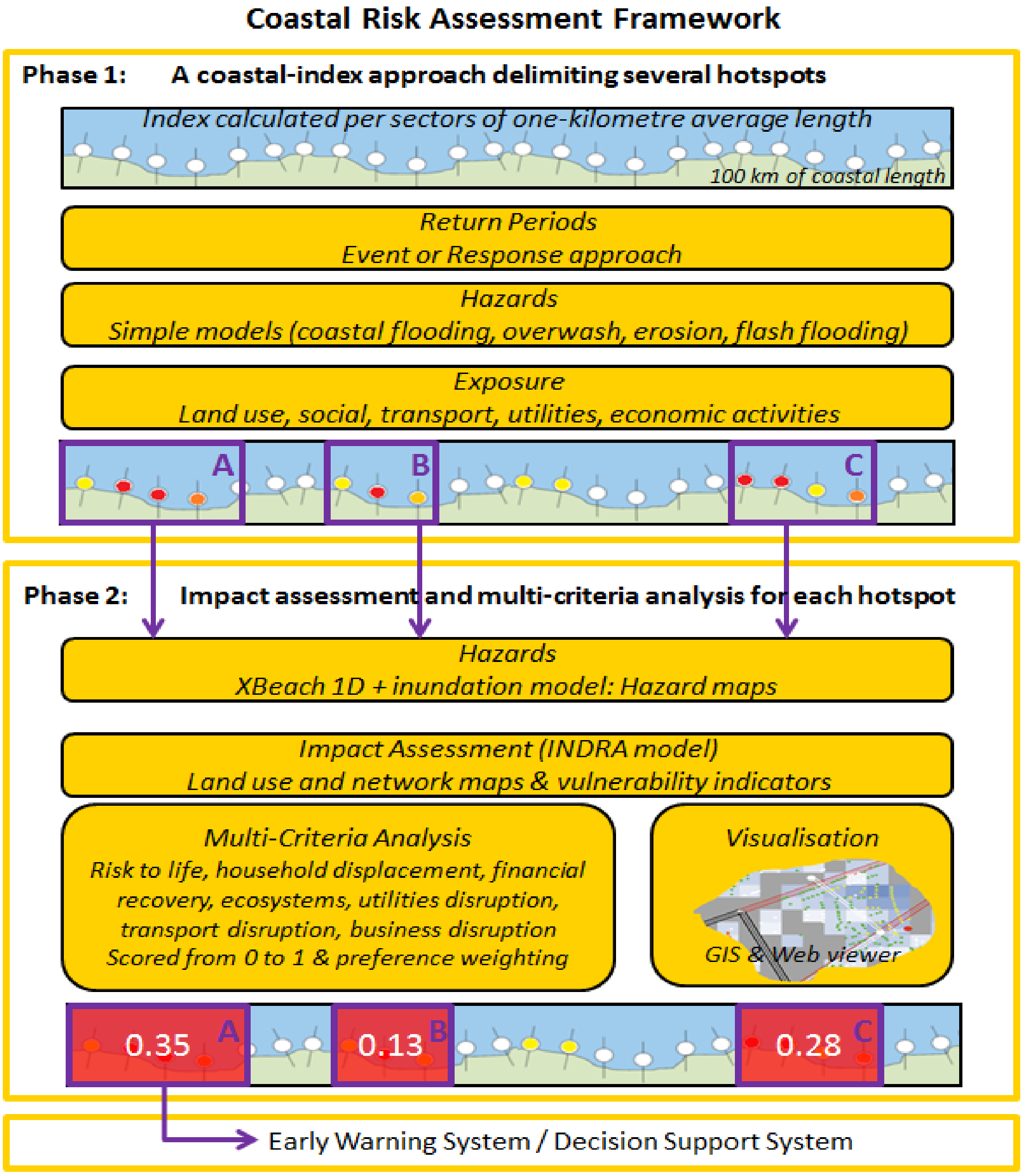

Figure 2.1: CRAF Overview

CRAF overview

- **Define regional scale of analysis;**
- **Identify decision makers and stakeholders and discuss current knowledge on risk;**
- **Proceed to Phase 1;**
- **Collect existing information on: storm events, geomorphology, land use, population, transport, utilities, economic activities, past events and existing risk assessments;**
- **Complete required valuation with stakeholders;**
- **Report and map Phase 1 Coastal Indices;**
- **Show and discuss results with stakeholders to define hotspots;**
- **Proceed to Phase 2;**
- **Collect existing information on receptors and vulnerability with the support of stakeholders where needed (update Library of Coastal Vulnerability Indicators);**
- **Run hazard and impact assessment model separately for each hotspot and considered return period;**
- **Report and map hazard and impact assessment;**
- **Show and discuss results with stakeholders: MCA and select one or more hotspots for further detailed analysis (WP3).**

3 Phase 1: Identification of hotspots using a Coastal Index approach

3.1 Introduction to Phase 1

The "identification of hotspots" is a screening process which distinguishes several hotspots in alongshore length by assessing the potential exposure for every 1 km coastal sector. The approach calculates Coastal Indices (CI) following an existing and established methodology (the index-based method). The methodology combines several indicators into a single index, thereby allowing a rapid comparison of coastal sectors[6 7 8 9]. However, the type of indicators considered in the index, the way they are ranked and the formula used to combine these variables may differ between studies. The following section describes the calculation process, the list of indicators to consider and their ranking. Two groups of indicators are required in the calculation: hazard indicators and exposure indicators.

3.1.1 Index, sector and hazard extent

Coastal areas are exposed to different hazards, such as flash flooding, coastal flooding, erosion, overwash and barrier breaching. The spatial extent of the exposure is primarily hazard and geomorphology dependent. Therefore, calculating a single Coastal Index for all hazards might be misleading. It is recommended to apply the approach separately for each individual hazard unless a dependency exists between hazards (e.g. erosion or barrier breaching inducing inundation). It is also recommended to have a morphologically-based average case and worst case scenario (e.g. 2 assessments for each hazard). For example, four coastal indices will have to be calculated for a coast exposed to erosion and coastal flooding.

For reporting, it is proposed to indicate the considered hazard using a subscript (i.e. flash flooding "ff", coastal flooding "cf", erosion "e", overwash "o", barrier breaching "bb") and the scenario type (i.e. average case "a" and worst case "w"). For example, the Coastal Index will be shortened as $CI_{cf-a,}$ for coastal flooding average case and CI_{cf-w} for coastal flooding worst case.

3.1.1.1 Sector

The coastal length (n km – the length may vary with the Case Study regional settings) is divided into sectors of one-kilometre average length (Figure 3.1). The same sectors are used for the different hazards and scenarios. However a different Coastal Index

[6] Gornitz, V.M. (1990) Vulnerability of the East Coast. Journal of Coastal Research, Special Issue 9, pp. 201–237.

[7] McLaughlin, S., McKenna, J. and Cooper, J.A.G. (2002) Socio-economic data in coastal vulnerability indices: constraints and opportunities. Journal of Coastal Research, Special Issue 36, pp. 487–497.

[8] Ramieri, E., Hartley, A., Barbanti, A., Duarte Santos, F., Gomes, A., Hilden, M., Laihonen, P., Marinova, N., Santini, M. (2011) Methods for assessing coastal vulnerability to climate change. ETC CCA Technical paper.

[9] Balica, S.F., Wright, N. G. and van der Meulen, F. (2012) A flood vulnerability index for coastal cities and its use in assessing climate change impacts. Natural Hazards (64), pp. 73-105.

value will be obtained for each hazard and scenario.

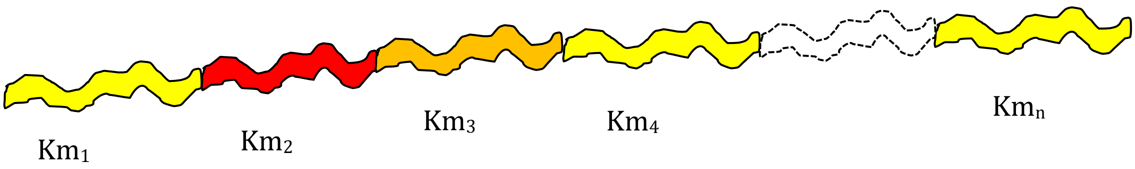

Figure 3.1: Example of different alongshore CRAF Sectors

3.1.1.2 Hazard Extent

The hazard extent represents the potential spatial hazard extent within the hinterland (Figure 3.2). If possible this hazard extent for flooding is known and clearly defined (grey shapes). But in some cases, without better information, a simple rectangle (blue square) will illustrate the potential extent with, as a result, an overestimation of the exposure. For erosion and overwash, the extension for the whole sector is represented by a buffer zone of equal distance along the sector's coastline.

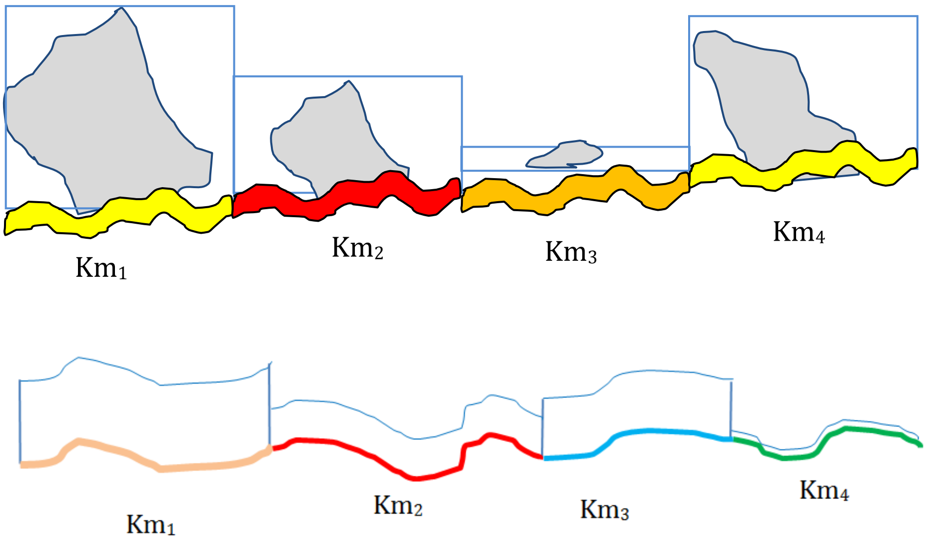

Figure 3.2: CRAF flood hazard extent (top image: flooding, bottom image: erosion and overwash)

3.1.1.3 Coastal Index

The Coastal Index (CI) is calculated by the square root of the geometric mean of the hazard indicator and the overall exposure indicator. The hazard indicator is ranked from 0 to 5 (None, Very Low, Low, Medium, High, and Very High). The overall exposure indicator ranks from 1 to 5 and is the result of the consideration of five types of exposure representative of potential direct and indirect impacts: Land Use (i_{exp-LU}), Population ($i_{exp-POP}$), Transport (i_{exp-TS}), Utilities (i_{exp-UT}), and Business (i_{exp-BS}). Each is ranked from 1 to 5 (None or Very Low, Low, Medium, High and Very High) and the overall exposure indicator is then calculated. See Section 3.1.4 for the full calculation method.

3.1.2 Hazard indicator

For each sector a specific-hazard indicator (None, Very Low, Low, Medium, High and Very High) and the extent of the exposure have to be assessed. To do so, following the approach and the methodologies proposed in D2.1 (*Coastal Hazard Assessment Module*)[10] it is necessary to:

1. Define the extreme event;
2. Select and apply the appropriate hazard formulae or scripts if available to assess the hazard intensities;
3. Define the hazard extent and the indicator value.

3.1.2.1 Extreme event

The CRAF aims to identify hotspots along the coast associated with given probabilities which have been specified by stakeholders and the relevant target safety levels. The number of hotspots will vary depending on the considered return period of the hazard, with a higher number of hotspots being associated to higher return periods. It is important therefore to define, for each coastal area, the most appropriate hazard return period(s) representative of an extreme event.

There is no unique way to define what an extreme event is and, usually, the concept of extremeness strongly depends on the context[11]. In a simple way, an extreme event can be defined as an event having extreme values of hydro-meteorological variables. From a coastal management perspective, extremes can be defined and/or quantified based on Beniston and Stephenson (2004)[12]:

- How rare they are, which involve notions of frequency of occurrence;
- How intense they are, which involves notions of threshold of exceedance;
- The impacts they exert (e.g. in social, economic and/or environmental terms).

The definition of extreme events and associated return periods will, therefore, vary between each regional case. Within the context of this work, it is clear that an extreme event should be able to cause morphological and/or socio-economic and environmental consequences. However, this initial step does not aim to quantify the socio-economic consequences and uses a simple hazard formulae. Therefore, initial assumptions have to be made, based simply on the frequency of occurrence.

Despite this site specificity, one possibility is to analyse common probabilities of exceedance. This is the approach adopted in the EU Floods Directive[13], which specifies

[10] Jiménez, J.A., Armaroli, C., Berenguer, M., Bosom, E., Ciavola, P., Ferreira, O., Plomaritis, H., Roelvink, D., Sanuy, M., Sempere, D. (2015) Coastal Hazard Assessment Module. RISC-KIT Deliverable. D2.1.
http://www.risckit.eu/np4/file/23/RISCKIT_D.2.1_Coastal_Hazard_Asssessment.pdf (accessed 05.11.2015).

[11] Stephenson, D.B. (2008) Definition, diagnosis, and origin of extreme weather and climate events. In: Diaz, H. F. and Murnane, R.J. (Eds), Climate Extremes and Society. Cambridge University Press, Cambridge.

[12] Beniston, M., Stephenson, D.B. (2004) Extreme climatic events and their evolution under changing climatic conditions. Global and Planetary Change, 44, pp. 1-9.

[13] EC (2007) Directive 2007/60/EC of the European Parliament and of the Council of 23 October 2007 on the assessment and management of flood risks. Official Journal L 288, 06/11/2007, pp. 27-34.

that flood hazard maps and flood risk maps will identify areas with a medium likelihood of flooding (at least 1 in 100 year event) and extremes or low likelihood events. The application of the Floods Directive in Catalonia (Spain) to fluvial inundation risk mapping has been done for 3 return periods (Tr = 10, 100 and 500 years), whereas for coastal inundation risk mapping the included *Tr* are 100 and 500 year[14]. It can also be considered that any low return period events with associated high losses will have already occurred and, as such, specific measures already have been taken to mitigate such risks. Unless recent inappropriate development in unprotected coastal areas has occurred, a minimum of a 100 year return period should be considered as sufficient for the assessment. For the Belgian coast a similar approach was used. EU Floods Directive reporting has been undertaken for return periods of 10, 100 and 1,000 years. Additionally, a return period of 4,000 years was used because the existing protection level at some locations is already very high.

An alternative approach is, at each site, to assess the most used and relevant return periods for coastal management purposes and adopt this as the considered return period for use in the CI. For areas with coastal management plans that consistently consider a maximum return period of 50 years, there is little point in defining a Coastal Index hazard for 1,000 years. The reverse is also true. Therefore, the coastal management life-span of each area should be taken into consideration when choosing the appropriate return periods for hotspot identification.

Another possible approach to select the *Tr* to be used in the analysis is based on the use of the concept of *lifetime* or *design life* of a coastal structure. In this case, the beach is considered as a coastal protection measure protecting the hinterland against the impact of a storm. Here the *lifetime* is the period over which the beach is expected to continue providing protection against the "design" condition, which in this case corresponds to the target storm[15]. With this, the user can make use of the relationship predicting the probability of exceedance, *P*, the lifetime, *L*, and the return period:

$$P = 1 - \left(1 - \frac{1}{Tr}\right)^{L}$$

To select appropriate or relevant *Tr* values, the user can fix *L* as the desired minimum lifetime of the beach and *P* as the accepted probability of occurrence of the event within such a lifetime as a function of the importance of the site.

[14] ACA (Water Agency of Catalonia) (2014) Mapes de perillositat i risc d'inundació del districte de conca fluvial de Catalunya. Memòria. Generalitat de Catalunya, Barcelona.

[15] Reeve, D. (2010) Risk and Reliability: Coastal and Hydraulic Engineering. Spon Press, London, p. 304.

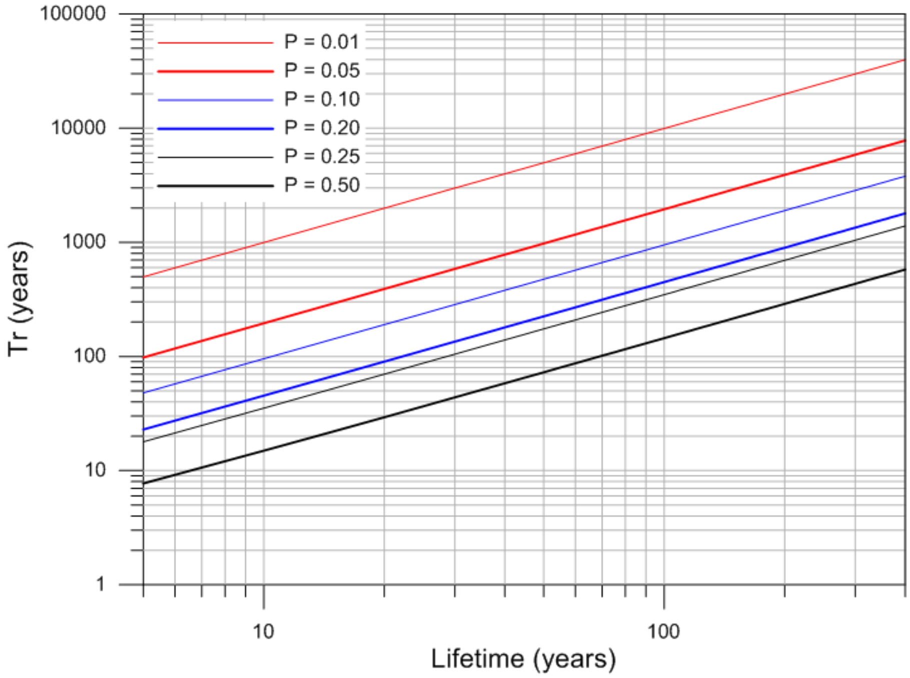

Figure 3.3: Event return period (Tr) for given probabilities of exceedance (P) within given lifetimes (L)

As a rule-of-thumb the higher the importance (e.g. in economic and/or social-environmental terms) of the hinterland, the lower the accepted probability will be. This means, for instance, that for high (economic, social and/or environmental) interest areas where the exceedance of protection capacity provided by the beach against the storm (inundation and/or erosion) should induce significant consequences, relative long lifetime and low probabilities of exceedance should be adopted. Figure 3.3 shows the corresponding return period, *Tr*, for events occurring at a given probability within given lifetimes.

From a practical standpoint, the selection of the lifetime and the accepted probability of exceedance determines the return periods for the events to be analysed. The first one, the *lifetime*, will make reference in the context of the objective of CRAF to the expected time horizon of the analysis. In other words, if the risk of coastal storms on a given coast is analysed, how long can it be assumed that the coast will provide the current level of protection? A conservative answer should be that the analysis considers a very long time period. However, recognising that sedimentary coasts are usually subjected to coastal processes affecting their stability and, in consequence, the current beach configuration (and the corresponding level of provided protection) will not be necessarily static (in fact, the most probable situation is that the coastal configuration will change). If it is assumed that the beach is functioning as a coastal protection measure, an analogy can be made with the usual lifetimes for such works. As an example, the Spanish Ministry of Public Works, in their recommendations for procedures of design maritime structures Puertos del Estado (2001)[16], proposes some values that could be used in this application, which have been selected as a function of the importance of expected consequences (Table 3.1).

[16] Puertos del Estado (2001) ROM 0.0. General procedure and requirements in the design of harbor and maritime structures. Spanish Ministry of Public Works, Madrid.

Table 3.1: Recommended minimum lifetime for coastal protection works[17]

Type of work	Importance	Minimum lifetime (years)
Defence against big floods*	High	50
Margins protection and defence	Medium	25
Beach nourishment and protection	Low	15

* It refers to defence works that in the case of failure may cause an important inundation of the hinterland.

The second one, the *probability of exceedance*, is also dependent on the importance of the implications of the hazard. Table 3.2 shows some recommended values of maximum allowable probabilities of failure for coastal protection works as a function of the (social, economic and/or environmental) consequences.

Table 3.2: Recommended maximum values of failure probability for coastal protection works as a function of their importance[18]

Importance	Maximum probability
Very High	0.0001
High	0.01
Medium	0.10
Low	0.20

3.1.2.2 Select and apply the Hazard Module

When assessing the magnitude of the hazards associated with the impact of an event of a given probability of occurrence, one of the points introducing uncertainty to the analysis is the assignment of the probability of occurrence. In hazard analysis in general and, in coastal flooding in particular, two main approaches exist, commonly known as the event and response methods[19]. The *event approach* (or deterministic approach) is a deterministic methodology, where the starting point is determined by the extreme probability distribution of wave heights and storm surges, plus some empirical relationships between other storm parameters of interest, such as wave period and storm duration *vs.* significant wave height. This method is mainly employed when the existing information for hazard analysis consists of pre-analysed forcing (wave and water level) information.

Once the probability of occurrence of the event is selected, wave height and storm surge are obtained from the corresponding extreme distributions, and the remaining parameters required to fully characterize the event are calculated by using the

[17] Ibid.

[18] Ibid.

[19] Garrity, N.J., Battalio, R., Hawkes, P.J., Roupe, D. (2006) Evaluation of the event and response approaches to estimate the 100-year coastal flood for Pacific coast sheltered waters. Proc. 30th Int. Conf. on Coastal Engineering, ASCE, pp. 1651-1663.

available deterministic relations. However, with this approach, each wave height is associated with just one value of other storm parameters, such as wave period and storm duration, which implies the loss of significant information about the natural variability of the process[20]. Once the event associated to a given probability has been defined, the different hazard parameters (to characterize flooding and/or erosion) are calculated and associated with the corresponding probability of occurrence.

In the *response approach* (or probabilistic approach), the entire original wave and water level time series are used to establish the hazard (flooding and/or erosion) parameters of interest, such as run-up, total water level, overtopping and eroded volume[21]. Due to the nature of the analysed problem, different combinations of wave conditions (events) will result in similar hazard conditions, and in order to properly assign a probability to such a response, it is necessary to jointly consider all possible options. A probability distribution of extremes is then fitted to the obtained dataset. From here, the hazard parameter of interest (associated with a given probability) will be directly calculated from its probability distribution. This method is especially recommended when wave variables during storms (e.g., H_s, T_p and duration), which are determining the magnitude of the hazard of interest are, poorly or partially correlated, as recommended by the FEMA guidelines for flooding studies[22] [23].

In this approach, users should mainly follow the response approach to assess the magnitude of hazards at regional scale. The probability distribution of relevant storm-induced hazards (e.g. inundation, erosion) at selected locations along the coast will be obtained by building hazard time series to be later subjected to extreme analysis.

In order to assess the intensities and the extent of the hazard, the methods indicated in Table 3.3 can be used. Detailed information on these methods is available in D2.1[24].

[20] Sánchez-Arcilla, A., Jiménez, J.A. and Peña, C. (2009) Wave-induced morphodynamic risks. Characterization of extremes. Coastal Dynamics 2009, World Scientific (CD), paper 127.

[21] As defined in Deliverable 2.1. Available at: http://www.risckit.eu/np4/file/23/RISCKIT_D.2.1_Coastal_Hazard_Asssessment.pdf (accessed 05.11.2015).

[22] Divoky, D., McDougal, W.G. (2006) Response-based coastal flood analysis. Proc. 30th Int. Conf. on Coastal Engineering, ASCE, pp. 5291-5301.

[23] FEMA (2007) Guidelines and Specifications for Flood Hazard Mapping: Atlantic Ocean and Gulf of Mexico coastal guidelines update. Federal Emergency Management Agency.

[24] Jiménez, J.A., Armaroli, C., Berenguer, M., Bosom, E., Ciavola, P., Ferreira, O., Plomaritis, H., Roelvink, D., Sanuy, M., Sempere, D. (2015) Coastal Hazard Assessment Module. RISC-KIT Deliverable. D2.1: http://www.risckit.eu/np4/file/23/RISCKIT_D.2.1_Coastal_Hazard_Asssessment.pdf (accessed 05.11.2015).

Table 3.3: Proposed methods for assessing the hazard intensities and extent

Hazard	Method	Outputs	Description
Overwash	Stockdon model (2006)[25], Holman model (1986)[26], or Nielsen and Hanslow model (1991)[27]	Run-up level	For Beaches – formulae
Overtopping	EurOtop (Pullen et al. 2007)[28] NNOvertopping	Run-up level and discharge	For Artificial Slopes – formulae
Overtopping	Hedges and Reis (1998)[29]	Discharge	For artificial slopes – formulae
Coastal inundation	Bathtub approach	Flood depth	
Flash flooding	FFPI	Index	
Erosion	Mendoza and Jimenez (2006)[30]	Eroded volume, shoreline retreat and depth	Formulae
Erosion	Kriebel and Dean (1993)[31]	Eroded volume, shoreline retreat	Model/formulae
Barrier Breaching	See D2.1, Section 5[32]	Breaching index	Methodology
Overwash extent	Simplified Donnelly(2008)[33]	Water depth	Formulae

[25] Stockdon, H.F., Holman, R.A., Howd, P.A., Sallenger, A.H. Jr. (2006) Empirical parameterization of setup, swash and run-up. Coastal Engineering, 56, pp. 573-588.

[26] Holman, R.A. (1986) Extreme value statistics for wave run-up on a natural beach. Coastal Engineering 9, pp. 527–544.

[27] Nielsen, P. and Hanslow, D.J. (1991) Wave runup distributions on natural beaches. Journal of Coastal Research 7, 4, pp. 1139-1152.

[28] Pullen, T., Allsop, N.W.H., Bruce, T., Kortenhaus, A., Schüttrumpf, H., van der Meer, J.W. (2007) EurOtop. Wave overtopping of sea defences and related structures: Assessment manual. www.overtopping-manual.com (accessed 05.11.2015).

[29] Hedges, T., and Reis, M. (1998) Random wave overtopping of simple seawalls: a new regression model. Water, Maritime and Energy Journal, 1(130), pp. 1-10

[30] Mendoza, E.T. and Jiménez, J.A. (2006) Storm-Induced Beach Erosion Potential on the Catalonian Coast. Journal of Coastal Research. SI 48, pp. 81-88.

[31] Kriebel, D. and Dean, R.G. (1993) Convolution model for time-dependent beach-profile response. Journal of Waterway, Port, Coastal and Ocean Engineering, 119, pp. 204-226.

[32] Jiménez, J.A., Armaroli, C., Berenguer, M., Bosom, E., Ciavola, P., Ferreira, O., Plomaritis, H., Roelvink, D., Sanuy, M., Sempere, D. (2015) Coastal Hazard Assessment Module. RISC-KIT Deliverable. D2.1: http://www.risckit.eu/np4/file/23/RISCKIT_D.2.1_Coastal_Hazard_Asssessment.pdf (accessed 05.11.2015).

[33] Donnelly, C. (2008) Coastal Overwash: Processes and Modelling. Ph.D. Thesis, University of Lund, p. 53.

3.1.2.3 Hazard extent and indicator value

Hazard extent

The hazard extent might be defined based on the best available information ranging from local knowledge, historic data or existing maps of potential hazard extent (see WP1 deliverables[34] for data collection). In the absence of information, an indicative length can be used as a proxy. The extent is then represented by a simple rectangle (indicative length by sector length). If it is possible, simple models can also be used to assess this extent. For erosion, buffer zones should be added (considering the Erosion Vulnerability Indicator described in D2.2[35]).

Indicator value

A hazard indicator will be ranked from 0 to 5 (None, Very Low, Low, Medium, High and Very High). A null value is used in the absence of hazard. The ranking of the indicator value from 1 to 5 will depend upon the hazard intensities. The hazard extent is already considered within the sector definition and should not be considered in this ranking to avoid double counting. The following intensities might be considered:

- Flooding: depth, velocity, duration;
- Overwash: depth and velocity;
- Erosion: a value of 5 for the shoreline retreat and lower values for buffer zones.

The user should define and report specifically how the ranking of the indicator has been undertaken. A simple process might be to define the maximum value of the hazard intensity for the whole coast and to categorize in 5 equal intervals (this should be done for the worst case scenarios to obtain the highest possible intensity value – the same intervals should then be used for other scenarios allowing a comparison between them). Thus, if the flood depth is considered as a main characteristic and the maximum potential value is 5 metres in depth, the following ranking could be used:

- No flood: None (0);
- Flood depth less than 1m: Very Low (1);
- Flood depth 1 to 2m: Low (2);
- Flood depth 2 to 3m: Medium (3);
- Flood depth 3 to 4m: High (4);
- Flood depth greater than 5m: Very High (5).

However, such a simple ranking approach could be improved by using natural breaks classification which considers the distribution of the intensities or could be approached from an impact perspective by establishing user defined intervals (for example, any depth above 3m is Very High and below 0.3m is Low).

3.1.3 Exposure Indicators

The exposure indicators (i_{exp}) measure the relative exposure for different receptor types. Five types are considered:

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[34] The WP1 Deliverables on data collection, review and historical analysis are all available at: http://www.risckit.eu/np4/public_deliverables.html (accessed 05.11.2015).

[35] Viavattene, C., Micou, A.P., Owen, D.J., Priest, S. and Parker, D.J. (2015) Library of Coastal Vulnerability Indicators. RISC-KIT Project Deliverable, D2.2: http://www.risckit.eu/np4/8/ (accessed 05.11.2015).

- Land Use;
- Social Vulnerability;
- Transport systems;
- Utilities;
- Business settings.

For each hazard and for each scenario (average and worst), five exposure indicators have to be considered. For each sector, a score between 1 and 5 (None or Very Low, Low, Medium, High and Very High exposure) should be assigned to each indicator. Note that not every score will necessarily be represented for each regional case (for example, if a regional coast lacks Very High exposure a score of 5 should not be assigned). The exposure will vary depending on the hazard extent. Therefore, the value will have to be calculated for each Coastal Index separately.

The data quality for assessing the exposure indicators may vary between types of indicators and between coastal regions. It is important to report this level of quality to the stakeholders. Therefore for each type it is required to clearly describe the data and the process used to assess the indicator. It is also recommended to highlight limits and insufficiencies in the current assessment and to indicate how this assessment could be enhanced.

A crucial task is to define the regional boundary. In order to do this, aspects such as administrative boundaries, coastal management plans, the presence and quantity of important assets or critical infrastructure etc. should be considered. A regional administrative area will often be too large for the purposes of the study (Figure 3.4), and users should select a group of municipalities which sufficiently represent the regional case i.e. considering its systemic characteristics (transport and utility networks, economic activities and dependencies between localities). As such, the knock-on or ripple effects (traffic disruption, rail closures, loss of power, loss of supply chains etc.) can be considered in the impact assessment.

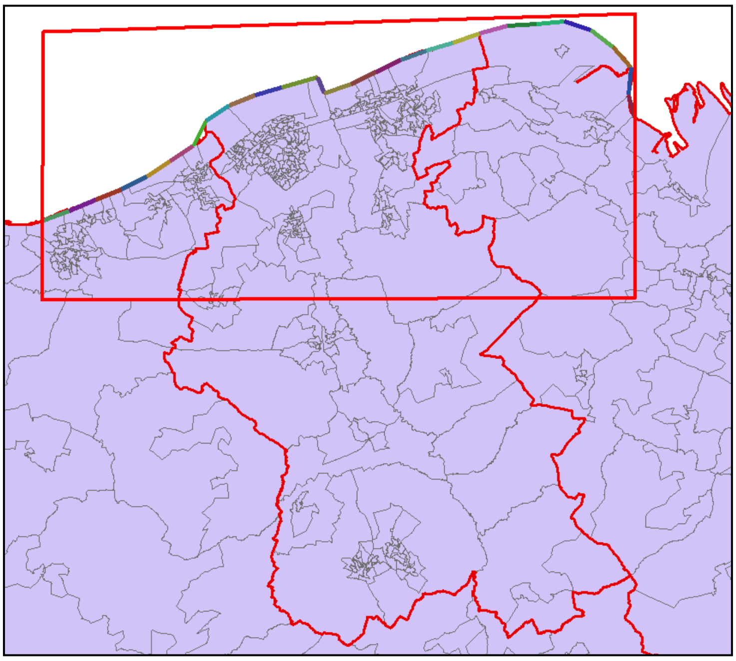

Figure 3.4: Defining the regional boundary

3.1.3.1 Land Use

The Land Use Exposure Indicator (i_{exp-LU}) measures the relative exposure of land uses along the coast. Importantly, the indicator does not consider the vulnerability of the different land uses. The indicator reflects two components for each sector: the exposed surface and an associated importance value for each land use.

$$i_{exp-LU} = \sum_{j=0}^{n} S_j * V_j$$

Where:

n = number of land use classes

S = Surface in m^2

V = Importance Value (e.g. 0 to 10)

To harmonize and simplify the process the indicator can be calculated using the land use classification in the Corine Land Cover dataset[36]. It is first necessary to identify the Corine Land Cover land use classes within the regional boundary. Then a representative value for each land use class should be defined based on their relative importance (see below). For instance, the different land use classes could be scored on a scale from 0 to 10 (or as deemed appropriate to differentiate the land use value), where a score of 10 might be attributed to continuous urban fabric, a score of 6 to permanently irrigated land and a score of 3 to pastures (a suggested approach of how this can be done is proposed in Box 3.1).

The approach does not allow for a different score to be given to the same land use class (e.g. all urban areas will have the same scores even though certain urban areas may be more important than others for specific reasons). But in very specific situations the user might want to reflect an important land use (e.g. a Ramsar site, a heritage site). In such cases, a different value might be attributed to the CLC points representing the considered site (with caution as it should not also be considered within the other exposure indicators thus creating a situation of double counting). In other circumstances, the representativeness of CLC might be questioned, for instance in the case of erosion where the scale of analysis is often limited to a narrow buffer zone along the coastline. In such cases alternative options are:

- To extract land use information from better georeferenced data (e.g. cadastral maps);
- To extract land use information from satellite or aerial imagery;
- To acquire land use information by field surveys.

There are many approaches to valuing land use. These include:

- Existing valuation: Valuations of land use may already exist for some regions, and these can be assessed for their suitability. An example is the approach undertaken in the Emilia-Romagna region of Italy as part of the EU Flood Directive implementation process, where land use has been scored based, primarily, on the level of human occupation/activity (i.e. urban areas,

[36] http://www.eea.europa.eu/publications/COR0-landcover (accessed 05.11.2015); for Case Studies not covered an alternative approach will have to be developed.

industrial zones and ports have a high score, whereas beaches and dunes are scored low)[37]. Other approaches may be based on the market value of the land (agricultural yields etc.). Users should consider if existing valuations reflect the actual "value" of the land use, and a judgement made on their suitability for this Phase 1 task.

- Stakeholder involvement: The identification of hotspots should reflect the views of a range of stakeholders. However, reaching a consensus on values at the regional scale will require time, skills and resources beyond the scope of the project as stakeholders are likely to value land-use based on their area of interest, knowledge and location.
- User judgement: In the first approach, the most suitable method for valuing land use is likely to be the best judgement of the user based on the information gathered from the engagement process. Furthermore, stakeholders and/or end-users have the option to discuss these values where they feel it is necessary to do so. It is important to produce a brief report on how and why the values have been chosen.

Box 3.1 Proposed approach with Corine Land Cover data

If using Corine Land Cover (CLC), the following steps are proposed in order to select and rank the land use. These instructions are written for (competent) ArcGIS users, but other GIS software is likely to function similarly.

1. Clip the CLC (study area) raster file by exporting the data (extent: current data frame)
2. Convert into a shapefile (points) (Arctool box)
3. Join the CLC legend* in a table format to the shapefile
4. Remove shapefile points such as water bodies (editing)
5. Attribute a value (0 to 10) to each point based on their land use label (using Label level 1, 2 or 3)
6. Spatial joint with the hazard extent shapefile (sum of "value" – same surface for all points)
7. Rank the sum of "value" from 1 to 5 (hazard extent shapefile)

*See: http://www.eea.europa.eu/data-and-maps/data/corine-land-cover-2000-clc2000-100-m-version-9-2007/corine-land-cover-2000-classes-and-rgb-color-codes/clc2000legend.xls (accessed 05.11.2015)

3.1.3.2 Social Vulnerability

The presence of a population is already quantified to a certain extent in the Land Use

[37] Perini, L., Calabrese, L., Salerno, G., Ciavola, P., Armaroli, C. (2015) Evaluation of coastal vulnerability to flooding: comparison of two different methodologies adopted by the Emilia-Romagna Region (Italy), NHESSD, 3, 4315-4352, doi:10.5194/nhessd-3-4315-2015, 2015. Available at: http://www.nat-hazards-earth-syst-sci-discuss.net/3/4315/2015/nhessd-3-4315-2015.html (accessed 05.11.2015).

Exposure Indicator (i.e. through the inclusion of the urban land use areas) (i_{exp-LU}) and as such does not need to be addressed within the Social Vulnerability Indicator. The Social Vulnerability Indicator ($i_{exp-SVI}$) only measures the relative exposure of different communities along the coast by considering their relative vulnerability to long-term health and financial recovery from an event. Such an indicator is developed by considering the socio-economic characteristics of the exposed areas. Census data are commonly used to characterize the different populations. The methodologies to calculate a SVI using census data are detailed in Deliverable 2.2 (*Library of Coastal Vulnerability Indicators)*. Census data are often the best available information. It is highly recommended, therefore, to use them for calculating the indicator. However, in specific circumstances, the characteristics of the population exposed to the hazard might be different from the average characteristics obtained from the Census Data, often due to differences in the scale of analysis (coastal zone versus municipality level). It is thus important, in a second step, to review these results and to decide if further refinements are necessary. However, such refinements might require intensive field survey and/or data collection.

3.1.3.3 Transport systems

One of the Land Use Classes of the Corine Land Cover classification refers to road and rail networks. However, the class is often a non-dominant one and the transport system does not appear in the LU exposure assessment. To analyse the transport system it is recommended to follow the 5-step approach proposed in Deliverable 2.2 (*Library of Coastal Vulnerability Indicators*). For this phase, collecting information for each transport network about the location and relative importance (capacity and use) of their assets (links and nodes) is essential for mapping and valuing the system. The Transport System Exposure Indicator (i_{exp-TS}) can then be derived for each 1km sector following the rules in Table 3.4.

Table 3.4: Transport System Exposure Indicator Values

Value	Rank	Description
1	None or Very Low	No significant transport network
2	Low	Mainly local and small transport network
3	Moderate	Presence of transport network with local or regional importance
4	High	High density and multiple networks (train, road airport) of local importance or regional importance
5	Very High	High density and multiple networks (train road airport) of national or international importance

3.1.3.4 Utilities

For utilities providing essential services (e.g. water, electricity, telecom, emergency) a Utilities Exposure Indicator should be derived for each 1km sector following the same approach as described for the transport system and the rules in Table 3.5.

Table 3.5: Utilities Exposure Indicator Values

Value	Rank	Description
1	None or Very Low	No significant utilities network
2	Low	Mainly local and small utilities network
3	Moderate	Presence of utilities networks with local or regional importance
4	High	High density and multiple utility networks of local or

		regional importance
5	Very High	High density and multiple utility networks of national or international importance

3.1.3.5 Business Settings

For Business Settings an indicator should be derived for each sector following the 6-step approach proposed in the Deliverable 2.2 (*Library of Coastal Vulnerability Indicators*). For this phase, collecting information and mapping the location of assets and their relative importance (input, output, number of businesses) is essential for the different business settings. The Business Settings Exposure Indicator ($i_{exp\text{-}BS}$) can then be derived for each sector following the rules in Table 3.6.

Table 3.6: Business Settings Exposure Indicator Values

Value	Rank	Description
1	None or Very Low	No significant economic activities
2	Low	Mainly local small economic activities
3	Moderate	Local or regional economic activities
4	High	Regional importance
5	Very High	National or international importance

3.1.4 Coastal Index

The Coastal Index (CI) (Table 3.7) is calculated using the square root of the geometric mean of the hazard indicator (i_h) and the overall exposure indicator (i_{exp}):

$$CI = \llbracket (i_h * i_{exp}) \rrbracket^{\frac{1}{2}}$$

The hazard indicator is ranked from 0 to 5 (None, Very Low, Low, Medium, High and Very High).

The overall exposure indicator is ranked from 1 to 5 and is the result of the consideration of five types of exposure representative of the potential direct and indirect impacts: Land Use ($i_{exp\text{-}LU}$), Social Vulnerability ($i_{exp\text{-}SVI}$), Transport ($i_{exp\text{-}TS}$), Utilities ($i_{exp\text{-}UT}$), and Business ($i_{exp\text{-}BS}$). Each is ranked from 1 to 5 (None or Very Low, Low, Medium, High and Very High) and the overall exposure indicator is calculated as:

$$i_{exp} = \llbracket (i_{exp-LU} * i_{exp-SVI} * i_{exp-TS} * i_{exp-UT} * i_{exp-BS}) \rrbracket^{1/5}$$

As the geometric mean is used, a null value should never be used for an exposure indicator.

The ranking is case specific and, therefore, will not support any cross case-studies or cross-hazard comparison.

Table 3.7: Calculating the Coastal Index

Sector	Km$_1$	Km$_2$	Km$_3$
Land Use ($i_{exp\text{-}LU}$)	3	2	3
Social Vulnerability ($i_{exp\text{-}SVI}$)	3	2	1
Transport systems ($i_{exp\text{-}TS}$)	2	3	1
Utilities ($i_{exp\text{-}UT}$)	4	2	1
Business Settings ($i_{exp\text{-}BS}$)	3	1	2
Exposure Indicator	2.93	1.89	1.43
Hazard ($i_{cf\text{-}a}$)	2	3	1
Coastal Index ($CI_{cf\text{-}a}$)	**2.42**	**2.38**	**1.20**

The coastal indices should be mapped and discussed with stakeholders (Figure 3.5). A hotspot may be a single sector or a combination of sectors with the highest CI (see the red circles in Figure 3.5). In consultation with stakeholders, the final shortlist of hotspots should be defined and a more detailed risk analysis undertaken in Phase 2. This continued engagement with stakeholders is also important in order to improve the quality and accuracy of the outcomes of the screening process.

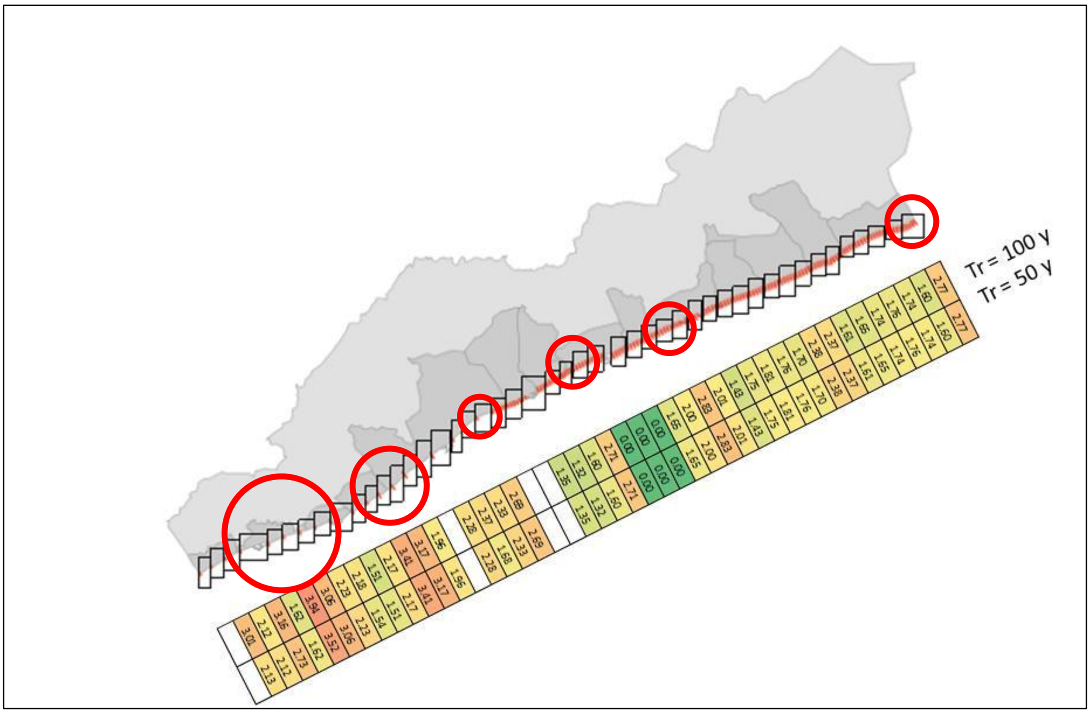

Figure 3.5: Coastal index for flooding, CI-cf along the Maresme coast (Catalonia, ES)

4 Phase 2: Hotspots risk analysis and selection

4.1 Introduction to Phase 2

Following the completion of Phase 1 the user should have identified several hotspots along the coast. As already explained in Section 3, although the Coastal Index approach is relevant for a first screening, is insufficient to fully assess the risk and select the hotspot(s) for even more detailed analysis (WP3). Phase 2 provides the techniques and the methods to undertake this intermediate risk assessment by analysing the impacts comparatively. In addition, Phase 2 builds on the approach adopted in Phase 1 as it considers vulnerability and recovery. To do so (see Figure 4.1), for each hotspot the user has to:

- Model the considered hazards for the selected return-period storm using a 1D, process-based, multi-hazard model (XBeach 1D) and, if necessary, a simple 2D flood model (Section 4.2);
- Assess the storm impacts at the regional scale using INDRA (Section 4.3);
- Score the hotspots using a Multi-Criteria Analysis (Section 4.4);
- Rank the hotspots scores;
- In consultation with stakeholders, select the hotspot(s) using complementary information provided through CRAF Phase 2 (e.g. visualisation maps, data quality, limits in methodology etc.).

However to rank and compare the hotspots it is necessary to frame consistently the analysis by:

- Considering the same return period(s);
- Considering the same regional scale, receptors and vulnerability dataset(s);
- Considering the same weighting in the MCA.

Through maintaining this consistency within the regional assessment boundary, the approach moderates the bias introduced by the uncertainty and the lack of data by being comparative in nature. Any deviation from this consistent approach will invalidate the comparison.

Phase 2 requires each shortlisted hotspot to be assessed separately (one event for one hotspot) and an MCA score generated for each. However, it could also be relevant to assess all shortlisted hotspots affected at the same time by the same event[38] (i.e. one storm multiple hotspots). This is because the combination of multiple direct impacts along the regional coast may lead to greater disruption.

It is important for the user to keep in mind that Phase 2 is not strictly a quantitative assessment of the risk and cannot be used as such for cost-benefit analyses without further development. The MCA scores should also not be compared with those scores obtained for other regional cases (i.e. it is only valid for intra-regional comparison).

[38] In CRAF an event is defined by a deterministic approach or response approach.

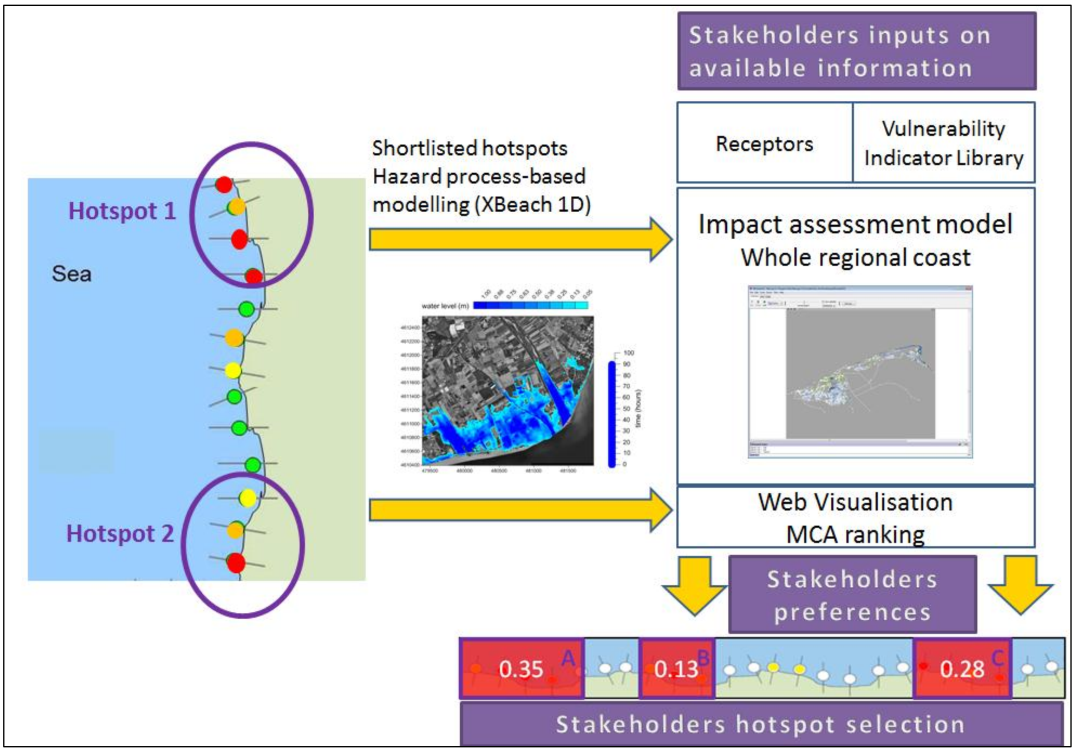

Figure 4.1 Approach and models in Phase 2

4.2 Hazard

The CRAF for storm-induced hazards has been designed to be generally applied in two phases or steps (Figure 4.2), to optimise the hazard assessment at large spatial scales (regional, in the order of 100 km):

- Phase 1 (identification of hotspots): in which the magnitude of the induced hazards (erosion and inundation related) is calculated using simple models at a regional scale. This will permit a first identification of sensitive areas along the coast to the impact of extreme events. This selection will be based on the frequency and intensity of the induced impacts in geomorphic terms;
- Phase 2 (hotspot selection): where the XBeach advanced model is applied to shortlisted sensitive stretches to better (more accurately) quantify the magnitude of storm-induced hazards.

4.2.1 Approach

In order to further analyse the hazards at these shortlisted hotspots, the adopted response approach (see Section 3.1.2.2) is maintained but uses more advanced models to quantify the associated magnitude.

The following information is used in Phase 2[39]:

- A number of hotspots along the coast which have been identified as sensitive, identified in Phase 1;
- Each hotspot will be characterized by a sediment grain size and a set of beach profiles. The beach profiles should be selected (number and location) to properly represent the spatial coastal variability at the hotspot scale and thus the potential variability in the morphodynamic response to the considered hazards. A spacing in the order of 200 m is recommended;
- The full set of storms identified in Phase 1 from the existing wave and/or water level (long) time series;
- A digital terrain model of the hinterland.

The following sections describe the approach and procedure to be applied for the different hazards.

4.2.1.1 Flooding-related hazards

Where inundation is the dominant hazard (i.e. coastal erosion is not an issue), such as for protected/sheltered estuaries and/or protected coastlines, the following steps should be used:

A. Compile for each of the identified stretches, the results obtained from Phase 1: which are the extreme probability distributions of total water level;

B. Select the target water levels associated with the return periods of interest (e.g. 10, 50, 100, 500 years);

[39] In addition, this has either been used in, or compliments, Phase 1.

C. Assess for target water levels the magnitude of the inundation in the analysed hotspot by using an inundation model. This must include (at least) the extent of the flood prone area and the water depth.

4.2.1.2 Erosion-related hazards

For cases where coastal erosion is the dominant hazard, such as for open sedimentary coasts affected by storms and where the extent of the storm impact is restricted to a narrow fringe without significantly affecting the hinterland, the following steps should be used:

A'. Compile for each of the identified stretches, the storm dataset used in Phase 1 (Retained variables defining the storm: Hs, Tp, direction, duration, water level).

B'. Apply the XBeach 1D model to selected beach profiles for analysed hotspots to compute storm-induced erosion for each identified/selected storm (A'). The following variables will be retained: (i) shoreline retreat; (ii) eroded volume in the beach (inner part of the beach profile); (iii) overwash (sediment) volume - if applicable-; (iv) volume of water – overtopping - entering the hinterland. The last two variables are not strictly erosion-related parameters, but they are included here because they are usually induced under erosive conditions and they are calculated using the morphodynamic model.

C'. Fit calculated magnitudes of storm-induced erosion (B', selected depending on the interest to the case) to an extreme probability distribution (e.g. G.P.D. when using POT to identify storms or G.E.V. when using annual maxima).

D'. Calculate the associated erosion magnitude (e.g. shoreline retreat) for each selected probability (return period of interest) (e.g. 10, 50, 100, 500 years).

4.2.1.3 Combined erosion/flooding related hazards

This section describes the process for coasts which experience both erosion and inundation. It can be considered to be the most typical situation. For example, it may correspond to an open sedimentary coast which when subjected to the impact of a storm the beach erosion induces a change in beach morphology which increases the volume of water entering the hinterland. In this case, we repeat the steps A' to D' previously described to assess erosion-related hazards. The main variable to be retained is the volume of water -overtopping- entering the hinterland (iv) associated with selected return periods. Then, it is also necessary to assess for target water levels the magnitude of the inundation in the analysed hotspot by using an inundation model. This must include (at least) the extent of the flood prone area and the water depth (equivalent to step C for flood-related hazards).

It should also be noted that, in the case of overwash-dominated situations where the hinterland is not inundated and is concentrated in a narrow fringe just behind the beach, the assessment of the magnitude of the affected area is directly solved by applying the XBeach model.

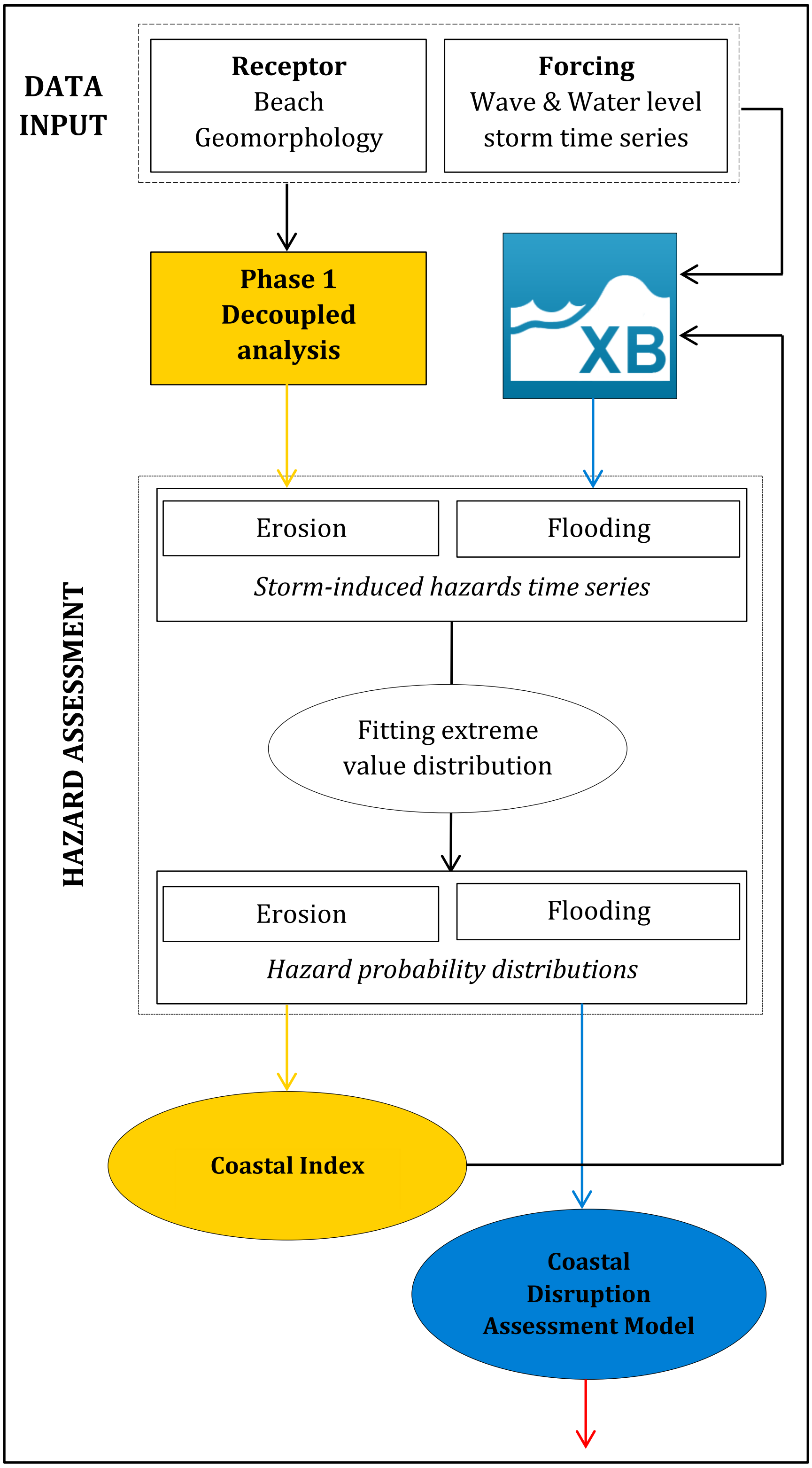

Figure 4.2: General Storm-induced Hazard Assessment Module. Flooding and erosion are the generic names used to designate a series of related hazards

4.2.2 Hazard modelling

With respect to storm-induced changes in beach morphology, in RISC-KIT XBeach 1D model has been selected and is described in detail in deliverables D3.2[40] and D2.1[41]. This 1D profile-mode version of XBeach has been selected because, although being a process-oriented model able to fully characterise the coastal response to the storm impact, it is not too time-consuming. This permits the adopted response approach to be maintained by applying it to a relatively large dataset of storms. Readers are referred to deliverable D.2.1 for details on model application.

For storm-induced inundation, there is not a specific model adopted and/or developed within RISC-KIT, and so the existing LISFLOOD-FP model is recommended. This is a raster-based inundation model, which has been successfully employed to simulate inundations in fluvial and coastal areas[42 43 44 45].

In LISFLOOD-FP, flooding is calculated by using a volume-filling process based on hydraulic principles and by embodying the key physical notions of mass conservation and hydraulic connectivity. It treats floodplain flows using a storage cell approach first developed by Cunge et al. (1980)[46], and which is implemented for a raster grid to allow an approximation for 2D diffusive wave and momentum equations for each direction. In this model, flow between cells is calculated according to Manning's

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[40] Roelvink, D., Dastgheib, A., Spencer, T. Möller, I., Christie, E., Berenguer, M., Sempere-Torres, D., van der Meer, J., Mehvar, S., Nederhoff, K., Vermin, W. (2015) Improvement of physical processes XBeach improvement & validation; wave dissipation over vegetated marshes and flash flood module. RISC-KIT Deliverable D3.2: http://www.risckit.eu/np4/file/23/RISCKIT_D.3.2_Improvement_of_Physical_Pr.pdf (accessed 05.11.2015).

[41] Jiménez, J.A., Armaroli, C., Berenguer, M., Bosom, E., Ciavola, P., Ferreira, O., Plomaritis, H., Roelvink, D., Sanuy, M., Sempere, D. (2015) Coastal Hazard Assessment Module. RISC-KIT Deliverable, D2.1: http://www.risckit.eu/np4/file/23/RISCKIT_D.2.1_Coastal_Hazard_Asssessment.pdf (accessed 05.11.2015).

[42] Bates, P.D. and De Roo, A.P.J. (2000) A simple raster-based model for floodplain inundation. Journal of Hydrology. 236, 54-77.

[43] Bates, P.D., Dawson, R.J., Hall, J.W., Horritt, M.S., Nicholls, R.J., Wicks, J., Hassan, M.A.A.M. (2005) Simplified two-dimensional numerical modeling of coastal flooding and example applications. Coastal Engineering 52, 793-810.

[44] Purvis, M., Bates, P.D. and Hayes, C.M. (2008) A probabilistic methodology to estimate future coastal flood risk due to sea level rise. Coastal Eng.; 55:1062–1073.

[45] Dawson, R. J., Dickson, M. E., Nicholls, R. J., Hall, J. W., Walkden, M. J. A., Stansby, P. K., Mokrech, M., Richards, J., Zhou, J., Milligan, J., Jordan, A., Pearson, S., Rees, J., Bates, P.D., Koukoulas, S., Watkinson, A. (2009) Integrated analysis of risks of coastal flooding and cliff erosion under scenarios of long term change, Climatic Change; 95: 249–288.

[46] Cunge, J.A., Holly, F.M., Verwey, A. (1980) Practical aspects of computational river hydraulics. Pitman Advanced Publishing Program, Boston, p.420.

formula. The model predicts water depths in each grid cell at each time step, simulating the dynamic propagation of flood waves over the floodplain.

In the analysis the data inputs are specified as a time series of water flow at the shoreline bordering the coastal plain (calculated through the overtopping rates). The input data for the LISFLOOD-FP corresponds to the calculated overtopping values associated with the selected return period for different points of discharge. These points are selected as a function of the beach morphology: ideally, a potential hotspot is described by a series of beach profiles, each one being representative of a coastal stretch of similar morphology and, in consequence, overtopping volumes calculated for a given profile are extended for the represented stretch. The final result of the model is data about the extent, depth, time, and mass flow of the flood.

For each shortlisted hotspot the outcomes of the XBeach 1D and inundation model is on its own insufficient to undertake a hotspot selection. Indeed, the information about storm-induced coastal hazard intensities is a fundamental, but only a partial element of risk assessment. To select the hotspot the hazard needs to be translated into coastal impacts. This process and its application within the CRAF are described in the next section.

4.3 Integrated Disruption Assessment (INDRA) model

The INDRA model is developed to align with current considerations of societal resilience. The Sendai Framework for Disaster Risk Reduction (2015-2030) warns that disasters are "significantly impeding progress towards sustainable development"[47] and of the necessity to better anticipate such risk for community and business. From a natural hazard perspective, unsustainable development can be interpreted as the lack of ability for a system or a sub-system to return to a state similar to the one prevailing prior to a disaster[48]. Turner et al. (2003: 8075)[49] indicate that the "resilience of the system is often evaluated in terms of the amount of change a given system can undergo and still remain within the set of natural or desirable states". The adopted Sendai Framework resilience definition is similar: "the ability of a system, community or society to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner including through the preservation and restoration of its essential basic structures and functions"[50]. In the CRAF the scale of analysis (system) is the region, the objective being to provide a model able to compare its resilience under the threat of coastal hazards on various hotspots along the coast.

It can also be noted that sustainable development also requires the stakeholders' perspective should be captured to better understand the desirable states[51]. This remains an important challenge and adds complexity to the characterization of a regional system as different stakeholders may have different perspectives, needs and purposes and, therefore, approach systemic sustainability differently[52]. The use of a Multi-Criteria Analysis, as a way to convey various preferences, was favoured in the model to compare the resilience and, as consequences, in valuing the model outcomes and expressing the risk.

Risk is defined in the CRAF as the product of the *probability of a hazard and its*

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[47] UNISDR (2015) Sendai Framework for Disaster Risk Reduction 2015 – 2030. March 2015. Geneva, Switzerland. P10. Available at: http://www.unisdr.org/we/inform/publications/43291 (accessed 05.11.2015).

[48] Birkmann, J. (2006) Measuring vulnerability to natural hazards: towards disaster resilient societies. United Nation University Press. ISBN 92-808-1135-5. p400.

[49] Turner, B.L., Kasperson, R.E., Matson, P.A., McCarthy, J.J., Corell, R.W., Christensen, L., Eckley, N., Kasperson, J.X., Luers, A., Martello, M.L., Polsky, C., Pulsipher, A., Schiller, A. (2003) A framework for vulnerability analysis in sustainability science. Proceedings of the National Academy of Sciences of the USA 100(14) (8 July): 8074-8079.

[50] United Nations Office for Disaster Risk Reduction (UNISDR) (2009) UNISDR Terminology on Disaster Risk Reduction. May 2009. Geneva, Switzerland. Available at: (http://www.unisdr.org/we/inform/terminology (accessed 05.11.2015).

[51] Fiksel, J. (2006) Sustainability and resilience: toward a systems approach. Sustainability: science, practice & policy Vol 2 Issue 2.pp 14-21.

[52] Green, C., Viavattene, C. and Thompson, P. (2011) Guidance for assessing flood losses. Deliverable 6.1. FP7 EU Project CONHAZ 244159. Available at: http://www.mdx.ac.uk/__data/assets/pdf_file/0006/58794/floodsWP_FINALREPORTsept11.pdf (accessed 05.11.2015).

consequences. These consequences (or impacts) are composed of two factors: the direct exposure (the density of receptors, e.g. number of people and buildings in an affected area) and vulnerability (receptor value and their sensitivity to experience harm). The current definition takes its origin in the Source-Pathway-Receptor (SPR) model[53]. The SPR approach focuses on assessing direct losses and attempts to measure the first order of losses (e.g. business disruption of flooded business) and is commonly employed in the field of economic loss assessment applied to natural hazards. The approach has its advantages but neglects higher order losses, also called indirect losses or induced losses[54] [55] [56]. Rose (2010)[57] proposes to change radically the current assessment approach by considering flows rather than stocks and by better integrating the time dimension. In the RISC-KIT project, this problem is also recognized and has been addressed in INDRA.

Figure 4.3 provides an overview of the impact assessment process developed in Phase 2. Overall the process provides a regional assessment of various impacts on different categories (population, business, ecosystems, transport and utilities). Regional assessment means that the final indicators are aggregated at the regional scale in order to reveal the relative impact and to compare hotspots. To do so, the impact is first calculated at the receptor levels (direct exposure) and, then, converted into the wider disruption impacts (indirect and systemic). As such, for:

- **Population**: Impacts on population are addressed by three different impact indicators. The risk to life impact is calculated for all land uses and indicates the potential risk to the population during an event. The potential damages to household property are also calculated considering the impacts of flood and erosion and, from there, displacement time and financial recovery is derived to indicate the indirect impacts on households;
- **Business**: similarly damages to business property are estimated. Such damages result in two indirect impacts: differences in financial recovery and the systemic consequences of business disruption at a regional scale for supply chains;
- **Ecosystems**: the direct impacts are converted into an ecosystem recovery

[53] Gouldby, B., Samuels, P., Klijn, F., Van OS, A., Sayers, P., Schanze, J. (2005) Language of Risk - Project definitions. EU Floodsite project. Available at: http://www.floodsite.net/html/partner_area/project_docs/FLOODsite_Language_of_Risk_v4_0_P1.pdf (accessed 05.11.2015).

[54] Messner, F.; Penning-Rowsell, E.; Green, C.; Meyer, V.; Tunstall, S., Van der Veen, A., (2007) Evaluating flood damages: guidance and recommendations on principles and methods. EU Floodsite project N. GOCE-CT-2004-505420.

[55] Penning-Rowsell, E.C., Priest, S., Parker, D., Morris, J., Tunstall, S., Viavattene, C., Chatterton, J., Owen, D.J. (2013) Flood and Coastal Erosion Risk Management: A Manual for Economic Appraisal, London, Routledge.

[56] Rose, A. (2010) Economic principles, issues, and research priorities in hazard loss estimation. In modelling spatial and economic impacts of disasters – Springer edition. Pp 13-36.

[57] Ibid.

indicator by assessing potential changes in specific ecosystems;

- **Others**: the direct impacts can be assessed for other land uses. However if not included in one of the previous categories they are not incorporated in the final regional indicators. If relevant for certain stakeholders, these impacts can be exported and further analysed by users;
- **Transport**: The direct impacts to specific assets (roads, rail lines or stations) are assessed considering their importance and location in the regional network in order to indicate the overall transport disruption;
- **Utilities**: The direct impacts to specific assets (water plants, power grids or substations) are assessed considering their importance and location in the regional network in order to indicate the overall loss of service.

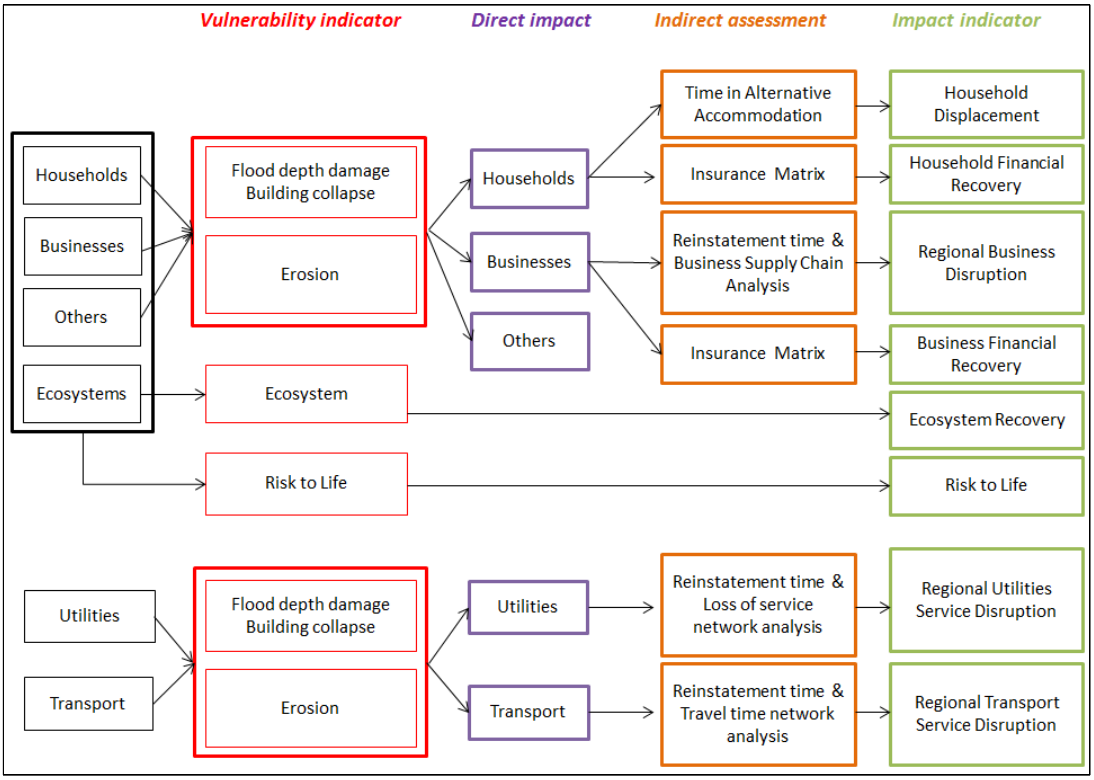

Figure 4.3: Overview of the impact assessment process in INDRA

Such assessment requires combining information on hazards, receptor location and their characteristics, vulnerability information and also on networks. To facilitate the process and to provide a structured assessment an open-source model has specifically been developed in RISC-KIT (INDRA). The model allows the assessment of direct and indirect impacts on receptors, the scoring and normalization of each indicator at a regional scale and the calculation of an MCA score considering preferences of stakeholders. The model is introduced in the next section. The different approaches to calculate each impact are then fully described as well as how to import the data into the model.

4.3.1 NetLogo Model

The INDRA model has been developed using the NetLogo free software version 5.2. The software can be downloaded from https://ccl.northwestern.edu/netlogo/.

INDRA (zip file), developed by FHRC-MU, is available from the RISC-KIT website (http://www.risckit.eu/np4/8/) with examples of data. The file can be unzipped as preferred by the end user, but it is recommended to unzip it in the "models" folder associated with the NetLogo software.

The model file (*INDRA.nlogo*) can be opened using the options "open" or "models library" in the file menu (Figure 4.4). The NetLogo consists of a menu, three tabs (Interface, Info and Code), a command centre window and an observer bar.

All the commands to run the impact assessment model are available on the interface. It is possible for the user to access the code, however it is not necessary to change it in order to run the model.

The interface contains 4 major interactive components:

- Input files;
- A map (a world) and associated menu;
- Plots for viewing results;
- A Multi-Criteria Analysis.

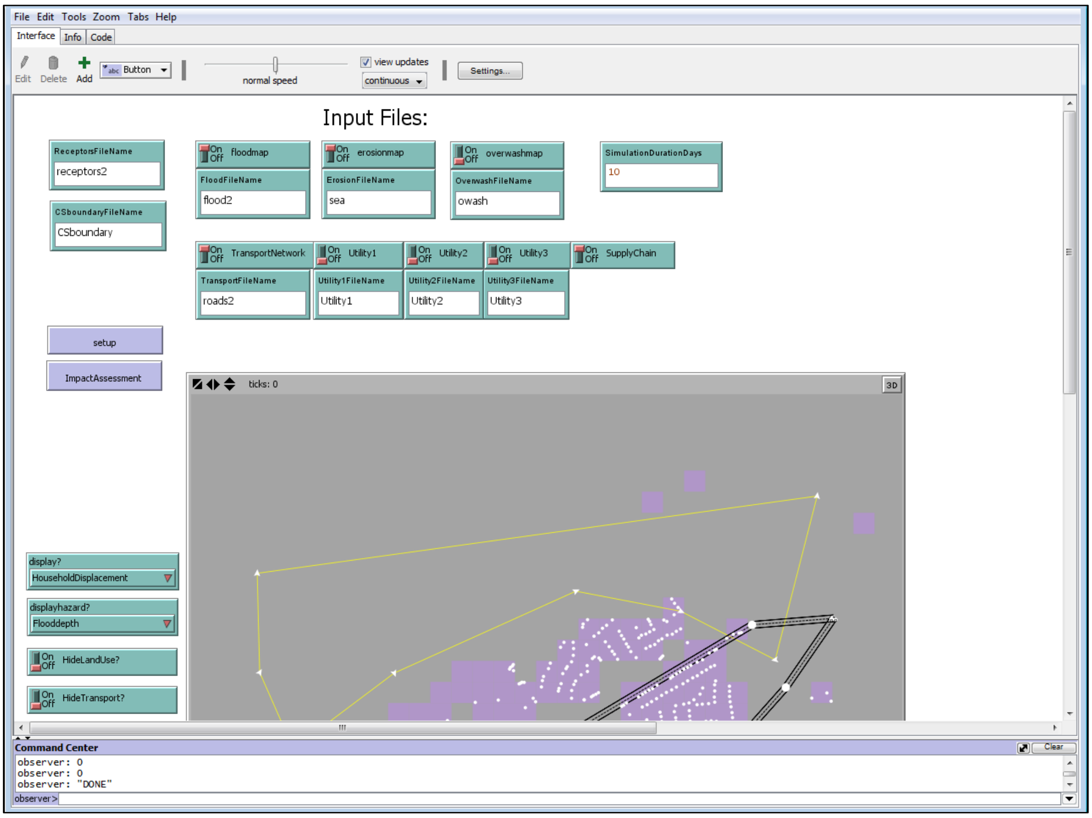

Figure 4.4: The INDRA (interface)

4.3.1.1 Input files[58]

A number of boxes are available at the top of the interface (Figure 4.5). The boxes allow the user to provide the names of the required files and specify if they are available or not. A Land Use file, Regional Boundary file and one hazard map (i.e. type of hazard, e.g. flooding, overwash etc.) are necessary requirements to run the model. The user has the opportunity to consider one or more hazard maps by turning turn on the relevant hazards switch (e.g. “floodmap”, “erosionmap” and “overwashmap”). Similar switches are available for the various networks. All of the input files must be in an “inputfiles” folder situated at the same root level as the model code file.

The “SimulationDurationDays” lets the user define the length of the simulation in days. This has consequences for the calculation of the disruption indicators.

The user can then press the “setup” button to load the data. Please see the next sub-section on how to prepare the files.

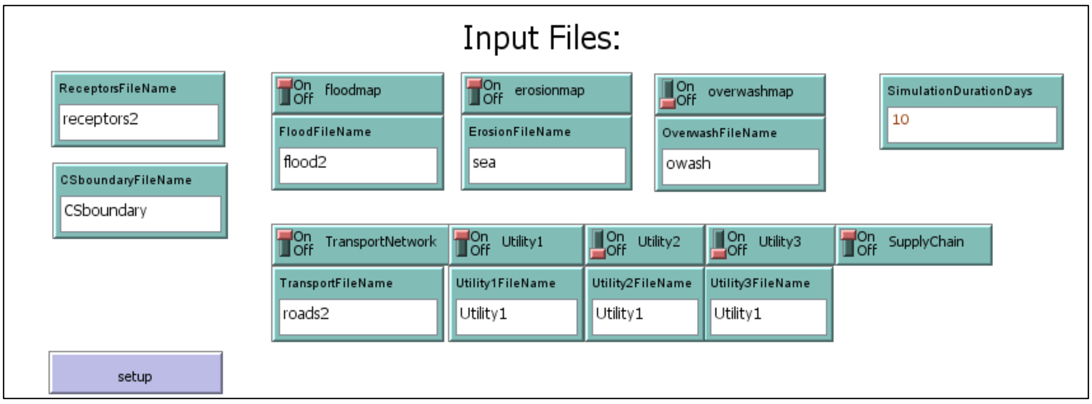

Figure 4.5: The Input Files Boxes

4.3.1.2 A map (a world) and associated menu

A simple map is available for visualising hazards, receptors and impacts (see Figure 4.6). Map functionality is limited in NetLogo. However, the user can change the impact and hazard display with some menu buttons. By right clicking on an object within the map the user can also inspect it. To run the simulation, simply click the “Impact Assessment” button.

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[58] See Appendix C for a full description of the Input files.

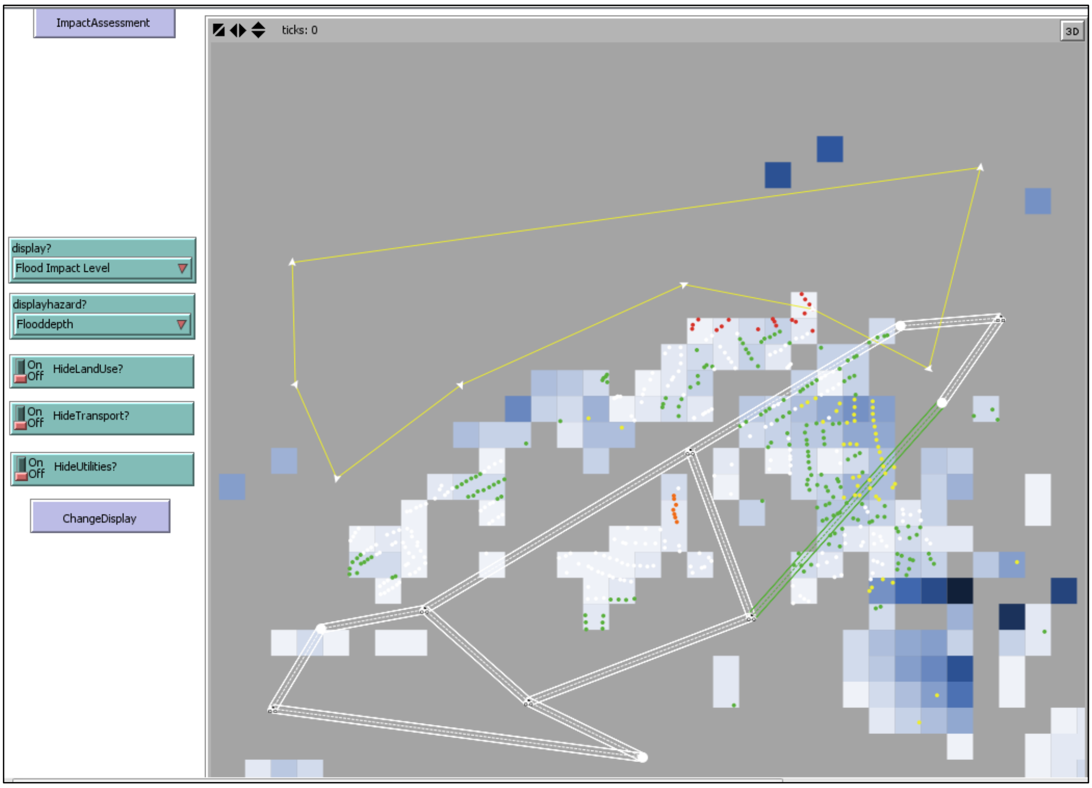

Figure 4.6: Visualisation Map

4.3.1.3 Plots for viewing results

The user can view their results on the visualisation map but also on different plots provided under the map (Figure 4.7).

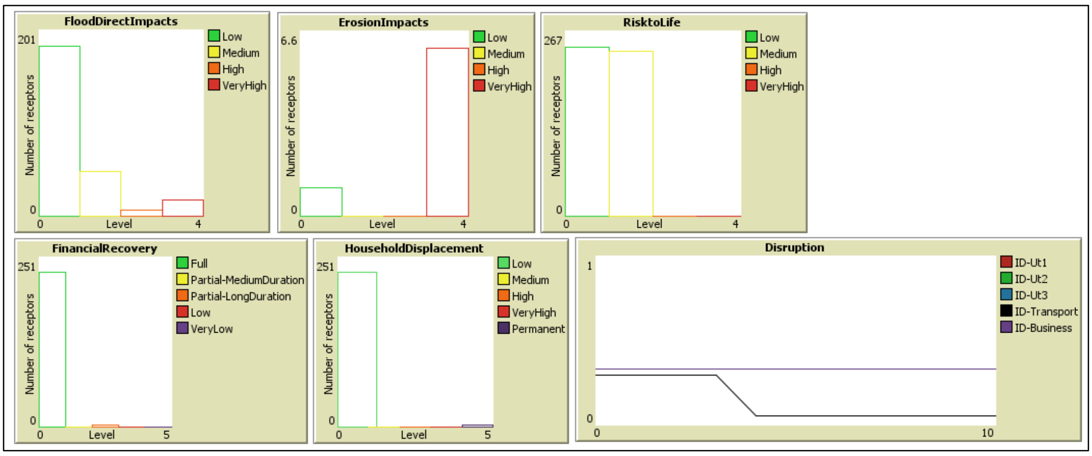

Figure 4.7: Impact Plots Interface

4.3.1.4 A Multi-Criteria Analysis Interface

The user can perform a Multi-Criteria Analysis within the model by inputting their preferences for the different indicators (see Section 4.4.4).

4.3.1.5 Outputs of results

The model automatically generates four output text files:

- "DirectImpactsLU.txt": outcomes for each land use receptor (Figure 4.8);
- "DirectImpactsTransport.txt": outcomes for each transport receptor;

- “DirectImpactsUtilities.txt”: outcomes for each utility receptor;
- “DisruptionImpacts.txt”: daily disruption indicators for businesses, utilities and transport.

The output text files can be used for GIS visualisation (the receptors ID being used to join the outputs with the original receptor shapefiles) and for further analysis.

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
receptorID	Rcode	MCAcat	area	nbunits	elevation	Fdepth	Fdv	Fduration	Fimpactlevel	Distancetoshore	Eimpactle	RecoveryTime	risktolife	financialrecovery	lossServic
237	HProp	Household	25	1	0.3	0.1	0.1	4	0	216.3885484	0	0	1	0	0
212	HProp	Household	25	1	0.3	0.5	0.5	4	1	302.1651207	0	0.28	2	1.15	1
207	HProp	Household	25	1	0.3	0.4	0.4	4	1	313.1203025	0	0.28	2	1.15	1
344	HProp	Household	25	1	0.3	0.2	0.2	4	0	148.07145	0	0	1	0	0
321	HProp	Household	25	1	0.3	0.1	0.1	4	0	110.8580648	0	0	1	0	0
89	HProp	Household	25	1	0.3	0.31	0.31	4	1	82.78935009	0	0.28	2	1.15	0
197	HProp	Household	25	1	0.3	0.31	0.31	4	1	185.0785553	0	0.28	2	1.15	0
400	HProp	Household	25	1	0.3	0.2	0.2	4	0	283.2657067	0	0	1	0	1
381	HProp	Household	25	1	0.3	0.31	0.31	4	1	213.702684	0	0.28	2	1.15	1
123	HProp	Household	25	1	0.3	0.2	0.2	4	0	101.5871011	0	0	1	0	0
305	HProp	Household	25	1	0.3	0.31	0.31	4	1	175.6352595	0	0.28	2	1.15	0
405	Sd	Ecosystems	25	1	0.3	0.1	0.1	4	4	61.0695664	0	1004	1	0	0
103	HProp	Household	25	1	0.3	0.2	0.2	4	0	467.3883452	0	0	1	0	0
96	Sd	Ecosystems	25	1	0.3	0.1	0.1	4	4	2.94E-10	0	1004	1	0	0
163	HProp	Household	25	1	0.3	0.8	0.88	4	2	164.1932508	0	1.94	2	1.655	0
33	Wl	Ecosystems	75	1	0.3	0.2	0.2	4	3	380.4040846	0	0	1	0	0
85	HProp	Household	25	1	0.3	0.1	0.1	4	0	152.564503	0	0	1	0	0
287	HProp	Household	25	1	0.3	0.2	0.2	4	0	129.4574917	0	0	1	0	0
416	HProp	Household	25	1	0.3	0.31	0.31	4	1	248.3460841	0	0.28	2	1.15	1
40	HProp	Household	25	1	0.3	0.31	0.31	4	1	169.8096289	0	0.28	2	1.15	0

Figure 4.8: Example of an output text file

4.3.2 Direct impacts

The direct impacts are the losses resulting from a direct exposure of receptors to the hazard: damages to properties and infrastructure, loss of stock and items, building collapse, injuries, fatalities etc. To assess the wider potential disruption impacts it is first necessary to consider this initial shock caused by a hazard (see Figure 4.3). To do so, the losses are expressed as a function of the receptor characteristics (expressed in terms of vulnerability), the intensity of the hazards, the presence of mitigation measures and the location and the elevation of each asset defining their level of exposure.

4.3.2.1 Selected approach

Deliverable 2.2, *Library of Coastal Vulnerability Indicators*[59] introduces the necessary concepts and methods to produce vulnerability indicators and provides existing indicators where available. These concepts and methods will not be covered again in this document. However, as the Library only provides a review of existing indicators and methods, it remains necessary to adapt some of these for the purpose of the CRAF.

The review of vulnerability indicators (Deliverable 2.2) has highlighted differences in the expression of vulnerability indicators depending on the receptor type, the considered hazard and the resulting impacts (Table 4.1). The availability of data from one country to another also differs largely and the consideration of local or regional differences is also often ignored with the indicator being built to reflect national averages. Although the use of detailed data for a full impact assessment and project appraisal are required, a simplified approach is considered the most appropriate for a

[59] Viavattene, C., Micou, A.P., Owen, D.J., Priest, S. and Parker, D.J. (2015) Library of Coastal Vulnerability Indicators. RISC-KIT Project Deliverable D2.2: http://www.risckit.eu/np4/8/ (accessed 05.11.2015).

screening approach such as the CRAF. The main considerations are for the approach to be:

- Applicable for various types of receptor;
- Applicable for multiple types of impact;
- Not data demanding;
- Sufficient to highlight major differences in impacts;
- Comparative rather than quantitative;
- Easy to use;
- Flexible (from less to more detailed approach).

Except for the very detailed depth-damage curves available for building assets, other vulnerability indicators are generally limited to a few hazard thresholds intensities in order to derive a magnitude of impacts. The approach was deemed sufficient and appropriate for the objectives of the CRAF Phase 2 impact assessment model. Therefore a generic approach is used for all receptors and the direct assessment, i.e.:

- To consider a receptor and the main related impact (Table 4.1);
- To define a scale of impact (None, Low, Medium, High and Very High) and to associate a descriptive information on the scale (Figure 4.9);
- To define the main hazard intensity responsible for the impact;
- To define a hazard threshold for each scale of impact.

The five-scale approach necessitates defining four thresholds with the information provided in the Library of Coastal Vulnerability Indicators. The application for specific receptors will be detailed in the following dedicated sections.

Table 4.1: Direct impact, hazards intensities and vulnerability indicators

Category	Direct impacts	Hazard intensities (main)	Vulnerability indicators
Built Environment (properties and other assets including transport and utilities networks)	Inundation damages	Flood depth, Duration	Depth-damage curves
	Collapse	Flood depth-velocity	Risk matrix
	Evacuation and collapse	Erosion distance shoreline	Distance-based approach
Population	Risk to life	Flood depth-velocity	Risk matrix
Ecosystems	Change in habitats	Duration, depth, sedimentation	Impact scale

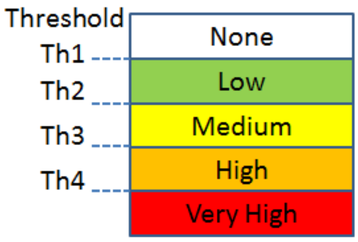

Figure 4.9: Impact scales and thresholds

The comparison between the different hotspots is not based on the direct impact assessment but on the indirect impacts (disruption) and the recovery process. In order to assess these, it might be necessary to consider the time required for receptors to return to their original state (resilience). The reinstatement time can, in some cases, simply be associated with the repair time. In other cases, various factors influence the recovery process and are difficult to disentangle. Thus reinstatement is associated with recovery time. The model allows such a consideration by associating an average time with the different levels of direct impacts.

4.3.2.2 Application of the methodology within the model

To assess the level of impact for the different receptors exposed directly to the hazard, for each receptor, the following information is required:

- The hazard intensities at the receptor's geographic location;
- The receptor characteristics;
- The receptor vulnerability.

Hazard intensities

Hazard maps (see Section 4.2) in a GIS format are directly imported into the model (Figure 4.10):

- A flood map consisting of polygons representing hazard intensities (depth, depth-velocity, duration etc.). The model will attribute the intensity values to the receptors falling within a polygon.
- An erosion map consisting of polygons, representing the marine domain and the shoreline. The model will consider that any receptor falling within a polygon is not part of the hinterland and will also calculate the distance between the receptor and the new shoreline.

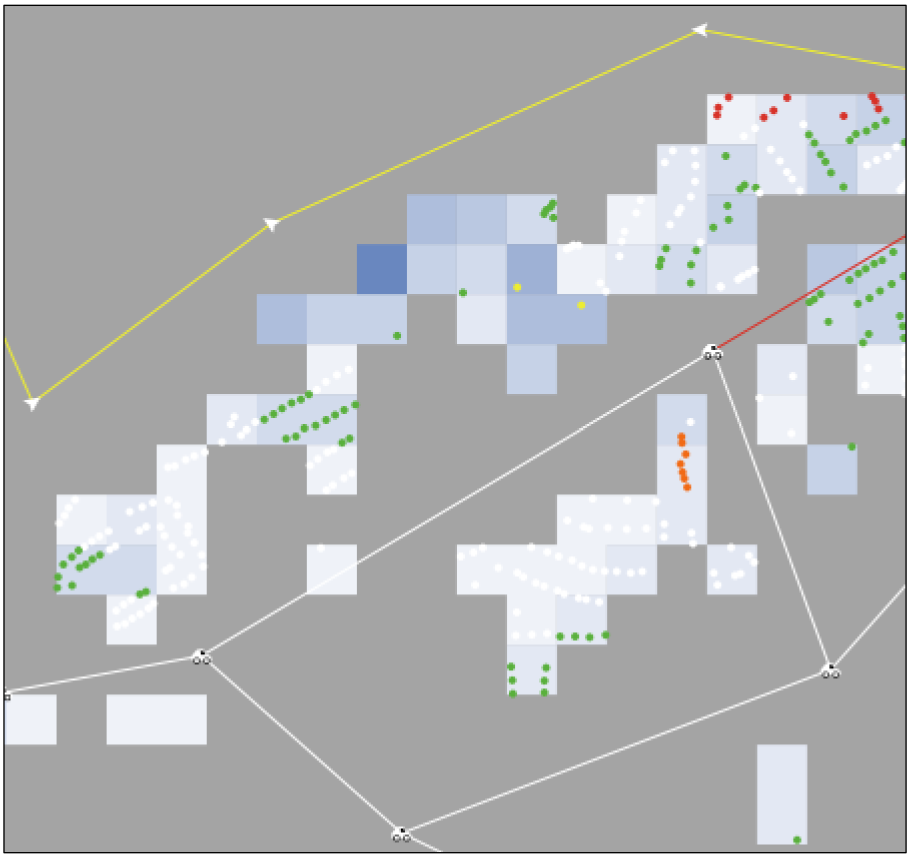

Figure 4.10: Land Use (dots), Road Networks (white and red lines and cars), shoreline (yellow line) and flood depth (blue squares) after importation in the model

Land use

Except for utilities and transport networks (see Sections 4.3.8 and 4.3.9) all the other receptors are imported in a GIS format (points shapefiles). The land use attributes inform the model about the type of land use, the nature of the area (for risk to life calculation), the associated number of receptors (if the land use such as a residential area represents multiple properties), the surface area and other information (see Appendix C for more details).

The user should note that the use of points and not polygons means that each land use will only be associated with one hazard intensity. For properties or assets the approach is relevant, but for larger sites (e.g. open spaces, leisure facilities, commercial units, ecosystems – depending of the hazard map resolution) it might be appropriate to split one area into multiple points. For instance, if the loss of a beach is important for touristic purposes, representing the beach by one point cannot provide the information of the potential surface loss by erosion. In such cases, the beach should be subdivided per a defined surface, each sub-division represented by a receptor point.

Vulnerability

The inputs to associate the hazard thresholds with an impact level for different receptor types are all provided in one text file. In order to prepare the text file, the following table (Table 4.2) should be completed using information from the Library of

Coastal Vulnerability Indicators (the value 9999 indicates that the threshold is not applicable):

Table 4.2: Examples of hazard thresholds with their impact levels

Category	Impacts	Hazard	Receptor	Code Receptor _Hazard	Th1	Th2	Th3	Th4
Built Environment	Depth-damage curves	Flood depth	Any Buildings	Prop_fd	0	0.25	0.9	9999
	Building collapse	Flood depth velocity	Any Buildings	Prop_fdv	9999	9999	3	7
	Erosion	Shoreline Change	Any Buildings	Prop_Er	10	5	9999	0
Population	Risk to Life	Flood Depth velocity	Low Vuln Site	N1_fdv	0	0.5	9999	7
Ecosystems	Sand dunes	Duration	Sand dunes	Sd_fdur	0	9999	1	2
	Woodland	Duration	Woodland	Wl_fdur	0	1	3	9999
	Crops	Flood	Winter cereals	Cwc_fd	9999	0	9999	9999

Similarly a value for reinstatement time can be associated for each threshold (a 9999 used if not applicable). Except for households (see Section 4.3.5) the value represents a number of days. For instance 5 days to repair a flooded sub-station. Both sets of information are included in the "CHT_ForINDRA.txt". For each receptor hazard code, a line in the file provides the following variables (see Figure 4.11):

- A comment in quotations introducing the considered vulnerability indicator (e.g. "dd curves for prop any type flooding") is not used by the model but is required;
- A CodeHazardThresholds in quotations: the code comprises two elements separated by an underscore. The first element is the reference code for the receptor (see receptor vulnerability code). The user is free to use a code of their choosing provided that it matches those used in the different receptor shapefiles. This is not the case for the hazard code. The following codes should be used if applicable (i.e. the hazard is considered in the assessment): fd (flood depth), fdv (flood depth-velocity), fdur (flood duration), od (overwash depth), odv (overwash depth-velocity), odur (overwash duration), er (erosion);
- Four numbers indicating the threshold value for Low, Medium, High and Very High impact. If a threshold is not applicable, a value of 9999 should be used.

For instance, Very High impact is not considered for flood damages or Low and Medium impact for building collapse (see Table 4.2);

- "Recovery" comments are used only to improve readability, e.g. describing what the value represents;

Four values indicating the reinstatement time for each impact. For instance, the blue-highlighted line (Figure 4.11) means that all property with Low impact will recover 3 days after the end of the event, a property with Medium impact will recover in 15 days. 9999 indicates that this is not applicable. Values are mainly expected for non-residential properties and infrastructure assets.

```
File  Edit  Format  View  Help
comments CodeHazardThresholds  threshold_1 threshold_2 threshold_3 threshold_4 "recovery" T1Rtime T2Rtime T3Rtime T4Rtime
"dd curves for household prop anytype flooding" "HProp_fd" 0 0.25 0.90 9999 "displacementscores" 0.28 1.94 2.62 9999
"building collapse for household prop any type flooding" "HProp_fdv" 9999 9999 3 7 "displacementscores" 9999 9999 2.62 5
"dd curves for household prop anytype overwash" "HProp_od" 0 0.25 0.90 9999 "displacementscores" 0.28 1.94 2.62 9999
"building collapse for household prop any type overwash" "HProp_odv" 9999 9999 3 7 "displacementscores" 0.28 1.94 2.62 9999
"Erosion for any household prop" "HProp_er"  10 5 9999 0 "displacementscores" 0 0 9999 5
"dd curves for business prop anytype flooding" "BProp_fd" 0 0.25 0.90 9999 "recovery" 3 15 180 9999
"building collapse for business prop any type flooding" "BProp_fdv" 9999 9999 3 7 "recovery" 9999 9999 180 1000
"dd curves for business prop anytype overwash" "BProp_od" 0 0.25 0.90 9999 "recovery" 3 15 180 9999
"building collapse for business prop any type overwash" "BProp_odv" 9999 9999 3 7 "recovery" 9999 9999 100 1000
"Erosion for any business prop" "BProp_er"  10 5 9999 0 "recovery" 0 10 9999 5000
"Risk to life for LowVulneSite" "N1_fdv" 0 0.5 9999 7 "notapplicable" 9999 9999 9999 9999
"Risk to life for MediumVulneSite" "N2_fdv" 0 0.25 1.1 7 "notapplicable" 9999 9999 9999 9999
"Risk to life for highvulsite" "N3_fdv" 0 0.25 0.5 1.1 "notapplicable" 9999 9999 9999 9999
"Sanddunes floodduration" "Sd_fdur" 0 9999 1 2 "notapplicable" 9999 9999 9999 9999
"Woodland floodduration" "Wl_fdur" 0 1 3 9999 "notapplicable" 9999 9999 9999 9999
"freshwatermarshes floodduration" "fw_fdur" 9999 0 2 10 "notapplicable" 9999 9999 9999 9999
"Sanddunes floodduration" "Sd_fdur" 0 9999 1 2 "notapplicable" 9999 9999 9999 9999
"Grassland floodduration" "Gl_fdur" 0 1 4 9999 "notapplicable" 9999 9999 9999 9999
"flooded crops winter cereals in March" "Cwc_fd" 9999 0 9999 9999 "notapplicable" 9999 9999 9999 9999
"flooded crops spring cereals in March" "Csc_fd" 9999 9999 0 9999 "notapplicable" 9999 9999 9999 9999
"flooded crops roots in March" "Cr_fd" 9999 0 9999 9999 "notapplicable" 9999 9999 9999 9999
"flooded crops grazed grass in March" "Cgg_fd" 9999 0 9999 9999 "notapplicable" 9999 9999 9999 9999
"EVI waterdepth0-1m" "SmMa1_fw" 0 0.3 0.6 2 "notapplicable" 9999 9999 9999 9999
"EVI waterdepth1-2m" "SmMa2_fw" 0 0.3 1 2 "notapplicable" 9999 9999 9999 9999
```

Figure 4.11: A snapshot of the "CHT_ForINDRA.txt"

Sections 4.3.3 to 4.3.9 now specify how the direct impacts are converted into the various Regionalised Impact Indicators.

4.3.3 Risk to Life

Although the number of deaths caused by flooding in Europe is relatively low compared with certain other hazards (particularly heat waves and earthquakes), the events with the highest death toll are usually associated with coastal flooding, flood defence failure and flash floods[60]. There are numerous factors and characteristics (including, but not limited to: social, physical, political, cultural and environmental) which lead to a loss of life during flood events[61]. As such, quantifying the potential number of fatalities remains a difficult and hazardous exercise. However, indicating the potential degree for injury or fatality during an event for a specific location is needed in risk assessment.

4.3.3.1 Selected Method

The most important determinants of the number of fatalities identified[62] [63] for events with the largest loss of life are:

- Unexpected events without substantial warning;
- Events at night;
- Where the possibilities for shelter are missing;
- High flood depths;
- High flow velocities, which can lead to the collapse of buildings and from which people are unable to escape;
- The rapid rise of waters, this is especially hazardous, as people may be trapped inside buildings;
- The physical strength and stamina of the impacted population and their ability to find shelter;
- Risk-taking behaviour;
- The absence of Disaster Risk Reduction measures, such as evacuation and rescue activities, hydrological forecasting, flood warning and response to it.

Many methods have been developed[64] [65] [66] [67] to assess potential risk to life from flood

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[60] Green, C., Viavattene, C. and Thompson, P. (2011) Guidance for assessing flood losses. Deliverable 6.1. FP7 EU Project CONHAZ 244159. Available at: http://www.mdx.ac.uk/__data/assets/pdf_file/0006/58794/floodsWP_FINALREPORTsept11.pdf (accessed 05.11.2015).

[61] Jonkman, S.N., Vrijling, J.K. and Vrouwenvelder, A.C.W.M. (2008) Methods for the estimation of loss of life due to floods: a literature review and a proposal for a new method. Nat Hazards (46). 353–389.

[62] Ibid.

[63] Brazdova, M. and Riha, J. (2013) A simple model for the estimation of the number of fatalities due to floods in Central Europe. Natural Hazards and Earth System Sciences Discussions, 1 (3). 2633-2665.

[64] Priest, S., Tapsell, S., Penning-Rowsell, E., Viavattene, C. and Wilson, T. (2008) Task 10: Building models to estimate loss of life for flood events. Executive Summary, FLOODsite Project, Report T10-08-10, HR Wallingford, UK.

[65] Jonkman, S.N., Van Gelder, P.H.A.J.M., and Vrijlink, J.K. (2002) Loss of life models for sea and river floods. In Wu et al. (eds.) Flood Defence 2002, Science Press New York Ltd., New York.

events, but most are limited to just a few of these characteristics when determining the cause of fatalities. A method which considers other aspects is the Flood Risks to People Project[68] in England and Wales, which developed a different model to predict loss of life during flooding. This method is different in that fatalities for a particular event are calculated as a function of injuries, which in turn are estimated according to the flood, area, and population characteristics, rather than applying a uniform mortality fraction to the exposed population as in the other studies[69]. The Risk to Life model proposed by Priest et al. (2007)[70] for the FLOODsite project[71] is based on this method and includes new data collected from flood events in Continental Europe. It is a generic semi-qualitative indicator, developed at EU level and using various sources of information. The Risk to Life model (see the Library of Coastal Vulnerability Indicators) is considered to be the most appropriate available option to measure the potential risk to life in the context of CRAF Phase 2 for many reasons: it is easy to use, being accessible to both experts of different disciplines and non-experts; the input data should be easily available within all countries; and finally the fact that the method was developed with new data collected from floods events with fatalities in various European countries, making it more applicable to all the European sites.

The method comprises two main input components:

- *Flood hazard:* The depth-velocity product;
- *Area vulnerability:* Three categories are proposed to indicate different vulnerabilities for locations affected by flooding. The categories are fundamentally based on the ability of those likely to be affected by a coastal event to find shelter and include four main factors: Type of land use, number of floors of a property, structural integrity of buildings (e.g. including the types of building material and the structural integrity of construction) and the presence of particularly vulnerable groups.

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[66] Brown, C. and Graham, W. (1988) Assessing the threat to life from dam failure. Water Resources Bulletin, 24 (6). 1303 – 1309.

[67] Graham, W.J. (1999) A procedure for estimating loss of life caused by dam failure. Dam Safety Office report DSO-99-6.

[68] The project was divided into two phases. See: HR Wallingford (2003) Flood Risks to People Phase 1. Final Report Prepared for Defra/Environment Agency Flood and Coastal Defence R&D Programme. *And:* HR Wallingford (2005) R&D Outputs: Flood Risks to People, Phase 2. FD2321/TR1. Defra/Environment Agency Flood and Coastal Defence R&D Programme. *And also*: HR Wallingford (2005) R&D Outputs: Flood Risks to People, Phase 2. FD2321/TR2 Guidance Document Defra/Environment Agency Flood and Coastal Defence R&D Programme.

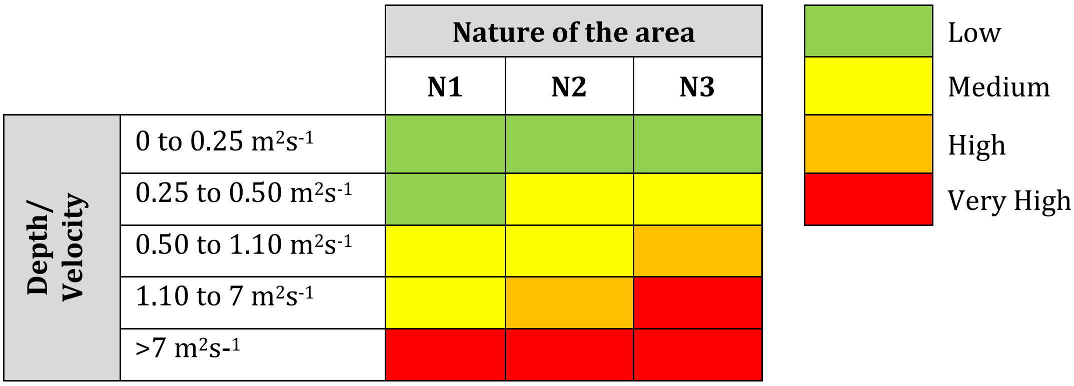
[69] Priest, S., Tapsell, S., Penning-Rowsell, E., Viavattene, C. and Wilson, T.. (2008) Task 10: Building models to estimate loss of life for flood events. Executive Summary, FLOODsite Project, Report T10-08-10, HR Wallingford, UK.

[70] Priest, S., Wilson, T., Tapsell, S., Penning-Rowsell, E., Viavattene, C. and Fernandez-Bilbao, A. (2007) Building a Model to Estimate Risk to Life for European Flood Events – Final Report. FLOODsite project report T10-07-10, HR Wallingford, UK.

[71] See http://www.floodsite.net/ (accessed 05.11.2015).

In order to compare the potential risk to life between hotspots, the original Risk to Life matrix has been simplified so only the risk scale is used as an output (Figure 4.12). It is therefore possible to associate with an area a Low, Medium, High and Very High (i.e. a value of 1, 2, 3 and 4) considering the nature of the area and the following thresholds for nature of the area N1:

- Low risk threshold: 0
- Medium risk threshold: 0.5 m^2/s^{-1}
- High risk threshold: not applicable[72]
- Very high risk threshold: 7 m^2/s^{-1}



Nature of the area	
N1	Low vulnerability (multi-storey apartments and masonry concrete and brick properties)
N2	Medium vulnerability (typical residential area with mixed types of properties)
N3	High vulnerability (including mobile homes, campsites, bungalows and poorly constructed properties)

Figure 4.12: Risk to Life Matrix

The scores from each land use receptor should then be aggregated and normalised to calculate a Regionalised Risk to Life Indicator:

$$I_{RtL} = \frac{\sum_{i=0}^{n}(S_i * RtL_i)}{\sum_{i=0}^{n}(S_i * 4)}$$

[72] High and Very High impact categories are principally associated with building collapse. In the N1 category, building collapse is not expected until the highest thresholds of depth/velocities and therefore it was not deemed appropriate to provide a threshold for High Risk. For N2 and N3, building collapse may occur at lower depth/velocities and therefore thresholds for all impact categories would be expected. See CVIL for a more detailed qualitative description of the model.

Where:

I_{Rtl}: Risk to Life Indicator;

n: Number of land use receptors;

S_i: Surface area i;

RtL_i: Risk to Life Score of area i;

4: Risk to Life Matrix highest score.

A value of 1 for I_{Rtl} indicates that all areas are exposed to a Very High risk, a value of 0 means that none are exposed.

4.3.3.2 Application of the methodology within the model

The Regionalised Risk to Life Indicator is calculated using three elements:

- Depth-velocity: the depth-velocity is provided by the flood maps imported in the model (Field "fdv" in the shapefile);
- The nature of the area: the calculation is only made using the land use data. Each land use in the shapefiles should be attributed a code providing information on the nature of the area. For instance N1, N2, or N3 could be used as a code for the vulnerability level (Figure 4.12). The user is free to use a code of their choosing provided that it is included in the "CHT_ForINDRA.txt" file (see following point). As such, the user can include various codes to also represent the existence of DRR measures (see the Library of Coastal Vulnerability Indicators for alternative matrices including DRR measures);
- The Risk to Life matrix: information on the risk to life scoring based on the nature of the area and the depth-velocity thresholds is provided in a similar way to the other direct impacts (examples in Table 4.2). For each code (i.e. nature of the area), the user needs to provide the different hazard thresholds. Using the Risk to Life matrix (Figure 4.12) as an example, it is necessary to include 3 lines (see Figure 4.13), one for each code (please note that recovery is not applicable in this case.) Also, a 9999 value is used as no High value is considered for nature of the area N1 – Low vulnerability areas.

```
"Risk to life for LowVulneSite" "N1_fdv" 0 0.5 9999 7 "recovery" 9999 9999 9999 9999
"Risk to life for MediumVulneSite" "N2_fdv" 0 0.25 1.1 7 "recovery" 9999 9999 9999 9999
"Risk to life for highvulsite" "N3_fdv" 0 0.25 0.5 1.1 "recovery" 9999 9999 9999 9999
"Sanddunes floodduration" "sd_fdur" 0 9999 1 2 "recovery" 9999 9999 9999 9999
```

Figure 4.13: Snapshot of "CHT_ForINDRA.txt" file for Risk to Life

The model will then automatically calculate the results.

4.3.3.3 Limitations and assumptions

- The population size, their characteristics and the change in their location are not considered in the model. Therefore the model cannot distinguish highly populated areas from non-populated areas or the differences in people's vulnerability;
- Only land use is considered in the calculation. The road network is not considered in the model for the risk to life calculation and for certain events with high depth-velocity, particularly during flash flooding or where a coastal

defence is breached, the risk to people inside vehicles can be high;

- A Risk to Life Indicator is not calculated for erosion as it is assumed that the areas will be evacuated.

Regionalised Risk to Life Indicator

- **Indicator of the potential degree of injury or fatality during an event for specific locations (based on the Risk to Life matrix). It is based on the characteristics of that location and the depth-velocity of the flood occurring;**
- **Classify all sites in terms of nature of the area (vulnerability of the area and existence of DRR measures);**
- **Adapt the Risk to Life matrix accordingly and add for each "nature of the area" code the considered depth-velocity thresholds in the "CHT_forINDRA" file;**
- **Attribute depth-velocity values to your flood map (field "fdv");**
- **Attribute the "nature of the area" code (field "NatArea") and a surface (field "Area") for each receptor in the receptor file;**
- **Each receptor will be attributed a value ranging from 0 to 4 by the model;**
- **The final Regionalised Risk to Life Indicator provides an aggregated and normalised score ranging between 0 and 1.**

4.3.4 Ecosystem recovery

Coastal habitats are already heavily degraded in European regions predominantly as a result of erosion and human development[73]. Extreme storm events may increase such pressure and accelerate the deterioration of some of these ecosystems. Coastal ecosystems are adapted to face coastal storms and therefore their conservation can be promoted by an ecosystem-based approach. However, these systems, even if adapted, may need time to recover from extreme events and this recovery will depend on their status, on the existence of alternative habitats, on other existing pressures and on the role of human management in their recovery[74]. During this recovery phase they may not fully provide ecosystem services and, therefore, a vulnerability assessment should carefully consider the potential changes in the delivery of these services.

These coastal ecosystems are not the only ones exposed on the coastal strip to extreme events, other ecosystems such as agriculture, forests and groundwater are not as adapted to coastal flooding and also have to be considered as they are impacted particularly by saline intrusion. For instance, the increase in salinity and frequency of flooding reduces the ability of trees to generate[75]. A study of the impacts of Hurricane Katrina reported the inland saltwater intrusion in groundwater has impacted on trees and plants, such as rice fields, taking up to two years to recover[76]. Salt water flooding usually causes more damage to crops and soils as high salt concentrations cause crop stress, restricted growth and death[77].

4.3.4.1 Selected Method

A key study on coastal ecosystem assessment was undertaken by McFadden et al. (2007)[78], within the INTEREG IIIB BRANCH project. This attempted to develop a Coastal Habitat Vulnerability Index (CHVI) for NW Europe based around four physical variables being recognised as particularly important controls on the vulnerability of

[73] European Environment Agency (2010) 10 messages for 2010 – coastal ecosystems. Available at :http://www.eea.europa.eu/publications/10-messages-for-2010-coastal-ecosystems (accessed 05.11.2015).

[74] European Environment Agency (2006) The changing face of Europe's coastal areas. Report No 6, European Environment Agency.

[75] Nicholls, R.J., Wong, P.P., Burkett, V.R., Codignotto, J.O., Hay, J.E., McLean, R.F., Ragoonaden, S. and Woodroffe, C.D. (2007) Coastal systems and low-lying areas. Climate Change 2007: Impacts, Adaptation and Vulnerability, contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK. 315-356.

[76] Williams, V.J. (2010) Identifying the economics effects of salt water intrusion after Hurricane Katrina. Journal of sustainable development 3 (1).

[77] Penning-Rowsell, E.C., Priest, S., Parker, D., Morris, J., Tunstall, S., Viavattene, C., Chatterton, J. and Owen, D.J. (2013) Flood and Coastal Erosion Risk Management: A Manual for Economic Appraisal. Routledge, London.

[78] McFadden, L., Spencer, T. and Nicholls, R.J. (2007) Broad-scale modelling of coastal wetlands: what is required? Hydrobiologia 577. 5-15.

saltmarshes and mudflats: (1) rate of relative sea-level rise, weighted by tidal range, (2) process environment, (3) accommodation space, including the effects of defences and (4) sediment supply.

Within the EU FP7 THESEUS project[79] an Environmental Vulnerability Index (EVI) was developed indicating the potential changes in a habitat following a storm event for different types of ecosystems. Depending on the level of change, the ecosystem might recover to the original state; however certain changes are so drastic that natural recovery of ecosystems is very unlikely without human intervention. The EVI results scale from 0 to 3 the different levels of change (See Table 4.3). Even though the indicators used in THESEUS consist of different methods, the advantage of the EVI is the consistency of the outputs, meaning that for most of the indicators there is the same scale (0 to 3), facilitating comparisons between ecosystems. The other advantage is that these indicators have the possibility to be used for extreme coastal events, not only sea level rise due to climate change. The THESEUS approach was therefore considered the most appropriate for use in the context of this project.

Table 4.3: Scale used for the Environmental Vulnerability Indicator (THESEUS Project)[80]

Scale	Description	Explanation
0	**Negligible**	Negligible impact to habitats/species
1	**Transient effect no long term change anticipated**	Changes within the range of a receptor's natural seasonal variation and full recovery is likely within a season.
2	**Moderate effect/Semi permanent change**	Changes are beyond a receptor's natural seasonal variation. Partial recovery is possible within several seasons, but full recovery is likely to require human intervention, or greater than 20 years for natural recovery.
3	**Permanent effect/change**	Changes are so drastic that natural recovery of receptor is very unlikely without human intervention. Or natural recovery will take longer than 20 years.

EVI are provided for various ecosystems within the Library of Coastal Vulnerability Indicators. The EVI outcomes are consistent with the CRAF direct impact scale, i.e.:

- Low impact: negligible impact (score 1)[81];
- Medium impact: transient effect/no long term change anticipated (score 2);
- High impact: Moderate effect/Semi permanent change (score 3);
- Very High impact: Permanent effect/change (score 4).

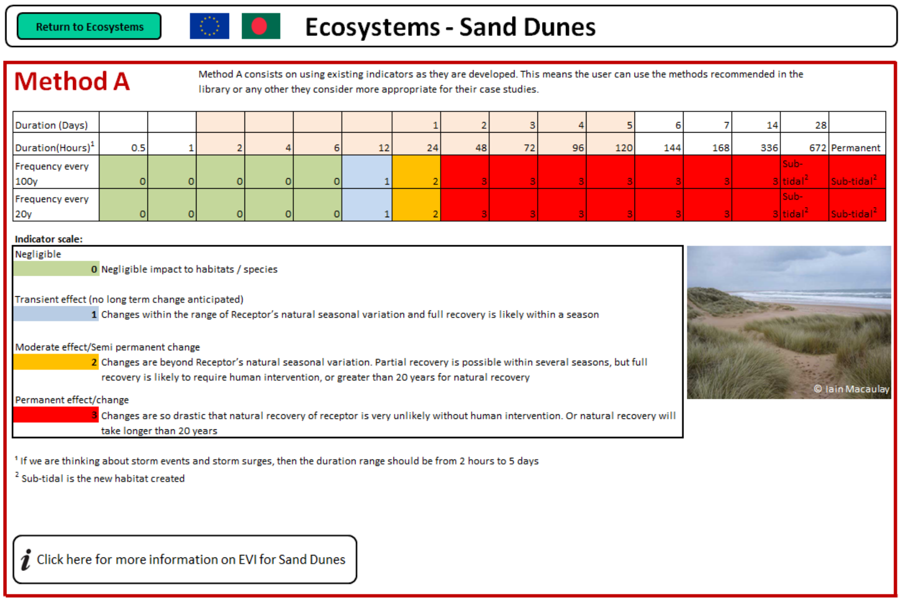
[79] Zanuttigh, B., Sitta, G. and Simcic, D. (2014) THESEUS Decision Support System User Manual. FP7 Theseus project 244104.

[80] Ibid.

[81] Please note that the scoring has been changed compared with those used in THESEUS.

Each impact level is defined by a hazard intensity threshold (for instance duration of 6, 12 and 24 hours - Figure 4.14). It should be noted that the hazard intensity to be considered differs from one ecosystem to another. To cover all types of ecosystem the following hazard intensities are required: depth, duration, wave height, sedimentation, soil salinity and seasonality. But most of these intensities cannot be represented by the hazard models and, therefore, indicative values based on expert inputs will have to be used if these impacts must be considered.

For erosion impacts the Erosion Vulnerability Indicator is used. However, only the highest impact should be considered (loss of land leading to a permanent change).


Return to Ecosystems

Ecosystems - Sand Dunes

Method A

Method A consists on using existing indicators as they are developed. This means the user can use the methods recommended in the library or any other they consider more appropriate for their case studies.

Duration (Days)							1	2	3	4	5	6	7	14	28	
Duration(Hours)[1]	0.5	1	2	4	6	12	24	48	72	96	120	144	168	336	672	Permanent
Frequency every 100y	0	0	0	0	0	1	2	3	3	3	3	3	3	3	Sub-tidal[2]	Sub-tidal[2]
Frequency every 20y	0	0	0	0	0	1	2	3	3	3	3	3	3	3	Sub-tidal[2]	Sub-tidal[2]

Indicator scale:

Negligible
0 Negligible impact to habitats / species

Transient effect (no long term change anticipated)
1 Changes within the range of Receptor's natural seasonal variation and full recovery is likely within a season

Moderate effect/Semi permanent change
2 Changes are beyond Receptor's natural seasonal variation. Partial recovery is possible within several seasons, but full recovery is likely to require human intervention, or greater than 20 years for natural recovery

Permanent effect/change
3 Changes are so drastic that natural recovery of receptor is very unlikely without human intervention. Or natural recovery will take longer than 20 years

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[1] If we are thinking about storm events and storm surges, then the duration range should be from 2 hours to 5 days
[2] Sub-tidal is the new habitat created

Click here for more information on EVI for Sand Dunes

Figure 4.14: Example of the EVI for Sand Dunes

The scores from each ecosystem should then be aggregated and normalised to calculate a Regionalised Ecosystem Recovery Indicator:

$$I_{Eco} = \frac{\sum_{i=0}^{n}(S_i * EVI_i)}{\sum_{i=0}^{n}(S_i * 4)}$$

Where:

I_{Eco}: Ecosystem Recovery Indicator;

n: Number of ecosystems;

S_i: Surface of ecosystem i;

EVI_i: EVI score for the ecosystem i;

4: EVI highest score.

A I_{Eco} value of 1 indicates that all ecosystems are permanently changed, a value of 0 that none are exposed.

4.3.4.2 Application of the methodology within the model

The ecosystem impact score is calculated using three elements:

- A hazard intensity: This is provided by the flood maps imported into the model (e.g. Field "fdepth" "fdv" "duration" in the shapefile);
- The calculation is only made using land use receptor data. For each receptor in the land use shapefiles, a code should be attributed providing information on receptor type. For instance Sd and Wl could be used as a code for sand dunes and woodland. The user is free to use a code of their choosing provided that it is included in the "CHT_ForINDRA.txt" file (see following bullet point). As such the user can include various codes to represent different ecosystem vulnerability indicators;
- The EVI for floods: information on the thresholds is provided in a similar way to the other direct impacts (examples in Table 4.2). For each code (i.e. nature of the area) the user has to provide the different thresholds hazards and an indication of the receptor code. 9999 values should be used for the recovery thresholds;
- A ErVI for erosion: the values should be as in the following examples "Erosion for sand dunes" "Sd_er" 9999 9999 9999 0 "recovery" 9999 9999 9999 9999.

4.3.4.3 Limitations and assumptions

- The Regionalised Ecosystem Recovery Indicator provides an overall value for all ecosystems[82] and does not let the user differentiate between them. However, as the information is also available for each individual land use a further analysis could be undertaken.
- The potential change to an ecosystem may alter its capacity to deliver ecosystem services. It is an important step in the impact evaluation process to consider loss of ecosystem services. But the simplified approach adopted by INDRA does not allow such considerations. However, the end user should have some knowledge about the importance of ecosystem services for the considered habitat during the MCA process. Supporting information is provided in Appendix A for the identification of these services.
- The potential change for some ecosystems depends on more than one hazard intensity but the approach does not allow the consideration of multiple intensities.

[82] Although within the MCA it is possible to distinguish natural ecosystems from agriculture.

Regionalised Ecosystem Recovery Indicator

- **An indicator of the potential change within ecosystems and their recovery time. It is based on the Ecosystem Vulnerability Indicators (Library of Coastal Vulnerability Indicators) and considering the flood hazard intensities.**
- **First, review all ecosystems in the region;**
- **Define the EVI for each and add the information in the "CHT_forINDRA" file;**
- **Attribute the required intensity values to the flood map;**
- **Attribute the ecosystem code (field "Rcode") and a surface (field "Area") for each receptor in the land use file;**
- **The model will attribute each ecosystem a value ranging from 0 to 4;**
- **The indicator provides an aggregated and normalised score of ecosystem recovery for the whole region ranging between 0 and 1;**
- **Use the exported results per ecosystem for further analysis if necessary.**

4.3.5 Household Displacement

Extreme coastal events can have significant disruptive impacts upon those societies affected. Studies focussing specifically on assessing community disruption pre-event are limited although there is some evidence discussing the impacts of past floods on communities and on community disruption[83] [84]. Tapsell and Tunstall (2001)[85] highlight that in the north of England, evidence suggested that flooding caused a breakdown in the community and thereby impacted the quality of community life for a significant period post flooding.

Disruption to the community may take a variety of forms. For example, alternative accommodation may be located many kilometres from the impacted location making it difficult to maintain links with friends, neighbours and school or work colleagues. Additionally, a key business, religious building or meeting point may be severely impacted leading to negative impacts on community cohesion[86]. In extreme situations, sections of the community may be forced to live elsewhere leading to social dislocation and even the loss of community identity[87]. Tapsell et al. (2002)[88] highlight the difficulty of identifying and assessing these tangible community impacts and Ketteridge and Fordham (1997: 196)[89] reiterate this point "The sense of loss and feeling of loneliness in the longer term is hard to qualify as often people lose not only their homes and possessions, they can lose their friends, their confidence, their dignity, and for a while at least, the fabric of their community".

Displacement (and especially the duration of any displacement) was highlighted by many as being one consequence of flooding and other disasters that has a significant

[83] Tapsell, SM and Tunstall, SM (2001) The Health and Social Effects of the June 2000 Flooding in the North East Region, report to the Environment Agency, Enfield: Flood Hazard Research Centre, Middlesex University.

[84] Whittle, R., Medd, W., Deeming, H., Kashefi, E., Mort, M., Twigger Ross, C., Walker, G., Watson and N. (2010) After the Rain – learning the lessons from flood recovery in Hull, final project report for, Flood, Vulnerability and Urban Resilience: a real-time study of local recovery following the floods of June 2007 in Hull, Lancaster University, Lancaster, UK.

[85] Tapsell, SM and Tunstall, SM (2001) The Health and Social Effects of the June 2000 Flooding in the North East Region, report to the Environment Agency, Enfield: Flood Hazard Research Centre, Middlesex University.

[86] Twigger-Ross, C. (2005) The Impact of Flooding on Urban and Rural Communities. R&D Technical Report SC040033/SR1. Environment Agency, Bristol.

[87] Green, C., Viavattene, C. and Thompson, P. (2011) Guidance for assessing flood losses. Deliverable 6.1. FP7 EU Project CONHAZ 244159. Available at: http://www.mdx.ac.uk/__data/assets/pdf_file/0006/58794/floodsWP_FINALREPORTsept11.pdf (accessed 05.11.2015).

[88] Tapsell, S.M., Penning-Rowsell, E.C., Tunstall, S.M. and Wilson, T. (2002) Vulnerability to flooding: health and social dimensions. Phil. Trans. R. Soc. Lond. 360. 1511-1525.

[89] Ketteridge, A.M. and Fordham, M. (1997) Flood warning and the local community context. In: Handmer, J. (ed.) Flood warnings: issues and practice in total system design. Hazard Research Centre. London: Middlesex University.

negative impact upon the psychological health[90] [91] [92] and a cause of anxiety and stress[93] [94] in individuals, but equally it has a collective impact upon community disruption and overall well-being[95] [96] [97]. It is important therefore to consider how long households may be required to live away from their properties or the length of time before community 'normality' can be restored. For example, in the 2007 floods in Kingston upon Hull, UK 12% of households were displaced for longer than 12 months and 5% for more than two years[98]. In very extreme events, such as Hurricane Katrina and its aftermath, thousands of households were displaced, many for several years and some have never returned to the same area[99]. However, the relationship between impact and disruption is not straightforward. Displacement itself may be necessary to avoid some negative impacts (e.g. having a positive impact on physical health as residents will not be living in damp conditions) but household displacement may cause other different negative impacts (e.g. longer-term displacement having a negative impact on mental health)[100].

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[90] Tapsell, SM; Tunstall, SM; Penning-Rowsell, EC; Handmer, JW (1999) The Health Effects of the 1998 Easter Flooding in Banbury and Kidlington, report to the Environment Agency, Thames Region, Enfield: Flood Hazard Research Centre, Middlesex University.

[91] Reacher, M; McKenzie, K; Lane, C; Nichols, T; Iversen, A; Hepple, P; Walter, T; Laxton, C; Simpson, J (2004) Health impacts of flooding in Lewes: a comparison of reported gastrointestinal and other illness and mental health in flooded and non-flooded households, Communicable Disease and Public Health, 7 (1): 1-8.

[92] World Health Organization (2013) Floods in the WHO European Region: health effects and their prevention, Edited by: Menne, B. and Murray, V., World Health Organisation Regional Office: Copenhagen, Denmark.

[93] Du, W., FitzGerald, G.J., Clark, M., and Hou, X-Y. (2010) Health impacts of floods, Prehospital and Disaster Medicine, 25(3):265–272.

[94] Few, R. & Matties, F. (eds) (2006) Flood Hazards and Health: Responding to the Risks of Climate Change. London: Earthscan.

[95] Tapsell, S. and Priest, S. (2009) Developing a conceptual model of flood impacts upon human health, FLOODsite project report T10-09-02, available at: http://www.floodsite.net/html/pub_guidance.htm

[96] World Health Organization (2002) Floods: Climate change and adaptation strategies for Human Health. Report on a WHO meeting 30 June – 2 July 2002, London, UK. Denmark: WHO Regional Office for Europe.

[97] Fernández-Bilbao, A., Twigger-Ross, C., Watson, N. et al. (2008) Improving Institutional and Social Responses to Flooding: Work Package 2 – Improving response, recovery and resilience. Final Report. FCERM R&D Project SC060019. Environment Agency, Bristol.

[98] Milojevic, A., Kovats, S., Leonardi, G., Murray, V., Nye, M., Wilkinson, P. (2014) Population displacement after the 2007 floods in Kingston-upon-Hull, England. Journal of Flood Risk Management (2014).

[99] Merdjanoff, A. A. (2013) There's no place like home: Examining the emotional consequences of Hurricane Katrina on the displaced residents of New Orleans. Social science research 42 (5), 1222-1235.

[100] Cummings, K.J., Cox-Ganser, J., Riggs, M.A., Edwards, N., Hobbs, G.R., Kreiss, K. (2008) Health

Despite the inherent complexity in household and, especially, community disruption and its significant impact both on the whole community as well as on individual health, it is important to represent it within INDRA.

4.3.5.1 Selected approach

Although it offers a simplification, household displacement provides some indication of disruption at the household level. This indicator will consider the numbers of households that are required to move away from their permanent residences and into alternative accommodation. The key assumption being: the longer the duration of time a household is in alternative accommodation the more severe the disruption of the household. The duration of household displacement may relate to the event itself (e.g. the severity of the damage sustained), the characteristics of the household (e.g. capacity to pay to repair/rebuild, insured/uninsured) and others causes are more event or receptor independent (e.g. the availability of materials or builders to repair/rebuild or the availability of alternative accommodation).

Similar to some of the other indicators, a semi-qualitative approach has been adopted to produce a Regionalised Household Displacement Indicator which assesses the potential negative impacts of displacement. It has been necessary to create a new approach as existing methodologies are lacking. As a result the approach remains simplified but open to further development to represent additional complexities.

A scale of impact (Table 4.4) has been developed which reflects the different durations of household displacement. The scale and qualitative explanations are based on a common-sense approach informed by information in the literature about the impacts of past events. The user may wish to adjust the specific household displacement durations based on the experience and knowledge of stakeholders if they are not deemed suitable for their regional case.

Table 4.4: Household displacement impact scale

Scale	Household displacement duration	Explanation
0	**Households are not displaced**	These households may evacuate their properties for the duration of a coastal event to prevent injury, however will return immediately afterwards. It is important to stress that those who are not displaced due to the coastal event (i.e. move into temporary accommodation) does not mean they not suffer disruption or any negative impacts. It can be unpleasant and uncomfortable (e.g. cramped, damp etc.) to remain within an affected property[101] [102] [103].

effects of exposure to water-damaged New Orleans homes six months after Hurricanes Katrina and Rita. American Journal of Public Health. May; 98(5): 869-75.

[101] Tapsell, S.M. and Tunstall, S.M. (2001) The Health and Social Effects of the June 2000 Flooding in the North East Region, report to the Environment Agency. Flood Hazard Research Centre, Middlesex University, Enfield.

[102] Thrush, D., Burningham, K. and Fielding, J. (2005) Flood warning for vulnerable groups: A

1	**Households displaced for up to 1 month**	**Minimum household displacement** - These households are displaced for a short period of time (up to one month). As such they will return to the community quickly following the event. Although they may suffer some disruption and repairs to their homes, their disruption is considered to be less than those who are out of their properties for a longer period.
2	**Households displaced >1 month and ≤3 Months**	**Short-term household displacement** - Households will reside in alternative accommodation for a short period of time. During this time residents will experience some of the negative impacts of living in unfamiliar alternative accommodation or with relatives. However, the shorter duration of the displacement means that ties to the community will generally not be lost. Retaining a sense of community post-event can provide support to households and enable them to better cope and recover[104 105].
3	**Households displaced for >3 Months and ≤12 months**	**Medium-term displacement** - A household is displaced for a medium length of time. It is likely that if residents are out of their properties for this period of time they may become more settled in their alternative accommodation [106]. However, residents will be impacted more by the negative impacts of being away from their homes. They will also be dealing with the stress of managing the ongoing repair and rebuilding process of their properties[107 108].

qualitative study. Report for the Environment Agency. Science Report SC990007/SR3.

[103] Carroll, B. Morbey, H. Balogh, R. and Araoz, G. (2006) Living in fear: Health and social impacts of the floods in Carlisle 2005. Research Report. Centre for Health Research and Practice Development - St. Martins College, Carlisle: Available at: http://cmis.carlisle.gov.uk/cmis/search.aspx (accessed 05.11.2015).

[104] Berke, P.R., Kartez, J. and Wenger, D. (1993) Recovery after Disaster: Achieving Sustainable Development, Mitigation and Equity. Disasters, 17: 93–109.

[105] Kaniasty, K., and Norris, F.H. in Neria, Y., Galea, S. and Norris, F. (eds) (2009) Mental health consequences of disasters. Cambridge University Press, New York.

[106] Although this assumes that it is obvious to residents (or insurers in the case that they are influencing the process of temporary accommodation) that the displacement will continue for a considerable period of time.

[107] Defra (2004) The Appraisal of Human Related Intangible Impacts of Flooding. R&D Technical Report FD2005/TR. Department for Environment, Food and Rural Affairs: London.

[108] Whittle, R., Medd, W., Deeming, H., Kashefi, E., Mort, M., Twigger Ross, C., Walker, G., Watson and N. (2010) After the Rain – learning the lessons from flood recovery in Hull, final project report for, Flood, Vulnerability and Urban Resilience: a real-time study of local recovery following the floods of June 2007 in Hull. Lancaster University, Lancaster, UK.

4	**Households displaced for >than 12 months**	**Long-lasting displacement** - Residents have still not returned to their properties for a long time following the event. Feelings of isolation and disconnection from their community are likely to be high. The duration of the displacement means that residents will be unable to 'move on' from the event as they will still often be dealing not only with living away from their homes and possibly families and friends, but will also be having to 'manage' the repair and rebuilding of their properties. There is evidence to suggest that this is a frustrating and stressful process in its own right which can be exacerbated the longer it goes on.[109]
5	**Households never return to the original property**	**Permanent displacement** - These households are affected permanently, that is they do not return to pre-event property. This may be for many reasons, including: the land the property stood on no longer exists; changed planning regulations do not permit resettlement[110]; not being able to afford to rebuild/repair a property; or selective out-migration[111] (which itself may be for a variety of reasons). As such, when there are considerable numbers of these types of household present, the overall nature of the community changes following the event[112].

Calculating the direct impacts to property

The displacement of, and subsequent disruption to, households is linked to the direct impacts to residential buildings due to inundation and erosion. It is necessary to define the 4 threshold values to calculate the 5 direct impact scales (None, Low, Medium, High and Very High) (see Section 4.3.2).

Inundation hazard (including overwash)

For inundation damage to property are calulated using depth-damage curves and the Building Collapse Matrix (see Table 4.1 and Library of Coastal Vulnerability

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[109] Dixon, K. M., Shochet, I. and Shakespeare-Finch, J. (2015) Stress during the rebuilding phase influenced mental health following two Queensland flood disasters more than the event itself. Australian and New Zealand Disaster and Emergency Management Conference, 3-5 May 2015, Broadbeach, Gold Coast, Queensland, Australia.

[110] As happened in the Vendée and Charente-Maritime Departments of Western France following Xynthia. See: Lumbroso, D. M. And Vinet, F. (2011) A comparison of the causes, effects and aftermaths of the coastal flooding of England in 1953 and France in 2010. Natural Hazards and Earth System Science 11 (8): 2321–2333.

[111] For example in Sri Lanka, following the 2004 Indian Ocean Tsunami. See: Nakit, A. Stigter, E. and Laczko, F. (2007) Migration, Development and Natural Disasters: Insights from the Indian Ocean Tsunami. International Organization for Migration, Geneva. http://publications.iom.int/bookstore/free/MRS30.pdf (accessed 05.11.2015).

[112] For example in St Barnard Parish, New Orleans, where the old sense of community was described by residents as being lost forever following Hurricane Katrina. See: Parker, D. and Tapsell, S. (2009) Relations between different types of social and economic vulnerability. Deliverable 2.1, ENSURE Project. European Commission, Brussels.

Indicators). The depth-damage curves established for different flood depth series are much greater in number than the 4 threshold values used in the CRAF (described in Section 4.3.2). Therefore, it is necessary for the user to reduce the precision traditionally used in their associated depth-damage curve to adapt the information for the more simplified scale adopted within INDRA. When selecting the thresholds, consider the type and extent of the damage sustained at different depths. For example, at very low depths (<0.25m) damage is likely to be restricted to flooring and carpets as well as some superficial damage to the internal fabric and building contents[113]. As depth increases, floodwaters come into contact with more susceptible building fabric and inventory items which are likely to need replacing. Above 0.90m, glass may break, roofs collapse and building foundations can be undermined[114]. Users should ideally employ the most relevant depth-damage curve for their regional case to identify the 4 thresholds. However, by analysing several flood damage and susceptibility curves from Europe[115] [116] [117] [118] [119] and Bangladesh[120] it has been possible to identify some more generalised depth thresholds (see Table 4.5). These curves were plotted and their inflection points compared. From this, it was observed that most of the curves show an increase in damage or susceptibility at similar flood depths. An average of these depths has been calculated and provided in Table 4.5. These depth threshold values should only be used where local data is not available or is insufficient. The Very High category relates to building collapse impacts. Building collapse impacts are usually not represented by depth-damage curves and therefore a value of 9999 should

113 Penning-Rowsell, E.C., Priest, S., Parker, D., Morris, J., Tunstall, S., Viavattene, C., Chatterton, J. and Owen, D.J. (2013) Flood and Coastal Erosion Risk Management: A Manual for Economic Appraisal. Routledge, London.

114 Kelman, I. and Spence, R. (2004) An overview of flood actions on buildings. Engineering Geology, 73. 297-309.

115 LATIS (2008) Flanders Hydraulics Research and Ghent University. Available at: https://biblio.ugent.be/publication/438486 (accessed 05.11.2015).

116 Ministère de l'écologie, du développement durable et de l'énergie (2014) Analyse multicritères des projets de prévention des inondations. Available at : http://www.developpement-durable.gouv.fr/Publication-du-guide-et-du-cahier.html (accessed 05.11.2015).

117 Velasco, M. Cabello, M and Russo, B. (2015) Flood damage assessment in urban areas. Application to the Raval district of Barcelona using synthetic depth damage curves, Urban Water Journal. Available at:
http://www.tandfonline.com/doi/abs/10.1080/1573062X.2014.994005
(accessed 05.11.2015).

118 Multi-Coloured Manual Online (MCM-Online) (2015) Flood and Coastal Erosion Risk Management Handbook and Data for Economic Appraisal 2015. Flood Hazard Research Centre, Middlesex University, London. See: http://www.mcm-online.co.uk (accessed 05.11.2015).

119 Huizinga, H. J. (2007) Flood damage functions for EU member states, HKV Consultants, Implemented in the framework of the contract #382442-F1SC awarded by the European Commission – Joint Research Centre.

120 Islam, K.M.N (1997) The impacts of flooding and methods of assessment in urban areas of Bangladesh, PhD Thesis, Middlesex University, London.

be attributed in this case.

Table 4.5: Flood damage thresholds

Impact	Explanation	Example Associated Minimum Depth (metres)
Low	Minor damage to flooring, carpets and some superficial damage to household inventory items. Mainly drying and cleaning required.	**0**
Medium	More household inventory items, such as tables and appliances, damaged. Building fabric severely damaged. Items likely to need replacing.	**0.25**
High	Building foundations can be undermined with some partial building collapse (windows breaking, doors forced open).	**0.90**
Very High	This damage will not be reflected in flood depth-damage curves. See the *Building Collapse thresholds* table.	**9999**

However, buildings may collapse during such events as a result of high flood depth velocities. Specific building collapse matrices have been developed and are used as a common indicator to assess such impacts (based on the depth-velocity product). The thresholds for building collapse, and the explanation for each threshold, are provided in Table 4.6. These are based on the Building Collapse matrix, adapted from Karvonen et al. (2000)[121], provided in the Library of Coastal Vulnerability Indicators. The Low and Medium thresholds are not considered as no building collapse is assumed and so a 9999 value is applied. The user should update this table with locally produced data, where available, in order to reflect the characteristics of the local built environment[122].

Both impacts for inundation (depth-damage and building collapse) might be assessed separately but when applying them to the same receptor the model will consider the highest impact score.

Table 4.6: Building Collapse thresholds

Impact	Explanation	Minimum Depth-velocity product (m^2/s)
Low	See the *Flood damage thresholds* table.	**9999**
Medium	See the *Flood damage thresholds* table.	**9999**

[121] Karvonen, T., Hepojoki, A., Huhta, H.-K. and Louhio, A. (2000) The use of physical models in dam-break analysis, RESCDAM Final Report, Helsinki University, 11 December 2000.

[122] See Section 4.2 of the Library Guidance Document for more information on this: Viavattene, C., Micou, A.P., Owen, D.J., Priest, S. and Parker, D.J. (2015) Library of Coastal Vulnerability Indicators. RISC-KIT Project Deliverable, D2.2: http://www.risckit.eu/np4/8/ (accessed 05.11.2015).

High	Moderate structural damage (windows and doors knocked out). Little damage to the major structural elements of the building.	**3**
Very High	Total structural collapse or major damage to the structure necessitating demolition and rebuilding.	**7**

Erosion hazard

For erosion, the Erosion Vulnerability Indicator (ErVI) proposed in the Library of Coastal Vulnerability Indicators will be used. The indicator is defined by the distance between a receptor and the shoreline as follows:

Table 4.7 details how these distance thresholds relate to the impact thresholds used in the model.

Table 4.7: Erosion thresholds

Impact	Explanation	Distance Threshold[123]
Low	Preventive: Below this threshold activities will be disrupted before and during the event for safety reasons	**Tp**
Medium	Post Monitoring Threshold: Below this threshold activities will also be affected by the need for monitoring in the aftermath of an event	**Tpm**
High	Not Applicable	**9999**
Very High	Loss Threshold: Below this threshold the asset will partially or totally collapse.	**Tl**

Distributing the receptors

The duration of household displacement is linked to the degree of impact experienced. However, there are other variables (such as the characteristics of the household, the availability of alternative accommodation or the availability of builders and materials to rebuild) which also impact upon the displacement duration. As such for events with similar flood depths the duration of displacement may vary, for example, between a few days and a couple of months.

To reflect this, the user needs to distribute the percentage of receptors (households) into the Household Displacement Indicator Matrix (Table 4.8) to reflect local circumstances. The rows of the Matrix shows the scale of displacement, as defined in

[123] See Section 4.3.2 of the Library of Coastal Vulnerability Indicators Guidance Document for an explanation of the distance thresholds used: Viavattene, C., Micou, A.P., Owen, D.J., Priest, S. and Parker, D.J. (2015) Library of Coastal Vulnerability Indicators. RISC-KIT Project Deliverable, D2.2: http://www.risckit.eu/np4/8/ (accessed 05.11.2015).

Table 4.4, and the columns indicate a property's direct impact (Low, Medium, High, Very High) from inundation, overwash and erosion. Each cell represents the proportion of total receptors displaced for the considered direct impacts (i.e. the sum of the cells in each column should total 1).

The information required to populate the Matrix may be derived from locally-focused research projects, national government or local administration reports, management plans, the specialist knowledge of stakeholders and end-users or inferred from past event data. Another approach is to use data provided by the insurance industry (where available), which can include detailed information on damage claims and the cost of displacement. Insurance data has been used to populate the Household Displacement Matrix for inundation in the UK and this approach will now be detailed to provide an example.

A dataset containing 5,000 insurance claims, which provides both a 'material damage cost' (the cost of direct damage from the flood event) and an 'alternative accommodation cost' (the costs associated with being away from the flood-affected property, such as hotel fees, alternative property rent etc.), has been analysed to link the likely flood depth at each property to the likely duration of the alternative accommodation. Using UK depth-damage curves and the average cost of household displacement (temporary and alternative accommodation) taken from Penning-Rowsell et al. (2013)[124], it was possible to ascertain the duration of an evacuation event for each of the three depth thresholds described above. The results of this show a strong correlation to other studies linking flood depth to displacement[125] [126]. The analysis of the dataset also gives an idea of the percentage of households who were not displaced for each flood depth. Although this approach is valid it is only accounting for those residents who claimed on their insurance and as such has some limitations[127]. These percentages are then linked to the displacement categories defined in Table 4.4. The information has been entered into the Household Displacement Matrix (Table 4.8) as an example (for inundation) for the user. However, the insurance data does not provide information for the Very High impacts (i.e. depth-velocity and building collapse) or whether or not households do or do not

[124] Penning-Rowsell, E.C., Priest, S., Parker, D., Morris, J., Tunstall, S., Viavattene, C., Chatterton, J. and Owen, D.J. (2015) Flood and Coastal Erosion Risk Management: A Handbook for Economic Appraisal. Available under licence at: www.MCM-Online.co.uk (accessed 05.11.2015).

[125] Tunstall, S., Tapsell, S. and Fernandez-Bilbao, A (2007) Vulnerability and flooding: a re-analysis of FHRC data. Country report England and Wales. FLOODsite Technical report T11-07-11.

[126] FEMA (2013) Multi-Hazard Loss Estimation Methodology Flood Model, HAZUS MH MR4 Technical Manual. Available at: http://www.fema.gov/media-library-data/20130726-1715-25045-5075/hazus_mr4_flood_tech_manual.pdf (accessed 05.11.2015).

[127] These data are based on insurance claims data and therefore may not be completely representative of all scenarios, namely where occupants are underinsured or entirely without insurance. In some circumstances, this may not be completely accurate; perhaps the occupants stayed with family or friends and did not claim for this, or they were unable to claim for the time spent out of their property due to their insurance policy etc.

return to a property following damage. Therefore, a conservative value of 0 could be assumed for Low, Medium and High impacts for Permanent displacement. However, other data should be sought for the Very High category.

The characteristics of the properties contained in the insurance dataset are not defined and so it is not possible to ascertain how the coastal event will impact on buildings of different types and sizes. The number of floors, size and building materials used for construction are likely to influence the susceptibility of the receptor to direct damages but this is not considered in the Matrix, which assumes that each receptor is the same type. Users are advised to consult experts or regional data for guidance on how to improve the Matrix by considering the characteristics of different types of property, if applicable, and how their susceptibility to hazards may differ[128].

A similar matrix should be developed for coastal erosion. Receptors need to be distributed for both the Medium (displacement occurs during the post-monitoring phase) and Very High impact category (where building collapse is experienced).

[128] See Section 4.1 of the Library Guidance Document for more information on this: Viavattene, C., Micou, A.P., Owen, D.J., Priest, S. and Parker, D.J. (2015) Library of Coastal Vulnerability Indicators. RISC-KIT Project Deliverable, D2.2: http://www.risckit.eu/np4/8/ (accessed 05.11.2015).

Table 4.8: Household Displacement Indicator Matrix, showing example percentages for inundation derived from UK insurance data

		Direct impact on property			
		Low	**Medium**	**High**	**Very High**
Households are not displaced	**0**	0.87	0.3	0.18	n/a
Households displaced for up to 1 month	**1**	0.03	0.04	0.01	n/a
Short-term displacement >1 month and ≤3 Months	**2**	0.05	0.17	0.07	n/a
Medium-term displacement >3 Months and ≤12 months	**3**	0.05	0.4	0.49	n/a
Long-lasting displacement Households displaced for >than 12 months	**4**	0	0.09	0.25	n/a
Households never return to the original property	**5**	n/a	n/a	n/a	n/a
Total receptor distribution		1	1	1	n/a

Calculating the Household Displacement Impact score

Using the above example for inundation using UK insurance data, the matrix highlights that when High impacts are sustained, 18% of households are not displaced, 1% are displaced for up to 1 month, 7% are displaced for 1-3 months, 49% are displaced for over 3 and up to 12 months, and 25% are displaced for over 12 months.

For each direct impact a score has to be calculated by the user (see Table 4.9). The Household Displacement Indicator score for each receptor is calculated by adding the household displacement scale weighted by the distribution of the receptors for the considered impacts. For example, each receptor exposed to High impact:

$$\begin{aligned} Example\ for\ High\ Impact\ & 0.18(0) + 0.01(1) + 0.07(2) + 0.49(3) + 0.25(4) \\ & + 0.00(5) \\ & = 2.62 \end{aligned}$$

The results given in Table 4.9, for this example, would be input into INDRA.

Table 4.9: Example Household Displacement scores for each flood depth direct impact category (assuming all types of residential properties are displaced to the same degree)

Direct damage impact on household	Low	Medium	High	Very High
Household displacement scores	0.28	1.94	2.62	9999

The scores from each of the households can then be aggregated and normalised to calculate the Regionalised Household Displacement Indicator:

$$I_{Hd} = \frac{\sum_{i=0}^{n} Hd_i}{\sum_{i=0}^{n} 5}$$

Where:

n= all residential properties in the region[129] (or all potentially exposed residential properties in the region);

H_d = Household Displacement Score for each household property;

5 = the maximum Household Displacement Score.

A value of 1 for I_{Hd} indicates that all households are displaced permanently (very unlikely), a value of 0 means that none are displaced.

4.3.5.2 Application of the methodology within the model

The Household Displacement scores have to be input into the “CHT_ForINDRA.txt” file

[129] This means the CRAF region (i.e. all household receptors within the regional boundary need to be included). However, to reduce the number of properties, the user has the choice whether to include only those properties within the region that are directly exposed to the hazard. This will result in a higher indicator value as the regionalisation of the indicator is based on a smaller sample.

as recovery information in place of the reinstatement time. This should be done for each receptor hazard code. Thus for flood depth, the values (for the UK) 0.28, 1.94, 2.62 are included followed by a value of 9999 because the fourth threshold is not considered. For flood depth-velocity the values 2.62 and 5[130] are included, preceded by 9999 and 9999 again, as the first two thresholds (Low and Medium) are not considered for building collapse. To facilitate the reading of the data file "displacement scores" can be used as a comment.

Within the model the displacement score will only be calculated for land use associated with the "Household" MCA category. The user needs to make sure that both the vulnerability code and the MCA category are associated with the current land use points.

```
comments CodeHazardThresholds  threshold_1 threshold_2 threshold_3 threshold_4 "recovery" T1Rtime T2Rtime T3Rtime T4Rtime
"dd curves for household prop anytype flooding" "HProp_fd" 0 0.25 0.90 9999 "displacementscores" 0.28 1.94 2.62 9999
"building collapse for household prop any type flooding" "HProp_fdv" 9999 9999 3 7 "displacementscores" 9999 9999 2.62 5
"dd curves for household prop anytype overwash" "HProp_od" 0 0.25 0.90 9999 "displacementscores" 0.28 1.94 2.62 9999
"building collapse for household prop any type overwash" "HProp_odv" 9999 9999 3 7 "displacementscores" 0.28 1.94 2.62 9999
"Erosion for any household prop" "HProp_er"  10 5 9999 0 "displacementscores" 0 0 9999 5
"dd curves for business prop anytype flooding" "BProp_fd" 0 0.25 0.90 9999 "recovery" 3 15 180 9999
"building collapse for business prop any type flooding" "BProp_fdv" 9999 9999 3 7 "recovery" 9999 9999 180 1000
```

Figure 4.15: Snapshot of "CHT_ForINDRA.txt" for household displacement

4.3.5.3 Limitations and assumptions

- A key assumption is that the longer a household is displaced, the higher the disruption experienced. However, this assumption can be challenged due to the complexities of post-event individual recovery. For instance, in some cases displacement is fundamental to avoiding negative health impacts. In other cases, some who are permanently displaced but resettle shortly after the event may be able to 'move on' and suffer fewer negative impacts from a displacement than those who remain in 'limbo' in temporary accommodation;
- A degree of uncertainty is inherent with any data used for distributing the receptors and the limitations should be considered and reported;
- This approach only considers that those who are displaced are disrupted. As such, those households remaining in flooding properties are disrupted in other ways than displacement and as such the model potentially underestimates the negative disruptive impacts;
- The approach only considers longer-term displacement, rather than also including emergency pre- or during-event evacuation;
- The approach does not consider the spatial extent, the pattern of displacement (i.e. only how long households are away for, not how far) or the potential change in way of life that displacement causes. Similarly, the approach is not able to convert displacement into measures of disruption or impacts on individual health or well-being. Furthermore, the approach does not reflect individual differences in household resilience to disruption;
- The impact on the community is not able to be represented as a score in the CRAF as each receptor's displacement is considered independently.

[130] These values are used for illustration purposes and assume that the score for High impact is the same as for flood depth and for Very High all those affected by building collapse are permanently displaced (i.e. scale of 5).

Community disruption assessment should be undertaken by more in-depth analysis. However, mapping the output of the individual receptor household displacement scores provides a very crude overview of the patterns of displacement within a community.

Regionalised Household Displacement Indicator

- **Indicates the potential degree of household disruption following an extreme coastal event based on the percentage and duration of household displacement;**
- **First, using the impact thresholds model approach, assess the direct damage to residential properties;**
- **Review the Household Displacement durations associated with the scale and refine these where necessary;**
- **Use relevant data or expert knowledge to distribute the percentage of households displaced for each duration and direct impact for the considered hazard. Use these to populate the Household Displacement Matrix;**
- **Calculate the Household Displacement scores and input into the "CHT_forINDRA" file;**
- **Each receptor will be attributed a Household Displacement Score by the model ranging from 0 to 5. These will then be aggregated and normalised within the model;**
- **The final Regionalised Household Displacement indicator provides a normalised and aggregated representation of the potential household displacement presented on a scale ranging from 0 to 1.**

4.3.6 Business Disruption

The disruptive consequential impacts of floods and other coastal events, arising from direct damage to business properties and their contents, can be substantial especially when impacts on supply chains and reputational values are taken into account. On occasions even small events can have major disruptive impacts whereas, sometimes, large events have fewer impacts. Much depends on the event and number, density and type of businesses which are affected. Unlike direct damages which are largely invariant of time, consequential impacts are time variant and often evolve in the days, months and even years after the event (Figure 4.16). However, the state-of-the-art of consequential business vulnerability assessment is not yet well developed and presents considerable uncertainties, partly because impacts are often diffuse and difficult to trace.

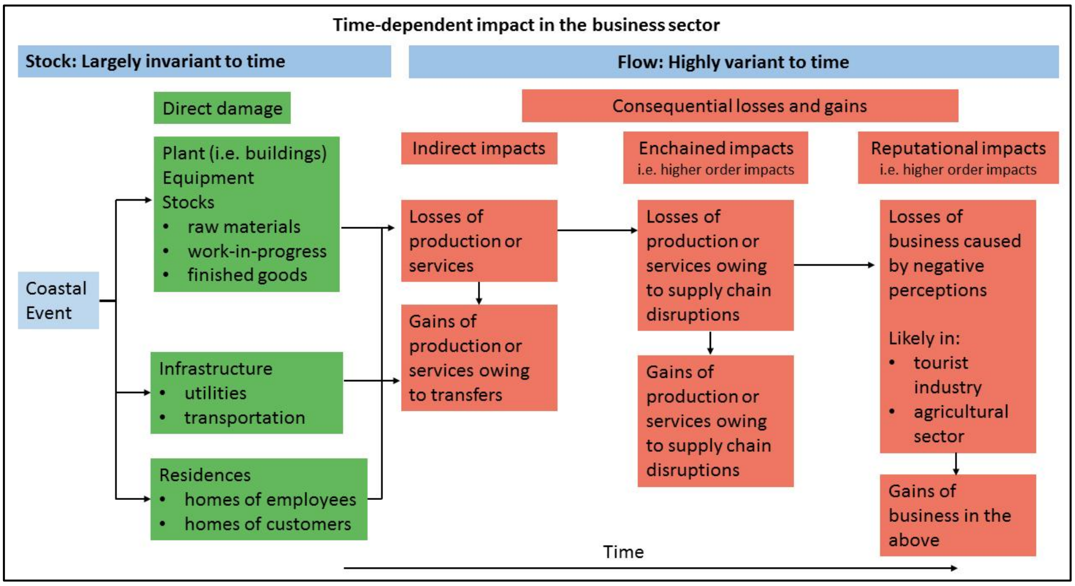

Figure 4.16: A conceptual perspective of flood impacts on businesses

4.3.6.1 Selected Method

Business disruption assessments are often limited to the duration of the coastal event and the initial indirect impacts (loss of production) of the event. Although there is likely to be a positive relationship between the duration of the event and direct damages which translates into businesses experiencing longer periods of disruption, it is the higher order impacts which are likely to be potentially most significant (i.e. enchained impacts and reputational impacts). The focus here is on addressing such consequential losses for the region.

It remains necessary to establish first the direct damages on businesses properties. The selected method is similar here to the use for residential properties, i.e. the identification of erosion and inundation thresholds and the corresponding impact scales (see Sections 4.3.2 and 4.3.5.1). Once impacted, the business disruption is also a function of time. In some cases production or services will return to pre-flood levels in a matter of days or weeks, and in other cases it may last for months or even years. The anticipated pace of business recovery is an important variable in evaluating the disruption, yet difficult to assess.

Reinstatement time

Within the CRAF approach reinstatement time for businesses is defined as the time it takes for the business to be able to operate after an impact (i.e. it is almost same as the repair time). In reality this does not mean that the business is necessarily fully operational, but that it is operating at some level.

Existing data about business recovery time is not so prevalent. Several studies[131] [132] [133] [134] [135] provide estimates of the cost of disruption or interruption, but it is not always clear from the literature if costs derive from the direct or indirect damages or both[136] and furthermore there is a large variation in costs between different studies, possibly due to the large variance in business types, premises, supply chains etc. Only a very limited number of studies[137] [138] provide data on the duration of disruption, limitation or restoration. A comparison between the German and US data for similar flood depths and the same business sector shows a difference in duration of between 8 and 10 months. This would seem to suggest that business interruption or limitation is not the same as recovery. It is difficult, therefore, to establish from the literature exactly when a business has recovered and this should be ascertained on a case-by-case basis at each location and the results entered into the model. Existing data, such as that described above, should therefore be used with caution as it is important that it is consistent with the INDRA definition of reinstatement time.

For instance, data provided by Kreibich et al. (2007)[139] (see Table 4.10) could be used

[131] Parker, D. J., Green, C. H. and Thompson, P. M. (1987) Urban Flood Protection Benefits: A Project Appraisal Guide. Gower Tech. Press, Aldershot.

[132] Chatterton, J., Viavattene, C., Morris, J., Penning-Rowsell, E. and Tapsell, S. (2010) The Costs of the Summer 2007 Floods in England. Project SC070039/R1. Environment Agency, Bristol.

[133] QW (2013) Impact of flooding on key business sectors in Devon and Somerset 2012-13, Final report 16 July 2013, SQW, Cambridge.

[134] Stone, K., Daanen, H., Jonkhoff, W., Bosch, P. (2013) Quantifying the sensitivity of our urban systems. Impact functions for urban systems. Deltares, Dutch National Research Programme Knowledge for Climate, Utrecht.

[135] United Nations Serbia and World Bank Group (2014) Serbian floods 2014, UN/World Bank, Belgrade.

[136] Meyer, V., Becker, N., Markantonis, V., Schwarze, R. (2012) Costs of natural hazards: A synthesis. CONHAZ project report, WP09_1. Available at: http://conhaz.org/CONHAZ_WP09_1_Synthesis_Report_final.pdf (accessed 05.11.2015).

[137]. Kreibich, H., M. Müller, A. H. Thieken, and B. Merz (2007), Flood precaution of companies and their ability to cope with the flood in August 2002 in Saxony, Germany, Water Resources Reserch, 43, W03408. Available at: http://onlinelibrary.wiley.com/doi/10.1029/2005WR004691/pdf (accessed 05.11.2015).

[138] FEMA (2013) Multi-Hazard Loss Estimation Methodology Flood Model, HAZUS MH MR4 Technical Manual. Available at: http://www.fema.gov/media-library-data/20130726-1715-25045-5075/hazus_mr4_flood_tech_manual.pdf (accessed 05.11.2015).

[139] Kreibich, H., Müller, M., Thieken, A.H., Merz, B. (2007) Flood precaution of companies and their ability to cope with the flood in August 2002 in Saxony, Germany, Water Resources Reserch, 43, W03408. Available at: http://onlinelibrary.wiley.com/doi/10.1029/2005WR004691/pdf (accessed 05.11.2015).

as an indication of the reinstatement time in Germany although it remains difficult to define if the duration of business limitation is inclusive or exclusive of the actual flood duration. The authors also provide values for business disruption, which is where no business is possible due to damage, power failure, problems with the supply chain etc., which is shown to be shorter than for limitation. The definition of business limitation provided is as follows: "business is operating, but not at a normal level due to ongoing restrictions such as unusable building areas, storage areas or machinery which leads to lower productivity or business volume"[140] and this seems to be more appropriate for use in terms of recovery.

Table 4.10: Average business limitation durations during the 2002 Saxony floods, Germany (adapted from Kreibich et al. 2007)[141]

Sector	Manu-facturing	Comm-ercial	Financial	Service	Agriculture	All
Mean Depth (m)	1.24	1.36	1.73	1.38	0.83	1.37
Mean Flood Duration (days)	3.5	4.7	6.4	6	5.8	4.7
Mean Duration of Business limitation (months, rounded)	2.5	3	3	3	4	3

Combining similar businesses into their relevant sector types (manufacturing, commercial, agricultural etc.) is a logical step and will remove a level of complexity from the task. A representative sample of businesses within each sector should then be contacted in order to obtain typical reinstatement durations. It is important to use the definition of reinstatement, and use this definition throughout, so that a meaningful comparison can be made across all businesses and sectors.

Once business reinstatement time and the associated losses of different businesses are identified the potential consequential losses can be assessed. Existing methodological research to address the question is discussed below.

Existing methodological approaches

The first approach concerns empirical analysis of supply chain impact pathways, particular demonstrated by Leach (2015)[142]. In this research the managers or owners of businesses in a recently flooded urban area of northern England were interviewed to discover their relationships with suppliers and customers, revealing their supply chains which are mapped. The impact of the flood on the mapped supply chains are portrayed as impact pathways and data on monetary and employment impacts

[140] Ibid.

[141] Ibid, p6.

[142] Leach, K. (2015) Impact of flooding and flood risk on community economic resilience in the Upper Calder Valley, 27th January, Localise West Midlands, UK, Commissioned by Calderdale Council and DEFRA.

throughout the supply chains were gathered.

This approach is insightful but is assessed as being too resource-intensive for the kind of risk screening method which is suitable for the CRAF. Another empirical approach undertook analysis of reputational impacts. The sub-discipline of tourism/tourism marketing has contributed a number of recent studies of the additional vulnerability that businesses experience following a disaster generated by public adverse perceptions of affected tourist destinations. This research, just two examples of which are referred to here[143] [144], has not generated predictive methods which may be employed in or adapted to the CRAF but instead provides empirical data on the decline and eventual recovery of tourist arrivals.

The Dutch Hoogwater Informatic System – Schade en Slachtoffer Module (HIS-SSM) (i.e. High Water Information System – Damage and Victim Module) has the capability to calculating business interruption loss potential[145]. Maximum amounts for business disruption are evaluated using the gross value added and, for secondary indirect losses outside of the dike ring, a multiplier is applied to this value derived from regional input-output tables for each economic sector. The methodology does not allow for large changes in the size of business interruption as a percentage of material damage. Instead these losses are related linearly to the scale of the flood and can only increase if more firms become flooded: a key limitation of HIS-SSM. Even so the method is an advance on the method of Penning-Rowsell et al. (2013)[146] because it seeks to take account of secondary business interruption costs although the choice of multiplier is not without issues.

Since Cochrane's seminal work[147], the use of input-output models has grown in order to address secondary order and higher economic impacts of natural disasters in which business interruption losses are central. Input-output models synthesise inter-industry connectivity and are usually used to evaluate the economic impacts associated with changes in industry output and demands, but they can be employed to evaluate the economic losses due to business interruption caused by a shock such as an earthquake or a flood. Such models evaluate the disturbance to the economic system caused by a disaster through changes in consumption and demand, as well as

[143] Ichinosawa, J. (2006) Reputational disaster in Phuket: the secondary impact of the tsunami on inbound tourism. Disaster Prevention and Management, 15(1): doi: 10.1108/09653560610654275.

[144] Huang, J.H. & Min, J.C.H. (2002). Earthquake devastation and recovery in tourism: the Taiwan case. Tour ism Management, *23*, 145-154.

[145] Kok, M., Huizinga, H., Vrouwenvelder, A. and Barendregt, A. (2005) Standaardmethode2004 Schade en Slachtoffers als gevolg van overstromingen. Technical Report. Rijkwaterstaat, The Netherlands.

[146] Penning-Rowsell, E., Priest, S., Parker, D.J., Morris, J., Tunstall, S., Viavatenne, C., Chatterton, J. and Owen, D.J. (2013) Flood and Coastal Erosion Risk Management: A Manual for Economic Appraisal, Routledge, London.

[147] Cochrane, H. (1974) Predicting the Economic Impact of Earthquakes, in H. Cochrane et al., Eds., Social Science Perspectives on the Coming San Francisco Earthquake, Natural Hazards Research Paper No.25, NHRAIC, University of Colorado, Boulder, CO.

through changes in supply and prices, generally at a national or regional level. The US FEMA HAZUS-MH Flood Model[148] contains an Indirect Economic Loss Module which evaluates the economic disruption or ripple effects that follow from direct losses. The module has at its core a computational algorithm which rebalances a region's inter-industry flows based on discrepancies between sector supplies and demands. Hallegate's adaptive regional input-output model (ARIO)[149] overcomes a key disadvantage of the Dutch HIS-SSM referred to above because it allows the relative amount of business interruption losses to increase as the scale of the flood increases. ARIO's principal merit is that unlike traditional input-output models, forward and backward propagations in the economic system are taken into account as well as adaptive behaviours such as producers finding alternative suppliers. The model therefore facilitates the evaluation of indirect costs in the aftermath of a disaster shock for the whole economy of a region by taking into account the effects of changes in demand and supply in several sectors of activity. Conventional input-output models normally do not consider productive capacity but in the ARIO model the greater the direct, material damage, the more limited is the production capacity (on the supply side) so that the recovery period is longer leading to greater business interruption loss. Such Computable General Equilibrium models (CGE) are alternatives to input-output models for evaluating indirect flood losses. Their advantage lies in the fact that elasticity in the economic systems is considered and the model therefore reflects the reality with more accuracy than input-output models.

Unfortunately, complex input-output analyses of the kind referred to above are inappropriate for the CRAF which requires a simple method of screening business disruption potential, although the concept of inputs and outputs which is common to graph theory approaches, provides a useful basis on which to proceed. Also, although input-output tables are available for some areas, they are not available for many including, for example, regional economies of the UK.

Methodological contributions to supply chain network analysis derive from various sub-disciplines including manufacturing economics, supply chain management, operations management and technological forecasting. The literature in this area is huge and so the research referred to here is highly selective and just indicative of the state-of-the art. There are many different models of supply chains but most of them are functionally not oriented towards the purpose of systemic vulnerability analysis. Models of supply topologies are an exception but these typologies are only published for a few industry sectors. The most useful work in the area of supply chain typologies categorises them as either serial, convergent, divergent or a mixture of all three and introduces the concept of tiers of suppliers within supply chains[150] [151]. Research on

[148] FEMA (Federal Emergency Management Agency) (2006) HAZUS-MH MR3 Multi-hazard Loss Estimation Methodology - Flood Model, Technical Manual.

[149] Hallegatte, S. (2008) An Adaptive Regional Input-Output Model and Its Application to the Assessment of the Economic Cost of Katrina. Risk Analysis 28, 779–799.

[150] Stadtler, H. and Kilger, C. (2008) Supply Chain Management and Advanced Planning, Concepts, Models, Software and Case Studies, 4th Ed, Springer, Heidelberg.

[151] Lambert, D.M. & Cooper, M.C. (2000). Issues in supply chain management. Industrial

hotel food supply chains in SW England provides valuable insights into the tiered, convergent structure of a type of business commonly found in coastal risk zones[152]. Four papers illustrate current approaches to analysing the vulnerability of supply chain networks. An approach using graph theory to quantify and mitigate supply chain vulnerability demonstrates that graphs may be used as visual maps to facilitate understanding of supply chain vulnerability and to support decision about disaster risk reduction[153]. Another approach focuses upon a methodology which is designed to inform innovative companies about the relationships which they may elect to develop including ways of managing relationship vulnerability. It characterises supply chains as dynamic, adaptive business ecosystems and focuses upon representing these systems as nodes which have both tangible (i.e. products and services) and intangible (i.e. exchanges between nodes) relationships[154]. The third of these research papers[155] focuses upon improved understanding of supply network disruptions which can occur when either a node (i.e. a business facility) or an arc (i.e. transportation) is disrupted so that material flows across the network are disrupted. Some network configurations are much less resilient than others. For example, a 'scale-free' network in which a few nodes have disproportionately more connections than others, and some nodes have few connections, is much more resilient than a 'centralised' network in which a few nodes connect to almost every other node, whereas the other nodes connect mainly to the highly centralised nodes. The fourth contribution, the 'Basilicata' approach[156] [157] is a conceptualisation of systemic vulnerability that leads to an operational assessment methodology and employs GIS tools. The approach which distinguishes between different types of node (i.e. conditioning and conditioned nodes) is essentially analysis of dependency which the researchers apply to flood and landslide events. Finally, Kim et al. (2015)[158] present a very useful review of the structure of supply networks and their significance in understanding supply network disruption and resilience.

Marketing Management. 29 (1), 65–83.

[152] Akkaranggoon, S. (2010) Supply Chain Management Practices in the Hotel Industry: An Examination of Hotel Food Supply Chains in South West England, DPhil, Management Studies, University of Exeter, Exeter.

[153] Wagner, S.M. and Neshat, N. (2010) Assessing the vulnerability of supply chains using graph theory, International Journal of Production Economics, 126, 121-129.

[154] Battistella, C., Colucci, K., De Toni, A.F., Nonino, F. (2013) Methodology of business ecosystems network analysis: A case study in Telecom Italia Future Centre, Technological Forecasting and Social Change, 80, 1194-1210.

[155] Kim, Y., Chen, Y-S. and Linderman, K. (2015) Supply chain network disruption and resilience: A network structural perspective, Journal of Operations Management, 33-34, 43-59.

[156] Pascale, S, Sdao, F, Sole, A (2010) A model for assessing systemic vulnerability in landslide prone areas, Natural Hazards Earth Systems Science, 10, 1575-1590.

[157] Albano, R, Sole, A, Sdao, F, Giosa, L, Cantisani, A, Pacale, S. (2014) A Systemic Approach to Evaluate the Flood Vulnerability for an Urban Study Case in Southern Italy, Journal of Water Resource and Protection, 6, 351-362.

[158] Kim, Y., Chen, Y-S. and Linderman, K. (2015) Supply chain network disruption and resilience: A network structural perspective, Journal of Operations Management, 33-34, 43-59.

Drivers of vulnerability

The selected method is also based upon a detailed review of literature to identify the principal drivers of the vulnerability of businesses to disruption. This included, for example, the impacts of floods on businesses in the Serbian floods of 2014[159], the Thai floods of 2011[160], the Elbe floods of 2002[161], and the floods in SW England in 2012/13[162]. Based on this review the key drivers of business disruption in flood events may be simplified as in the following formula:

Business vulnerability = f (D, RC, BCP, Rec)

where:

D = Flood depth (which is usually positively associated with flood duration) leading to depth-damage relationships for business buildings or facilities;

RC = A combination of the strength of an area's business linkages and the proportion of productive capacity directly damaged in an event;

BCP = Extent of business continuity planning including direct and consequential loss insurance and;

Rec = The degree to which an area's institutional arrangements are geared up for a swift and efficient recovery. Estimation of D allows RC to be estimated. BCP and Rec are DRR methods considered only when business vulnerability potential in the absence of DRR has been evaluated.

Coastal infrastructure assets create demand

The approach also links coastal infrastructure assets where they are key attractions of demand in coastal tourist resorts. So for example, in the Library of Coastal Vulnerability Indicators[163] three coastal business settings are considered to cover a large proportion of the cases likely to be found along European coastlines.

The first of these is a location characterised as a **Beach frontage urban area and tourist resort**. The principal coastal infrastructure of such a location is likely to be intimately related to the business economy. Beaches, promenades, piers and, maybe, other infrastructure assets of this type (e.g. car parks) are likely to be key tourist attractions or facilities on which a significant proportion of businesses in the local economy will depend to different degrees.

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[159] United Nations Serbia and World Bank Group (2014) Serbian floods 2014, UN/World Bank, Belgrade.

[160] Masahiko, H and Upmanu, L. (2012) Flood risks and impacts: A case study of Thailand's floods in 2011 and research questions for supply chain decision making International Journal of Disaster Risk Reduction.

[161] Kreibich, H., Seifert, I., Merz, B. and Thieken, A. (2010) Development of FLEMCos – a new model for the estimation of flood losses in the commercial sector, Hydrological Sciences Journal, 55, 8, 1302-1314.

[162] SQW (2013) Impact of flooding on key business sectors in Devon and Somerset 2012-13, Final report 16 July 2013, SQW, Cambridge.

[163] Viavattene, C., Micou, A.P., Owen, D.J., Priest, S. and Parker, D.J. (2015) Library of Coastal Vulnerability Indicators. RISC-KIT Project Deliverable, D2.2: http://www.risckit.eu/np4/8/ (accessed 05.11.2015).

Similarly, in the case of the second common coastal business setting, the **Coastal harbour (with or without marina) and related urban area**, the harbour and related facilities (harbour walls or piers, moorings, landing stages, boat repair facilities etc.) may well be its raison d'être or the area will depend, at least to some degree on the harbour.

In the third setting, the **Port and related commercial and industrial zones**, breakwaters, docks, ro-ro/ferry terminals, breakbulk and gas terminals, cranage, container handling facilities, storage and road and rail tracks etc. comprise the infrastructure assets that could be compromised by flooding and which could lead to business supply chain disruption.

Differential vulnerability of coastal business economies

It is essential to evaluate the vulnerability of coastal business economies in the context of their position in the economic cycle of growth and decline and against the background of the fortunes of the regional/national economy in which they are located. A growing coastal economy within a regional or national economy which is also growing is likely to be less vulnerable to the shock of a flood than one which is in decline and/or is part of a regional or national economy with rising unemployment and low or zero economic growth rates. For example, whereas coastal business economies along Italy's Adriatic coast may be buoyant even though the national economy has been in difficulty, they are likely to be less vulnerable than many of Britain's coastal resorts which have been in decline for decades.

Coastal economies based heavily on tourism (e.g. the Beach frontage urban area and tourist resort) are likely to be the most vulnerable of the three coastal business settings previously described, primarily because the infrastructure assets on which demand for them is based are in the front line of exposure to storm surge and reputational loss is a significant risk. The Coastal harbour (with or without marina) and related urban area is likely to be next in terms of vulnerability: again in the front line against storm surge though constructed to relatively robust standards but with highly damageable vessels and related assets. Port and related commercial and industrial zones are, in the whole, likely to be least vulnerable because their infrastructure is likely to be well adjusted to extreme coastal events.

Business Disruption Indicator

Based on these literature considerations the selected method is a Business Supply Chain Model which seeks to characterise the principal connectivities and inter-dependencies within a chosen area. The method is derived from graph theory approaches and seeks to model the principal business facilities which are the nodes and the business interactions or exchanges (or arcs in supply theory terminology). Out of necessity for the CRAF, the method is deliberately based on simplifying the complexity of a business economy within a coastal setting and its hinterland in order to:

- Be relatively simple and easy to use;
- Where feasible, allow secondary source data to be employed;
- Allow vulnerability to be screened and evaluated;
- Provide a sound basis on which to make a decision about whether to pursue the evaluation of business disruption by refining input data and/or further using a more complex and time-consuming complementary method.

The approach takes a 'helicopter view'. How one characterises a coastal business economy's supply chain network depends on the perspective you choose to take. Different participants in the supply chain will have different perspectives of how the network is configured. For the CRAF a helicopter view needs to be taken which focuses upon (a) the principal coastal infrastructure assets (b) the principal clusters of businesses (e.g. hotels, food and drinks suppliers, restaurants etc.) (nodes) and (c) the lines of conveyance (arcs) between these which may be disrupted by an event such that either one or more nodes is flooded, or one or more links are severed or a combination of both. As a result a business supply chain can be represented by a network similar to the one in Figure 4.17 and the indicator calculated as the sum of the reduction in the supply capacity of each of its nodes weighted by their relative economic importance:

$$I_{BD} = 1 - \frac{1}{\sum We} \sum_{i=1}^{d} (We_i * \frac{Cimp_i}{Cnorm_i})$$

Where:

I_{BD}: Indicates the percentage of supply capacity loss for the whole network;

d: Number of supply nodes;

C_{imp}: Supply capacity of the node *i* in impacted supply chain;

C_{norm}: Supply capacity of the node *i* in normal supply chain;

For I_{BD} a value of 1 indicates that the supply chain is fully impacted (no supply), a value of 0 that the supply chain is not impacted.

The I_{BD} is then calculated for each simulation time, the different components of the network being repaired over time. The Regionalised Business Disruption indicator integrates the I_{BD} over the period of the simulation and provides a value of between 0 and 1.

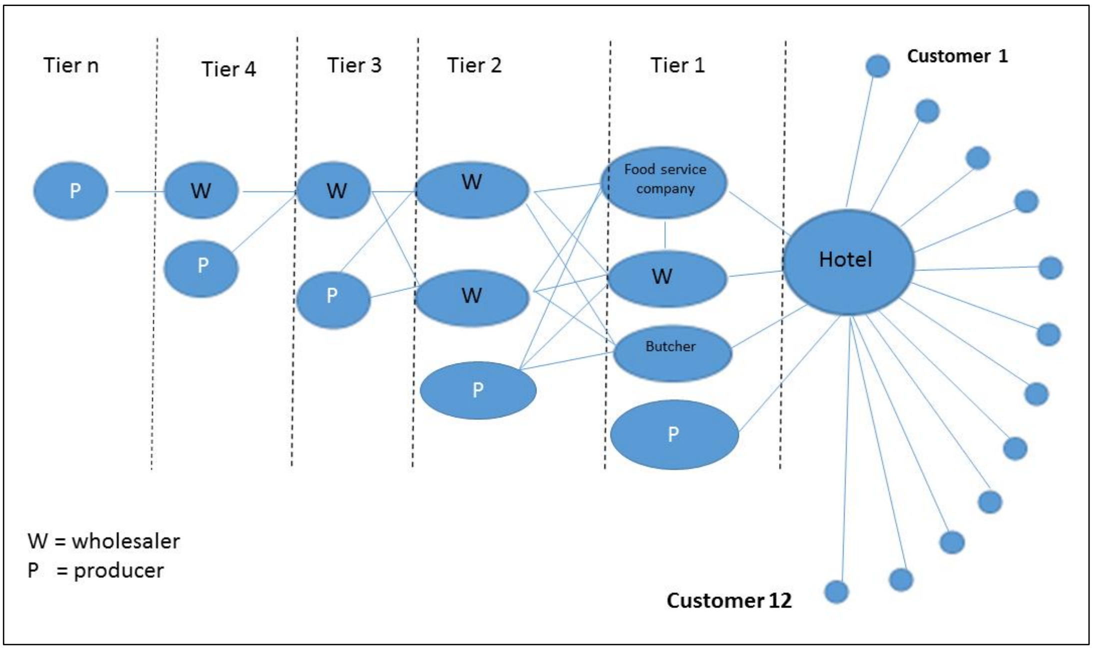

Figure 4.17: Example of a hotel supply chain[164]

Depending on the resources available, the identification of supply chain structures may be undertaken at various levels of generality or detail and accuracy. The business development unit of the local municipality, or the local chamber of commerce, may well be able to assist with this exercise. Contacting one or more of the principal businesses may allow the structure to be further confirmed.

Capacity may be measured in various ways: units of production or service (e.g. number of chilled meals, passengers, tonnes of cargo), employment (no. of employees), turnover or value added etc. It is not necessary to use the same unit of production etc. for each node because the key measure of impact is the proportion of business which is lost because of disruption. So a hotel's capacity may be most appropriately measured by bed spaces. For a restaurant the unit of measurement is likely to be seating places but for a food supplier it may be boxes of food products, chilled meals or whatever the main unit of output is. Again, depending upon the resources available, information on capacity of production/service may be assessed at various levels of generality or detail and accuracy. Data on hotel accommodation is usually available from the local tourist office or municipality. Data on the capacity of manufacturing and logistical supply businesses is more difficult to obtain – though employment figures may be more easily available –and it may well be necessary to contact a number of key companies to gain some general capacity information.

In order to assess the supply capacity INDRA follows these 4 successive steps:

- Calculate for each node the supply capacity considering the loss of supply from directly or indirectly impacted receptors (e.g. flooded, other network disruption);
- Calculate the supply capacity for each node starting at tier n by estimating the

[164] Adapted from Akkaranggoon, S. (2010) Supply Chain Management Practices in the Hotel Industry: An Examination of Hotel Food Supply Chains in South West England. DPhil, Management Studies, University of Exeter, Exeter.

reduced capacities in the supply chain from the previous tier as a ratio between the impacted supply capacity and the normal supply capacity of all nodes of the previous tier;

- Define for the last tier (tier 0; i.e. hotel in Figure 4.17) if the supply is reduced per a loss in demand resulting from a lack of attractiveness induced by the loss of other receptors (e.g. beaches, promenades, piers etc.);
- Calculate the final supply capacity for each node by estimating the reduced capacities in the supply chain between one tier and the next, starting with the final tier (tier 0). This is calculated as a ratio between the impacted supply capacity and the normal supply capacity and as such is equivalent to the reduction in demand.

The indicator score is then calculated for each simulation day, the number of businesses return to production increasing based on their reinstatement time. The final business disruption indicator integrates the score over the period of simulation.

4.3.6.2 Application of the methodology within the model

The methodology is adapted from the approach proposed in the Library of Coastal Vulnerability Indicators in order to fit the models requirement.

Step 1 - Define the boundary of the analysis: business settings and regional boundary

The model does not aim to represent all economic activities and all supply chains but the most relevant ones economically that might be impacted. It is first necessary to consider what the main economic activities for the region are and if some of the businesses contributing to these economic activities are potentially exposed (see step 3).

The three generic coastal business settings which, between them, are likely to describe the vast majority of sites or locations where a vulnerability assessment is likely to be required:

- Beach frontage urban area and tourist resort;
- Port and related commercial and industrial zones;
- Coastal harbour (with or without marina) and related urban area.

Step 2 - Approach key stakeholders to acquire data

Undertaking a business systemic vulnerability assessment usually involves contacting one or more stakeholders in order to obtain information and data about the inter-dependencies which exist between coastal infrastructure (e.g. beaches, piers etc.) and business assets, and the linkages between businesses.

Step 3 - Produce a table listing the key assets – the Asset Matrix

At the outset it is necessary to identify the major businesses and groups of businesses within the coastal locality and the region in which it is located. Initially, the focus should be mostly upon the local scale (including the businesses located in the extreme flood zone and those beyond it). The table (Figure 4.18) provided in the Library of Coastal Vulnerability Indicators can be used to refine the selection of the supply chain to be considered (please refer to the Library for more information on how to use it). Multiple dependant supply chains may exist in each context and will have to be identified.

							More detailed quantitative approach	More detailed qualitative approach						
	Column:	1	2	3	4	5	6	7	8	9	10	11	12	
		Asset ID (assign a unique code)	Asset Description	Input	Output	Number of businesses, length (m), capacity(c), mean or visitor count per day (v)	Average number of employees per business	Size distribution of business (Micro 0-9; Small/Med 10-249, Large 250+)	Likelihood of Exposure? (high, medium, low, none) (i.e. direct exposure to flooding)	Sensitivity to damage/loss (high medium, low, none)	Is the asset unique to sub-region? (Yes/No)	Surrogate measures	Dependency (list factors)	Esti dura repair, ment the 52 disr
3	(IS) Infrastructure assets													
	(BA) Business assets													
		Notes 1 It is necessary to calculate this value for businesses in each of the three size categories. This is done as follows: Multiply the Average Number of Employees per business by the Average Earnings per (a) (b) Sensitivity to damage/loss includes (a) direct physical damage and/or (b) indirect, consequential loss N/A - Not applicable BA - All Business Assets IS - All Infrastructure Assets												

Figure 4.18: A snapshot of the "Step 3 Asset Matrix"

Step 4 - Define the supply chains and produce a schematic

Once selected the supply chain should be defined following the example proposed in Figure 4.17, i.e. a chain of tiers. Yet since everything is likely to be connected to everything else, it is necessary to establish a boundary for the business flows or where each supply chain is to be terminated: this is called the 'sink' – a node that has zero output because goods and services are not provided to others. The "sink" is considered in the model as a "demand" or "customers" node. On the other hand, a node that has zero input is a 'source' – the point of origin of goods and services. Each node should also only represent activities that will directly limit the production of related nodes. Elements of the supply chain including the source(s) and the sinks may be inside or outside of the regional boundary defined for the case study. As such the approach considers the relative regional and non-regional contributions to the supply chain. Those supply nodes which have a higher proportion of supply capacity from external to the region (and therefore are not impacted) are likely to be less disrupted by events, than those with a lower proportion.

Figure 4.19 provides a very simple example to explain how the information will be input into the model. The supply chain here has 3 tiers, Tier 2 are sources (A and C) and Tier 0 the sink node (D), E is the demand node and in this case F is a node representing the attractiveness of the area[165]. At the end of the supply chain network is the sink in which the direction of the network runs. So, for example, the final destination of the supply chain may be hotels dependent upon coastal infrastructure assets for their customers and dependent upon suppliers of food and drink.

[165] The attractiveness is not considered as a chain in the model.

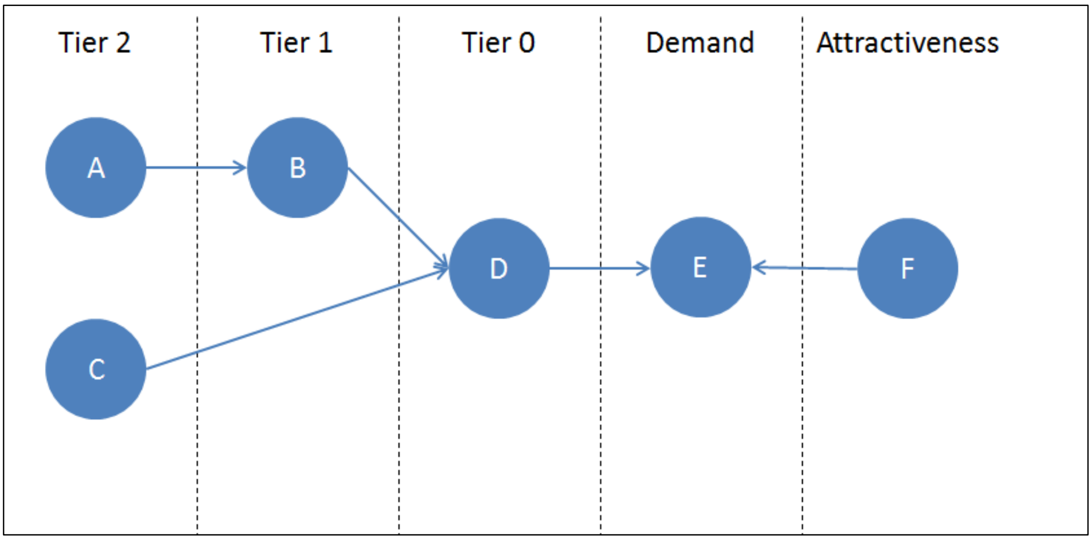

Figure 4.19 Example of a simple supply chain

Based on the earlier steps it is also required to define for each node their relative capacity. It may be measured in various ways for different nodes: units of production or service (e.g. number of chilled meals, passengers, tonnes of cargo), employment (no. of employees), turnover or value added etc. It is only necessary to use the same unit of production for a specific node.

The capacity, and spare capacity, has to be defined at the receptor levels if the business is within the regional boundary. The total capacity of businesses outside the region is represented by a single value at the node level.

A similar approach is used for attractiveness.

Step 5 – Produce the input files

Information on the different business vulnerabilities and associated reinstatement times has to be provided in the "CHT_ForINDRA.txt" file.

Information on the supply chains is provided in a text file ("SC_forINDRA.txt").

```
"Supplynode" "description" "type" "ImportanceWeight" "OutBoundaryCapacity"
"A" "ProducerGoodA" "S" 1 0
"B" "Distributor" "S" 1 10
"C" "ProducerGoodA" "S" 1 10
"D" "ServicesD" "S" 3 10000
"E" "customers" "D" 0 20
"F" "Site Attractiveness" "A" 0 80
"LINKAGE"
"A" "B"
"C" "D"
"B" "D"
"D" "E"
"F" "E"
```

Figure 4.20: Snapshot of a "SC_forINDRA.txt" file

The first line is not considered by the model but indicates the file contents.

Each following line informs about each node of the supply chain, a space is used to delimitate the variables and brackets are used for string variables. Each line should provide the following variables:

- The name of the node: this is a unique reference code chosen by the user;

- A comment in quotations describing the node (e.g. “Distributer”);
- The type of node: “S” for a supply node (a tier node), “D” for a demand node, “A” for an attractiveness node;
- A weighted value to indicate the economic importance of the nodes;
- A value indicating the capacity provided by businesses situated outside the areas (for instance if restaurants were only 10% supplied by local production the value should represent 90% of the total supply capacity expressed in the unit chosen by the users).

Information about the receptors considered as businesses belonging to one of the nodes is also required. In the point shapefile the user should provide information on land uses for three fields:

- "BS_ref" : the unique reference code of the node for which the business is associated (or the attractiveness node) - the demand node is not represented by a land use;
- "BS_cap": The capacity of the business in normal conditions;
- "BS_scap": The spare capacity of the business in normal conditions.

BS_ref	BS_cap	BS_scap
A	2	0.2
A	2	0.2
A	2	0.2
A	2	0.2
D	3	0.3
D	3	0.3
D	3	0.3
D	3	0.3
D	3	0.3
D	3	0.3
D	3	0.3
D	3	0.3
A	2	0.2
A	2	0.2
A	2	0.2
A	2	0.2
A	2	0.2
D	3	0.3

Figure 4.21: A snapshot of the Land Use shapefile for business disruption inputs

Information on the tier level is not provided as it is automatically defined by the model.

4.3.6.3 Limitations and assumptions

- The model, as so far articulated, has a number of important limitations. In reality, supply chains are rarely a simple chain of nodes and are likely to be more complex chains and networks which are more challenging to model than shown above;
- Secondly, coastal supply chains become disrupted in three principal ways: (a) coastal infrastructure assets (e.g. beaches) are degraded or lost, (b) business facilities (e.g. plants and buildings) (i.e. nodes) are damaged or destroyed, and (c) lines of conveyance (i.e. arcs) are cut (e.g. rail, road and other forms of

transportation may be disrupted). The consequences for the supply capacity of a line of conveyance being cut are almost the same as a node being put out of action. The Business Supply Chain Model is linked to utility disruption models to predict the impact of flooding on these linkages. However, the potential of business disruption caused by a lack of accessibility is not considered in the model;

- The current model implies that businesses have adopted a JIT (Just-in-time) system of supply. Although many businesses have moved to JIT supply systems, some will not have done so and will have a stock of goods available to them which presents a buffer against supply chain disruption. Creating such a buffer is one way in which businesses adapt to supply chain uncertainties and this may or may not be considered as a DRR measure. Incorporating information on JIT and non-JIT businesses into the model is simple enough but acquiring the information is heavy in terms of data acquisition and therefore unattractive at this level of analysis. The issue does not apply to services which are usually supplied on a daily or weekly basis;
- Although the model takes the disruption reducing effects of business transfers into account, it does not account for deferral of business or trade. One way in which some businesses cope with disruption is to defer production or service delivery until a later date and then catch-up in time. An additional cost may be involved in deferral (e.g. staff overtime costs) but this is not taken into account in the model. The model also neglects the potential for additional source of supply obtained outside the region;
- Based on existing knowledge, there are limits on the predictability of business recovery durations and rates and upon the amount, duration and rate of reputational loss and recovery;
- Reputational impacts are only indirectly considered in the model by associating the attractiveness component.

Regionalised Business Disruption Indicator

- **Indicator of the potential degree of business disruption (reduction of capacity) for various supply chains at the regional scale;**
- **Based on the supply chain analysis technique;**
- **First, define and scheme economically important supply chains at risk in the region;**
- **Provide information on the supply chains in a text file ("SC_forINDRA.txt");**
- **Attribute the node code, capacity and spare capacity to the land uses;**
- **Attribute a vulnerability indicator and reinstatement time for the land uses in the "CHT_forINDRA.txt" file;**
- **The change in supply capacity for each node will be recalculated based on the disruption of business and a regional indicator value from 0 to 1 estimated;**
- **The final indicator provides the degree of business disruption over time (0 no disruption, 1 full loss of capacity) for the considered supply chains.**

4.3.7 Financial Recovery

A key factor linked to the resilience of coastal societies from extreme events is the ability of individual households and business to recover financially. Not all households and business will have to recover independently of any assistance, there are a diverse set of financial recovery mechanisms (including government compensation, government and private-market insurance, tax relief, charity, welfare relied) used internationally as Disaster Risk Reduction Measures (DRRs) to assist financially those affected by coastal hazards. However, not all areas will have these and not all people will have access. Therefore, even when recovery mechanisms are available, there is often a gap between the insured and uninsured losses, which in some countries is considerable[166]. The presence and comprehensiveness of these measures need to be included when considering the ability or likelihood of individuals achieving full or partial financial recovery from coastal events.

Although considered important to societal resilience, methodologies for the inclusion of this variable within risk assessment approaches are lacking. What does exist generally concentrates upon estimating only the direct damages experienced rather than also including the ability to recover. Therefore, for the CRAF it has been necessary to develop and utilise a new approach which is explained in the following sections. Importantly, the simplified approach adopted is ultimately based upon the assumption that those households/businesses which receive a greater degree of financial assistance (through various mechanisms or access to outside resources) are more likely to recover from coastal events and recover more quickly, than those who do not have this access.

4.3.7.1 Selected method

A semi-qualitative approach has been adopted to assess the ability of households to financially recover from extreme coastal events. This utilises a matrix-based approach to identify and assign the various potential states of financial recovery likely to be achieved by domestic households and businesses. The matrix has two different inputs, the characteristics of the receptor (household or business property) which draws on the different types of recovery mechanisms (Table 4.11: the rows in the matrix) and the severities of the direct impacts of coastal hazard experienced by a property (Table 4.11: the columns in the matrix). This assessment does not aim to provide a quantitative value for the financial amount or percentage that is able to be recovered, but instead presents a scale of financial recovery impacts from 1 (full recovery) to 5 (very low recovery) (see Table 4.12).

The approach includes four different matrices; one for households for coastal flooding/overwash, one for households for coastal erosion and separate ones for business properties affected by coastal flooding/overwash and coastal erosion (see the Library of Coastal Vulnerability Indicators). It has been necessary to develop separate matrices for coastal flooding/overwash and coastal hazard events because the receptor type may differ between events. For instance, private market insurance is available in the UK for coastal flooding however coastal erosion is excluded from all policies. Therefore, in this circumstance the receptor type, and the associated degree of financial recovery, will differ between the different hazards. Different from the approach for coastal flooding/overwash, the coastal erosion matrices only presents different impact scores for receptors in the 'Very High' direct impact category (i.e.

[166] Centre for Economics and Business Research (CEBR) (2012) Lloyd's Global Underinsurance Report, October 2012, Lloyd's: London, UK.

when a property suffers from total or partial collapse) and therefore for the Low and Medium categories of direct impact a score of 1 is assumed for each receptor type. This is because the losses associated with the monitoring thresholds (i.e. alternative accommodation costs) are assumed to be low and from which households will financially recover[167].

Table 4.11: A simplified version of the Household Financial Recovery Impact matrix[168]

			Direct impact on property			
			Low	**Medium**	**High**	**Very High**
	Characteristics of receptor related to financial recovery		**Low financial damages sustained**	**Medium financial damages sustained**	**High financial damages sustained**	**Very high financial damages are sustained**
Receptor types and their characteristics	**Household with no insurance**	**NoI**	2	3	4	5
	Household with no insurance, but resident has self-insured	**NoIself**	1	2	3	4
	Household with no insurance, but which are able to access a small/medium amount of government compensation	**NoIScomp**	1	2	3	4
	Household with no insurance, but which are able to access a large amount of government compensation	**NoILcomp**	1	1	2	3
	Partly insured household	**PartI**	1	2	3	4
	Household with full coverage for buildings and contents insurance	**FullI**	1	1	1	2

A typology of receptors has been developed (Table 4.13) to characterise the type and degree of financial assistance each property will receive (or have access to) following an extreme coastal event. This has been based on international analyses of the commonly adopted approaches to assisting financial recovery from flood events[169] [170].

[167] Importantly, these categories are not able to account for any long-term negative impacts associated with any monitoring activities (such as a reduction in the market value of a property or it being red-lined).

[168] The full versions located in the Library of Coastal Vulnerability Indicators provide a more detailed qualitative description as well as the score of Financial Recovery Impact (i.e. 1 to 5).

[169] Priest, S.J. (2014) Review of international flood insurance and recovery mechanisms: Implications for New Zealand and the resilience of older people, Research report for the

There are six receptor types for households and six for businesses and the method is based upon the principle that any household or business property will be able to be uniquely assigned to one of these categories. Those properties which users consider not to fit into any of these categories will have to be considered separately and either a new receptor type and consequently impacts developed by users[171] for a specific case or users should utilise an existing receptor type which is considered to be indicative of the likely degree of recovery possible.

Table 4.12: Scales of Financial Recovery Impact

Degree of financial recovery	Full	Households		Business properties	
	↓	1	**Full financial recovery** – households will recovery with no/few adverse impacts.	1	**Full financial recovery** - businesses able to continue with little impact on the running of the business and overall profits.
		2	**Partial financial recovery – medium duration** households will achieve partial financial recovery that will take many months to achieve.	2	**Partial financial recovery** – with a medium duration. Businesses will be able to achieve a partial recovery (the business may shrink in the short to medium term) that will take many months to achieve.
		3	**Partial financial recovery – long duration -** households will achieve partial financial recovery that will take over a year to achieve.	3	**Partial financial recovery with a long duration.** Businesses will be able to achieve a partial recovery (the business may shrink in the medium to long term) from being affected but this will take over a year to achieve
		4	**Low degree of financial recovery** possible for households and/or will take many years/decades to achieve.	4	**Low degree of financial recovery** and/or will take many years/decades to recover. A business may shrink significantly as a result of the event, It may be necessary to relocate the business and it would require significant rebuilding.
	Very low	5	**Very low financial recovery is possible** – The household suffers major and permanent changes to their way of life.	5	**Very low financial recovery is possible.** This means that a business would shrink significantly. This would change the nature of the business and in many situations a business would not be able to recover, leading to permanent closure.

Community Resilience and Good Ageing: Doing Better in Bad Times Project. Available at: http://resilience.goodhomes.co.nz/publications/ (accessed 05.11.2015).

170 Penning-Rowsell, E.C and Priest, S.J. (2015) Sharing the burden: who pays for flood insurance and flood risk management in the UK, Mitigation and Adaptation Strategies to Global Change, 20(6). 991-1009.

171 i.e. they will need to add a new row into the matrix and define the likely possible recovery impact scores and categories.

Table 4.13: Financial recovery mechanisms

Households	Code	Business properties	Code
Household with no insurance	NoI	**Non-insured/self-insured smaller-to-medium sized business -** a business which has no or very little insurance coverage	BNoI
Household with no insurance, but resident has self-insured. This can either be intentional (i.e. conscious decision prior to the event) or unintentional (e.g. is able to access loans or savings).	NoIself	**Non-insured/self-insured larger business or a business corporation*** – although not insured via the private market, these businesses will have significant resources from which to draw to financially recover.	BMNCself
Household with no insurance, but a small/medium amount of government compensation is provided*.	NoIScomp	**Non-insured/self-insured business** – but the health of a business or access to resources, such as business loans or government assistance (e.g. tax breaks) to tide the business through the difficult recovery period.	BNoISelf
Household with no insurance, with a large degree of government compensation*.	NoILcomp	**State owned business*** – in these situations the state is responsible for financial recovery. The circumstances and duration of recovery will depend upon the specific state involved; **-** however state-led recovery may be less efficient than market-led approaches.	BStateown
Partly insured household* – the homeowner has insurance (but some elements may not be fully insured; i.e. they may have only buildings or contents insurance/not all elements may be eligible for coverage; may have some degree of underinsurance).	PartI	**Partly Insured business*** – The business will have some insurance, however not all elements are insured (i.e. may only have structural, contents or business interruption insurance/not all elements may be eligible for coverage; may have some degree of underinsurance).	BPartI
Household with full coverage for buildings and contents insurance – This situation assumes that all/most financial losses will be compensated by insurance cover.	FullI	**Fully insured business** (with Structural, Contents and Business Interruption insurance) – these businesses will recover most/all of their losses from insurance.	BFullI

NB. * These situations assume that any further financial recovery in addition to the insured element would need to be borne by the individual household or business/business group.

Calculating the direct impacts on a property

The first task is for users to calculate the direct damages occurring to any property and assign each receptor within the hotspot to a category of Low, Medium, High and Very High. To achieve this, users should apply the threshold approach explained in detail in Section 4.3.5.

Assigning recovery mechanisms to each property

Users should first identify which properties are business premises and which are households and the following procedure should be undertaken separately for each type of property. The next step for users is to identify the potential recovery mechanisms which are present within their regional case. This will include users considering whether government compensation or insurance is available to either households or businesses that are affected by coastal flooding/overwash or erosion. Those mechanisms which are not applicable (i.e. the UK government offers no compensation to households affected by flooding) can be excluded at this stage[172].

The next step is to assign a recovery mechanism to each property. From an ideal perspective when utilising this approach, information would be included about each individual property or business. However, it is likely that these data will not be available without undertaking a comprehensive survey of all properties of interest. Therefore, it is proposed that users should adopt an area-based approach to attribute a likely recovery mechanism, rather than surveying each individual receptor[173]. There is a clear limitation to this, as the larger the area, the higher potential for misrepresenting the recovery mechanism of receptors. If such data are used, a strong knowledge of the variance of such data would assist in understanding the limitation and validity of the result. Users need to decide (based on the available data and expert knowledge) the most appropriate disaggregated level considering the size of all of the hotspot areas.

For each area of assessment (e.g. municipality A, municipality B etc.) it is necessary to distribute properties across each recovery mechanism. The level of complexity and detail of this distribution will vary according to any data that may be available to assist users, or from expert judgement by local stakeholders[174]. For each of the receptor types (e.g. NoI, NoISelf, FullI) users are required to enter a percentage value into an input table to represent the proportion of the total properties which have those characteristics. For example, if municipality A is considered to have 50% of households that are fully insured, 30% of households partly insured and 20% of households with no insurance, then the user would enter these values into the input table in the corresponding cells. All other cells should have an input value of 0.

[172] i.e. 0 should be entered for this receptor category in the input table.

[173] Although the model will consider the chance of any single receptor being located within any single receptor class.

[174] For instance, local stakeholders may argue that one area/municipality has a high amount of deprivation when compared to another and as such the % of receptors assigned to the category of NoIself (i.e. those with no insurance, but will be able to access loans or savings) will be lower than in a more affluent household.

Data utilised for assigning the receptors

As previously stated the level of detail with which it is possible to apply this approach depends upon the data that is available. This section describes the potential datasets that can be utilised to assign each of the different receptors. Importantly, these data will need to be considered separately for flooding/overwash and coastal erosion situations if it is thought that the penetration rates are different for the different hazards. If they are considered to be the same then the same distribution can be used for both matrices. Additionally, available data of this type can be quite generalised and at a low level of disaggregation. Therefore, it will be relevant to speak to local stakeholders to refine available data.

Insured or not insured

Data about the uptake or penetration of insurance for natural hazards will provide a basis for the distribution of the numbers of those who have some degree of insurance. Various estimates for countrywide assessments of the market penetration of insurance are available[175] [176]. At a basic level these data could be used to distinguish between the receptors which are insured or not insured; and these data can simply be input as two categories into the model input table[177] (e.g. see Table 4.15). So for the case of Italy where the penetration of insurance is low at c. 3% (and if no better data were available); it might be decided to assign 3% of properties to the insured category and the remaining 97% will then be assigned across the non-insured categories. However, these values represent a national-level assessment and users should examine whether data are available at a more disaggregated level and therefore more applicable to this scale of analysis. Taking again therefore the example of Italy, it is thought that the South of Italy has the lowest penetration of insurance averaging less than 0.5% whereas the penetration in the North is considerably higher[178]. Urban agglomerations in the North have the highest insurance penetration rate of c. 7% but overall the Northern regions average between 1 to 5%[179]. As such, this regional information might be utilised to amend the more general national figures presented and more local information is not available. Alternatively uses might decide to utilise a maximum or minimum percentage to obtain a range.

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[175] See: Priest, S.J. (2014) Review of international flood insurance and recovery mechanisms: Implications for New Zealand and the resilience of older people, Research report for the Community Resilience and Good Ageing: Doing Better in Bad Times Project. Available at: http://resilience.goodhomes.co.nz/publications/ (accessed 05.11.2015).

[176] See: Maccaferri, S., Cariboni, F. and Campolongo, F. (2012) Natural Catastrophes: Risk relevance and Insurance Coverage in the EU, JRC Scientific and Technical Reports. Available at: http://ec.europa.eu/finance/insurance/docs/natural-catastrophes/jrc_report_on_nat_cat_en.pdf (accessed 05.11.2015).

[177] Although users will need to distinguish between whether to enter into fully or partly insured and no insurance or no insurance but self-insured (see later sections).

[178] Associazione Nazionalefra le Imprese Assicuratrici (ANIA) (2011) Danni da eventi sismici e alluvionali al patrimonio abitativo italiano: studio quantitativo e possibili schemi assicurativi, Available at: http://www.ania.it/export/sites/default/it/pubblicazioni/monografie-e-interventi/Danni/Danni-da-eventi-sismici-e-alluvionali.pdf (accessed 05.11.2015).

[179] Ibid.

In some circumstances, existing survey data may include information about the numbers of households or businesses that have insurance. In the UK, for instance, the Living Costs and Food Survey (LCF)[180] presents data regionally about the uptake of different types of household insurance policies (e.g. buildings and contents); and as such a regional insurance uptake figure could be applied within the model. Additionally, the aforementioned survey provides a further disaggregation of the data according to the income of the survey respondent. By using corresponding data about the income of residents within the application areas (i.e. from the census), then an even more refined estimate of insurance penetration could be applied. Conversely, insurance is not available at all for coastal erosion and as such for the coastal erosion matrix all of the receptors should be therefore assigned to the non-insured categories.

INDRA users should look for sources of data to provide these types of insurance penetration rates. However, it is important to ensure that the insurance product for which the data has been identified is applicable to the hazard being considered. For instance, in The Netherlands coastal flooding is not a standard peril for household insurance policies and therefore any data about penetration rates for household policies would not be suitable in this case. In the French situation, the CATNAT programme is linked to household fire policies and therefore it will be data about these insurance products that would be of interest. Additionally, information about the penetration of business insurance is likely to be held separately depending on the country of the case study.

Partially insured (PartI) or Fully insured (FullI)

Following the identification of the percentage of total properties or businesses as being insured or not insured, it is necessary to further distinguish between whether they are fully or partially insured. How this is achieved depends again on the availability of data as well as the type of insurance product that is utilised (i.e. private market system on a 'sum-insured' basis; government natural perils scheme). For most insurance approaches there will be a number of people who do not have full coverage; meaning there is a shortfall between the amount of damage experienced and the amount of recompense that those affected receive. This gap may be for a number of reasons. Firstly, some policyholders will only have taken out a policy for the structure of a property or the contents, rather than for both, and according to the categorisation of receptors adopted; those without both types of coverage should be assigned to the *PartI* category as there will be considerable losses that are not covered[181]. Secondly, the insurance product offered may not provide recompense for all of the damages, only some of them. In this case all of those insured should be considered to be within the *PartI* category, rather than being considered fully insured. Finally, some of those for whom insurance is calculated on a "sum-Insured[182]" basis may not have purchased

[180] An survey presented annually (though collected throughout any one year) which collects information on spending patterns and the cost of living that reflects household budgets across the country.

[181] As described in the section above data may be available according to the different penetration rates of different policies.

[182] A sum insured refers to the amount of cover, expressed in dollars, that is provided by an insurance policy. It is the maximum amount payable on each claim under the policy. Commonwealth of Australia (2011). Natural Disaster Insurance Review: Inquiry into flood insurance and related matters, Commonwealth of Australia; Canberra, Australia. p146. Available at: http://www.ndir.gov.au/content/report/downloads/NDIR_final.pdf (accessed

sufficient coverage for all of their losses and as such are considered to be 'underinsured.' This can be a significant problem[183], depending upon the level of underinsurance (i.e. what is the gap between the amount received and the total damage) and the scale of the problem (i.e. how many policyholders are underinsured). Estimating the percentage of households to which this applies can be difficult. Past event data may provide some estimates[184], alternatively insurance corporations may choose to highlight the issue to encourage homeowners to better assess the value of the property they should be insuring. For example, the Association of British Insurers in the UK estimates that as many as 20% of properties are underinsured[185].

To provide an example of how to assign those insured between the *FullI* and *PartI* categories, if it is known in our assessment area that 55% of all households have both types of insurance (buildings and context) and a further 30% have either contents or buildings insurance. The resulting input table (Table 4.14) would resemble that in scenario(a). However, if it is also known that 1 in 10 households are likely to be underinsured then a further 10% of those properties within the *FullI* category should be moved into the *PartI* category (illustrated in scenario (b)).

Table 4.14: Example of distributing the total of those insured between the fully insured and partially insured categories

	Insured (as a % of total properties)		**Not insured (as a % of total properties)**
Scenario	*FullI*	*PartI*	*NoI* or *NoISelf*
(a)	55%	30%	15%
(b)	49.5%	35.5%	15%

Government compensation

Some countries will offer government compensation to those affected by coastal flooding and therefore affected residents and businesses may be assisted in their financial recovery by this mechanism rather than by insurance. Government compensation schemes vary considerably both in the way that they operate and also the amounts of compensation that are provided (i.e. the percentage of the total loss that is covered). Users will need to investigate the type of approach that is used and estimate the likely percentage of the population who are eligible and the likely amounts that will be compensated. The latter is required as the matrices divide these receptors into two categories: those who receive a high degree of compensation and those who receive a small/medium amount of compensation.

Eligibility within government compensation schemes generally fall into two

05.11.2015).

183 Priest, S.J., Clark, M.J. and Treby, E.J. (2005) UK Flood insurance: the challenge of the uninsured, Area, 37 (3). 295-302.

184 Welsh Consumer Council (1992), In deep water: A study of consumer problems in Towyn and Kinmel Bay after the1990 floods, Welsh Consumer Council, p103.

185 Association of British Insurers (not date) Is your home underinsured? Available at: https://www.abi.org.uk/~/media/Files/Documents/Publications/Public/Migrated/Home/Is%20your%20home%20underinsured.pdf (accessed 05.11.2015).

categories:

- All those affected are eligible[186] - in this situation 100% of properties would be assigned;
- Those that specifically target lower income households – in this case census data could be used to identify how many people fall into the lower income quartiles.

In the case of ex-ante compensation schemes (i.e. those which are permanently established) the information detailing the terms of the scheme, who is eligible and the likely sums to be expected will be covered in the policy or the legislation detailing the scheme. It is more difficult to identify these values in the case of *ad hoc* compensation approaches which are initiated in the aftermath of events. In both situations, it is possible to utilise post-event data to better understand the impact of these schemes on financial recovery.

For example, in the case of Germany, despite Federal law prohibiting regional or central government compensation from flood damages, assistance has been provided in events termed to be catastrophic[187]. Following the 2002 flood event, the Flood Victims Assistance Act (*Flutopferhilfesolidaritätsgesetz*) was passed to provide financial aid amounting to approximately €10 billion from both Federal and EU funding sources. Residential claimants to the fund received a high amount of compensation and up to 80% of their property damages (at the full cost of repair or reconstruction); although a deductible was applied[188]. It is likely that following an extreme event in the future further governmental assistance may be provided, but whether it will be to the same high degree (which was argued to be a special case so as not to undermine the redevelopment in the east of Germany) is questionable. Users therefore have the opportunity to examine the outcomes from past events to estimate the numbers who receive compensation and the degree of compensation provided. It might be prudent to adopt a conservative approach to estimating the potential for *ad hoc* compensation to enable recovery. Ultimately, the amount of compensation provided will be linked to a range of variables including the political significance of the event, what resources a government has available at the time, how many people are affected and consequently how thinly these, often limited, resources will be spread.

Distributing those not insured or compensated (as a % of total properties)

The final differentiation that needs to be made is between the splitting of the non-insured/non-compensated categories between those who will have access to some loans or savings from which to recover (*NoIself*) and those who will not be able to (*NoI*). The most appropriate data to use in this case is statistical data related to the number of people who do or do not have any savings[189]. Additionally, there is likely to

[186] Often a compensation scheme will need to be declared in order for residents or businesses to receive any funding.

[187] Fiselier, J. and Oosterberg, W. (2004) A quick scan of spatial measures and instruments for flood risk reduction in selected EU countries., Ministry of Transport, Public Works and Water Management, Directorate-General of Public Works and Water Management, RIZA Institute for Inland Water Management and Waste Water Treatment.

[188] Mechler, R., and Weichselgartner, J. (2003) Disaster Loss Financing in Germany—The Case of the Elbe River Floods 2002. Interim Report IR-03-021, IIASA, Laxenburg.

[189] Such as the EuroStat's Household Saving Rate - The gross saving rate of households -

be a very strong link here between income and access to these other resources, so one approach would be to use data about the distribution of income (i.e. from the census or Eurostat[190]) to assign percentages to this category.

Alternatively, if users are having difficulty splitting this category, then they could decide to take a worst-case scenario and place all uninsured into the *NoI* category or a best-case scenario and put all into the *NoISelf* category. The rationale for doing so should be recorded and detailed within the assumptions.

Calculating the Financial Recovery Impact score

Following the steps above, one input file should be created containing the relevant information for each of four matrices. However, if an area is not subjected to one of the hazards (e.g. coastal erosion) then it is not necessary to include this information within the input file. Table 4.15 provides example figures that would be entered into an input file.

Table 4.15: Example input for business properties

	Each of the below are expressed as % of the total number of properties in the area					
Municipality	BNoI	BMNCself	BNoISelf	BStateown	BPartI	BFullI
A	10	0	10	0	65	15
B	5	0	10	0	75	10
C	10	0	15	0	60	15

The model considers each of the receptors separately and utilises an approach which reflects the chances of a single property residing in any one of these categories and consequently assigns the recovery impact score that would result. For example, if a business property within municipality A which is affected by a 'High' impact on property is considered; there is a 10% chance that it has 'No insurance', 10% chance that it has 'No insurance, but self-insured', a 65% chance that it is 'Partly insured' and a 15% chance that it is 'Fully insured'. The model will utilise the matrix as a look up table and assign the Recovery Impact Score from the appropriate cell in the matrix (i.e. those for receptors as exposed to High direct impacts (see circled values in Table 4.16)).

http://ec.europa.eu/eurostat/web/products-datasets/-/teina500 (accessed 05.11.2015).

190 http://ec.europa.eu/eurostat (accessed 05.11.2015).

Table 4.16: Highlighting the Recovery impact score values utilised in the example

		Direct impact on property			
		Low	**Medium**	**High**	**Very High**
Characteristics of receptor related to financial recovery	**Impact scenario**	Low financial damages sustained	Medium financial damages sustained	High financial damages sustained	Very high financial damages are sustained
Non-insured/self-insured smaller to medium sized business	BNoI	2	3	4	5
Non-insured/self-insured larger businesses or business corporations	BMNCself	1	1	1	2
Non-insured/self-insured business	BNoISelf	1	2	3	4
Partly Insured business	BStateown	1	2	3	4
Fully insured business	BPartI	1	1	1	2
State owned businesses	BFullI	1	1	2	2

The consolidated impact score for the example receptors is therefore calculated in the model as follows:

$$\begin{aligned} &\textit{Example receptor in muncipality A} \\ &\quad = 0.10(4) + 0.00(1) + 0.10(3) + 0.00(2) + 0.65(3) + 0.15\,(1) \\ &\quad = 2.8 \end{aligned}$$

Therefore, the indicative Business Financial Recovery Score for this receptor is 2.8.

The same process will be performed by the model on each receptor within the assessment area for both of the hazards (if applicable). If a receptor is considered to be impacted by both coastal erosion and coastal flooding/overwash a separate impact score will be generated for each, however the model will automatically assume the highest of these two scores as the indicative one. Calculating the score for each receptor in turn in this way (i.e. by considering the chance that it is in one category or another) avoids the need to run the model multiple times. If utilising a GIS it is recommended that the impact score for each receptor is mapped to highlight the distribution of scores, as well as presenting an overall final recovery score. The scores from each of the receptors should then be aggregated and normalised to calculate the Regionalised Business Financial Recovery Indicator[191]:

[191] A similar approach should be adopted to calculate the Regionalised Household Financial

$$I_{Bfr} = \frac{\sum_{i=0}^{n} Bfr_i}{\sum_{i=0}^{n} 5}$$

Where:

n= All business properties in the region (or all potentially exposed business properties in the region);

Bfr = Business Financial Recovery Score for each business property;

5 = the maximum Business Financial Recovery Score for each business property.

Each hotspot should have two outputs: a Regionalised Business Financial Recovery Indicator and a Regionalised Household Financial Recovery Indicator.

4.3.7.2 Application of the methodology within the model

Once the user has defined one or more areas with the distribution of recovery mechanisms (such as in Table 4.15), the user needs to input these values in the "Insur_forINDRA.txt" file.

```
File  Edit  Format  View  Help
Comments Area_InsuranceCode RatioOfPropertyUnderTheInsurance HazardlowImpact HazardMedImpact HazardHighImpact HazardVeryHighImpact
"theNorthAreaforHouseholds_withnoinsurance_Flooding" "ResNorthin_NoI_F" 0.15 2 3 4 5
"theNorthAreaforHouseholds_withSelfinsurance_Flooding" "ResNorthin_NoIself_F" 0.0 1 2 3 4
"theNorthAreaforHouseholds_withSmallGovCompensation_Flooding" "ResNorthin_NoIScomp_F" 0.0 1 2 3 4
"theNorthAreaforHouseholds_withLargeGovinsurance_Flooding" "ResNorthin_NoILcomp_F" 0.0 1 1 2 3
"theNorthAreaforHouseholds_withPartinsurance_Flooding" "ResNorthin_PartI_F" 0.355 1 2 3 4
"theNorthAreaforHouseholds_withFullinsurance_Flooding" "ResNorthin_FullI_F" 0.495 1 1 1 2
"theNorthAreaforBusiness_withNoinsuranceOrSelfinsuredsmall_Flooding" "BusNorthin_BNoI_F" 0.1 2 3 4 5
"theNorthAreaforBusiness_withNoinsuranceOrSelfinsuredLarge_Flooding" "BusNorthin_BMNCself_F" 0.0 1 1 1 2
"theNorthAreaforBusiness_withNoInsurselfinsur_Flooding" "BusNorthin_BNoIself_F" 0.1 1 2 3 4
"theNorthAreaforBusiness_StateOwned_Flooding" "BusNorthin_Bstateown_F" 0.0 1 2 3 4
"theNorthAreaforBusiness_withPartinsurance_Flooding" "BusNorthin_BPartI_F" 0.65 1 1 1 2
"theNorthAreaforBusiness_withFullinsurance_Flooding" "BusNorthin_BFullI_F" 0.15 1 1 2 2
"theNorthAreaforHouseholds_withnoinsurance_Erosion" "ResNorthin_NoI_E" 0.15 1 1 9999 5
"theNorthAreaforHouseholds_withSelfinsurance_Erosion" "ResNorthin_NoIself_E" 0.0 1 1 9999 4
"theNorthAreaforHouseholds_withSmallGovCompensation_Erosion" "ResNorthin_NoIScomp_E" 0.0 1 1 9999 4
"theNorthAreaforHouseholds_withLargeGovinsurance_Erosion" "ResNorthin_NoILcomp_E" 0.0 1 1 9999 3
"theNorthAreaforHouseholds_withPartinsurance_Erosion" "ResNorthin_PartI_E" 0.355 1 1 9999 4
"theNorthAreaforHouseholds_withFullinsurance_Erosion" "ResNorthin_FullI_E" 0.495 1 1 9999 3
"theNorthAreaforBusiness_withNoinsuranceOrSelfinsuredsmall_Erosion" "BusNorthin_BNoI_E" 0.1 1 1 9999 5
"theNorthAreaforBusiness_withNoinsuranceOrSelfinsuredLarge_Erosion" "BusNorthin_BMNCself_E" 0.0 1 1 9999 2
"theNorthAreaforBusiness_withNoInsurselfinsur_Erosion" "BusNorthin_BNoIself_E" 0.1 1 1 9999 4
"theNorthAreaforBusiness_StateOwned_Erosion" "BusNorthin_Bstateown_E" 0.0 1 1 9999 4
"theNorthAreaforBusiness_withPartinsurance_Erosion" "BusNorthin_BPartI_E" 0.65 1 1 9999 2
"theNorthAreaforBusiness_withFullinsurance_Erosion" "BusNorthin_BFullI_E" 0.15 1 1 9999 2
```

Figure 4.22: Snapshot of a "Insur_forINDRA.txt" file

The first line is not considered by the model but indicates the file contents.

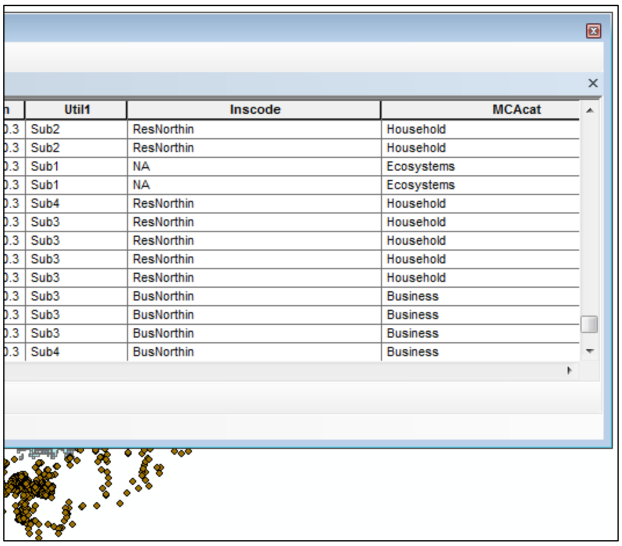
Each following line informs for an area the distribution value followed by the impact score for each impact level (such as in Table 4.16) of the considered recovery mechanisms in the following order:

- Comments: A text describing the area, the insurance and the hazard. Not used by the model – only informative to the user;
- An area recovery mechanism code: the code will be used by the model to attribute the values. The code comprises three elements separated by an underscore: an area code (the user can use the code they want for an area), an recovery mechanisms code (imposed for the model see below) and a hazard code (imposed for the model: Flooding, Erosion);
- The distribution value (e.g. 0.15);
- The 4 score values (e.g. 2, 3, 4, 5). The user should use the values provided in Appendix B.

Recovery Indicator.

For each area the user should provide 6 lines for businesses and households. The recovery mechanisms codes for businesses are: BNoI, BMNCself, BNoISelf, BStateown, BPartI, BFullI. The recovery mechanisms codes for households are: NoI, NoIself, NoIScomp, NoILcomp, PartI, FullI.

The user also needs to attribute the relevant assessment area to each property (i.e. municipality a, b etc). To do so, in the land use point shapefile, the user needs to attribute the area insurance code in the "Inscode" field. If not applicable, the code "NA" can be used.



Util1	Inscode	MCAcat
Sub2	ResNorthin	Household
Sub2	ResNorthin	Household
Sub1	NA	Ecosystems
Sub1	NA	Ecosystems
Sub4	ResNorthin	Household
Sub3	ResNorthin	Household
Sub3	ResNorthin	Household
Sub3	ResNorthin	Household
Sub3	ResNorthin	Household
Sub3	BusNorthin	Business
Sub3	BusNorthin	Business
Sub3	BusNorthin	Business
Sub4	BusNorthin	Business

Figure 4.23: Snapshot of the land use shapefile for financial recovery

4.3.7.3 Limitations and assumptions

- The key assumption in the approach relates to the assignment of recovery mechanisms to each of the properties. The detail of this element depends upon the availability of data on which to base this attribution. In the most basic sense users could attribute receptors to a small number of categories (e.g. insured/not insured) and repeat the analysis in terms of a worst case or best case situation. Users should clearly document the attribution decisions taken and the rationale.
- The uncertainty of results for this impact will depend upon the degree of disaggregation of the information used to attribute the recovery mechanism of the receptor (e.g. is information available at a property level scale or have decisions needed to be made based upon more general national or regional data). Additionally, its representativeness is also related to the degree of diversity in recovery mechanisms present within an assessment area. This means that there is likely to be more confidence in the results for areas where recovery mechanisms are institutionalised (i.e. insurance for hazards is compulsory) or where one mechanism dominates (e.g. recovery is available by government compensation) than situations where there is high variability of approaches. As such, generalised national level data are unsuited to be used in cases where a high diversity may be present.
- For simplicity, the approach presented does not differentiate between property owners and tenants. This is important in terms of financial recovery as tenants (both in terms of residential properties and businesses) will often be less affected in terms of financial loss. If users think that this is particularly relevant for a regional case, it is possible to represent this within the model but either will require the creation of additional rows (i.e. receptor types and related scales) within the matrices or the assumption for instance that all households with insurance involve tenants and the impact scales altered accordingly.
- The approach does not consider the potential gains in terms of recovery, i.e. due to claiming of insurance some people are in a better position after the event than before.
- Some countries (e.g. Italy, Austria, Germany[192]) have both compensation and insurance systems and although efforts are made to avoid people receiving compensation for the same damages this may be occurring in some isolated cases. However, the impact of this is considered to be low and as such one of the key assumptions of the model is that a property will only be able to have one financial recovery mechanism assigned and as such not receive benefit from multiple mechanisms. If a user does think that multiple mechanisms are present then most favourable category (i.e. the one with the lowest score) should be selected and the best case scenario adopted.

[192] Although German and Italian compensation is provided on an *ad hoc* basis and as such is not guaranteed following an event.

Regionalised Financial Recovery Indicator(s)

- **Separately for businesses and households, provides an indication of the potential degree of financial recovery following an extreme coastal event for specific locations;**
- **First, identify the recovery mechanism present within the regional case, identify data availability and assign to each assessment area the distribution of each recovery mechanism. This information can be used to prepare the "Insur_forINDRA.txt" file;**
- **Using the threshold model approach(s), prepare the "CHT_ForINDRA" file both residential and business properties (if not already created for household displacement and business disruption);**
- **Assign the assessment area code to each property;**
- **Each receptor will be attributed by the model a Financial Impact Score ranging from 1 to 5;**
- **These will then be aggregated and normalised within the model. The final indicator provides an independent representation of the potential for household and business financial recovery for each hotspot presented on a scale ranging from 0 to 1.**

4.3.8 Transport Disruption

As the speed and ease of people's travel and goods exchange relies heavily on the efficiency of transport systems, their functionality is essential for the economy of a country and the well-being of its citizens[193]. Recent European cases demonstrate that in addition to potential sizable damages on the transport infrastructure, regional extreme events could also bring about wide-spread impacts far beyond the damaged area, and for the whole transport network, often for long periods of time.

During spring 2013, several central European countries were severely affected by flooding followed by disruption to transport and supply chains. The main railway bridge across the River Elbe that serves all trains to and from Berlin via Hannover in Germany was affected by flooding and remained closed until November 2013. During winter 2013/14, the United Kingdom was affected by repeated coastal events, such as violent winter storms and widespread and persistent flooding. The whole transport system was severely impacted: rail lines closed, services for commuters were suspended and flights and ferries were cancelled. During the storms in February 2014 in Devon, UK the coastal section of the main south-west railway at Dawlish was cut off from the rest of the rail network for two months[194].

The transport system is a pillar of the functioning and development of society due to its complex composition and interdependencies and can include underground, land, maritime or air transport. Models developed to study transport systems take into account[195]:

- The movement of people;
- The movement of goods;
- Transport infrastructures (roads, railways, bridges, inland waterways, harbours etc.);
- The activities they serve and;
- Their geographic environment.

4.3.8.1 Selected Method

Transport systems are usually modelled by networks with links and nodes, on which people, goods and vehicles are carried in flows. To build an efficient model for, more or less detail can be considered, depending on the desired level of sophistication, and topological rules used to govern each link of the network plus possible supplementary characteristics related to the local management of traffic.

In order to carry out an impact analysis of the transport network using INDRA, simplifications were made and the analysis confined to rail and road systems.

As the transport system can be affected by various types of indirect impacts (Figure 4.24), several complex and sophisticated tools have been developed for a wide-range of projects and

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[193] Ouyang, M., Zhao, L., Hong, L., Pan, Z. (2014) Comparisons of complex network based models and real train flow model to analyse Chinese railway vulnerability. Reliability Engineering & System Safety, 123, March 2014, 38–46.

[194] European Environment Agency (2014) Adaptation of transport to Climate Change in Europe: Challenges and options across transport modes and stakeholders. Report, No 8/2014. Available at: http://www.eea.europa.eu/publications/adaptation-of-transport-to-climate (accessed 05.11.2015).

[195] Allsop, R. E. (2008) Transport Networks and their use: how real can modelling get? Centre for Transport Studies, University College London. Available at: http://www.statslab.cam.ac.uk/~frank/TALKS/allsop_rs.pdf (accessed 05.11.2015).

studies[196 197 198 199 200 201 202]. These have, to a large extent, focused on the assessment of economic costs.

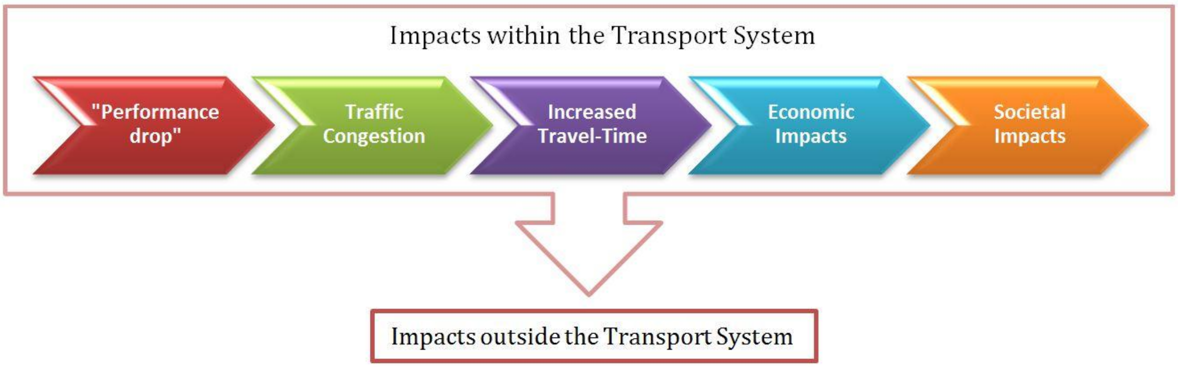

Figure 4.24: Proposed Conceptual drawing of Indirect Impacts of Transport Systems

Even though the impacts assessed by more dynamic indicators may be very interesting to analyse (e.g. congestion, time, speed and traffic-flow loss) complex approaches based on the use of flows or system-dynamics are required. Additionally, these indicators typically need precise or quantitative data inputs such as: the disruptive event occurrence time; the location of each train or vehicle during the occurrence of the event; the origin/destination pairs required to characterise traveller's paths; travel demand and supply data; the travel cost or travel time of each link (which depends on the traffic flow on each link); the departure time of each train of the rail system etc. and sometimes survey data about travellers' behaviour. These historical data and observations can be difficult to access and, as a consequence, alternative indicators that describe the impacts on the performance of transport system have been assessed for use in INDRA.

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[196] European Environment Agency (2014) Adaptation of transport to Climate Change in Europe: Challenges and options across transport modes and stakeholders. Report, No 8/2014. Available at: http://www.eea.europa.eu/publications/adaptation-of-transport-to-climate (accessed 05.11.2015).

[197] Chen, A., Yang, H., Lo, H.K. and Tang, W. (2002) Capacity reliability of a road network: an assessment methodology and numerical result. Transportation Research B, Vol. 36, No.3, 225-252.

[198] Mattsson, L-G. and Jenelius, E. (2015) Vulnerability and resilience of transport systems – A discussion of recent research. Transportation Research. Part A: Policy and Practice. Volume 81, November 2015, Pages 16–34.

[199] Sohn, J. (2005) Evaluating the significance of highway network links under the flood damage: An accessibility approach. Transportation Research Part A: Policy and Practice. Volume 40, Issue 6, July 2006, Pages 491–506.

[200] Franchin, P. (2013) Methodology for systemic seismic vulnerability assessment of buildings, infrastructures, networks and socio-economic impacts. SYNER-G Reference Report 1. Joint Reaserch Centre.

[201] European Environment Agency (2014) Adaptation of transport to Climate Change in Europe: Challenges and options across transport modes and stakeholders. Report, No 8/2014. Available at: http://www.eea.europa.eu/publications/adaptation-of-transport-to-climate (accessed 05.11.2015).

[202] Ni, J., Sun, L., Li, T., Huang, Z. and Borthwick, A.G. (2010) Assessment of flooding impacts in terms of sustainability in Mainland China. J. Environ. Manage. 2010 Oct; 91(10):1930-42.

Among the different types of impacts on the transport system that were considered as a result of the literature review, one that has been retained concerns the loss of accessibility, as this can be seen as "the principal 'product' of the transportation system"[203]. Accessibility-based metrics can give a general perspective on the indirect impacts on the transport network and its level of service by measuring the facility to reach a destination.

The notion of accessibility seems all the more useful for this project as it enables a study of the impacts of a disruptive event at a regional scale and to identify the critical components, such as a main road or rail line, without having to go into accurate quantitative details. Moreover, using a network-topology-based approach, the accessibility loss indicators are seemingly more adapted to the study of multiple-link disruptions. Given the choice of parameters to consider, it is possible to get a more, or less, realistic assessment, and thus a more, or less, complex model. These indicators make the assessment of impacts from different scenarios possible by nodes and links removals.

The main input data needed for the related accessibility-based metrics concern the location of the principal transport network components (links and nodes) and the length of the links. Other additional data may be required, such as the population of an area or the annual average daily traffic flow of a road, as part of the development of a weighted accessibility metric. A principal tool required by those accessibility-based metrics is the basic Dijkstra's algorithm[204] which is used to perform the calculations of the shortest distance between two pairs of nodes.

As a result of the literature review, three main indicators were chosen to support the development of the model and enable the assessment of the loss of accessibility for the whole network:

- The Cost Indicator[205] this basic network connectivity loss indicator can be applied to the assessment of the connectivity impacts on the whole network by identifying the difference between the indicators before and after the occurrence of a disruptive event. As the transport network is a set of nodes and weighted links, calculating the shortest travel cost among all possible routes between two different nodes can give a relative idea about the connectivity in the network. The value obtained should increase with the extension of the alternative routes, and thus with the number of disrupted links and disconnected nodes;
- The Accessibility-based combined airline/railway system vulnerability: this indicator, which uses the performance metric and the railway accessibility measure developed by Min Ouyang et al. (2015)[206] can be adapted to study the system vulnerability of the

[203] Demirel, H., Kompil, M, and Nemry, F. (2015) A framework to analyze the vulnerability of European road networks due to Sea-Level Rise (SLR) and sea storm surges". Transportation Research Part A: Policy and Practice (2015). Volume 81, November 2015, 62–76, Page 66.

[204] See: Dijkstra, E. W. (1959) A note on two problems in connexion with graphs. Numerische Mathematik 1: 269–271. Available at: http://link.springer.com/article/10.1007%2FBF01386390 (accessed 05.11.2015).

[205] Mattsson, L-G. and Jenelius, E. (2015) Vulnerability and resilience of transport systems – A discussion of recent research. Transportation Research. Part A, Volume 81, November 2015, Pages 16–34.

[206] Ouyanga, M., Pana, Z., Honga, L., Hea, Y (2015) Vulnerability analysis of complementary transportation systems with applications to railway and airline systems in China. Reliability Engineering & System Safety. Volume 142, October 2015, 248–257.

combined road/rail networks. Adding up the number of other nodes that are accessible from each node (in the same way as for the previous sum of the shortest travel costs) gives a relative indication of the connectivity of the network. The comparison between the values obtained before and after the disruptive event gives a figure that can then indicate the ratio of lost accessibility. Figures showing the relative loss of accessibility in the overall network can simplify the process of comparing different events;

- The Weighted Accessibility Score of an Area[207]: this indicator takes into account the influence of distance-decay and traffic volume on the accessibility of a given area following a disruptive event. An accessibility score is calculated for an area and the importance of the accessibility loss of a certain link on the whole network can be deduced, in order to determine the components of the network that will cause the most important loss of accessibility if disrupted. Although this approach does not consider congestion effects in identifying the shortest paths and treats single-link failures so that it can establish a ranking among them, this method includes the notion of traffic flows without having to integrate flow calculations.

To enable the comparison between the different impact scenarios a unique Transport Disruption indicator has been developed from these three main methods. Notions of non-access and extra-travel time can interest a large range of stakeholders and, as a consequence, the developed indicator should assess both loss and a reduction of spatio-temporal accessibility. Furthermore, a comprehensive transport system is considered by INDRA (i.e. roads and railways are considered) and the links can represent either rail lines or main roads that connect nodes (rail stations or road junctions).

The loss of accessibility within a transport network relates to the loss of the option to go from one place to another. This can be all the more serious when access to a destination is associated with critical services (e.g. not being able to reach a hospital). The network nodes (representing stations or road junctions) should have an associated value related to their importance within the regional network. These values need to be included in the indicator calculation. As the increase in distance travelled does not fully represent travel disruption (e.g. travel speed is not accounted for and an increase in the distance travelled is not as meaningful for the rail network) the increase in travel time seems a more appropriate measure to assess the reduction of accessibility for both types of transport.

The indicator developed to assess indirect impacts of coastal extreme events on the transport network has been called the Weighted Disconnection and Time Lengthening Indicator (WDTL).

$$\mathrm{WDTL} = \frac{\mathrm{WD2}}{\mathrm{WD1}} \times \frac{\mathrm{TL1}}{\mathrm{TL2}}$$

Where:

1 is before the disruptive event;
2 is after the disruptive event.

This combines a Connectivity Ratio and a Time Ratio.

[207] Sohn, J. (2005) Evaluating the significance of highway network links under the flood damage: An accessibility approach. Transportation Research Part A: Policy and Practice. Volume 40, Issue 6, July 2006, Pages 491–506.

The Connectivity Ratio $\frac{\mathrm{WD2}}{\mathrm{WD1}}$ gives information on the loss of connectivity to the places with more or less importance. Different weights can be associated to each transport node in order to give an indication of the seriousness of the situation in the case where the considered node would become inaccessible. As an example, the road junction that is related to a hospital could be given a weighting value of 9 while a road junction that is related to a waste ground could be given a value of 1. As these values will vary depending on the differing importance; geographical, political, financial, economic, social or cultural, the choice of weighting values is left to the judgement of user.

WD1 =

$$\sum_{\mathrm{i}_{\mathrm{d}1}=1}^{\mathrm{N}}\left(\sum_{\mathrm{j}_{\mathrm{d}1}=1}^{\mathrm{n}_{\mathrm{i}_{\mathrm{d}1}}} \mathrm{W}_{\mathrm{j}_{\mathrm{d}1}}\right)$$

Where:

$n_{i_{d1}}$: Is the number of nodes which are accessible from the node i_{d1}, before the disruptive event;
$W_{j_{d1}}$: Is the weight of the node j_{d1} which belongs to the set of the $n_{i_{d1}}$ nodes that are accessible from the node i_{d1}, before the disruptive event;

WD1: Is the sum of all the weights accessible by each node of the whole network before the occurrence of the disruptive event.

WD2 =

$$\sum_{i_{d2}=1}^{N}\left(\sum_{j_{d2}=1}^{n_{i_{d2}}} W_{j_{d2}}\right)$$

Where:

$n_{i_{d2}}$: Is the number of nodes which are accessible from the node i_{d2}, after the disruptive event;
$W_{j_{d2}}$: Is the weight of the node j_{d2} which belongs to the set of the $n_{i_{d2}}$ nodes that are accessible from the node i_{d2}, after the disruptive event.

If the Connectivity Ratio is equal to:

0: Each node has been isolated from all the other nodes. The whole network has been completely disconnected following the disruptive event;
1: Not any pair of nodes that was previously connected has been disconnected due to the disruptive event.

However, even though some links have been cut without leading to the remoteness of a node, their closure can lead to an increase in shortest possible travel distance between two nodes. This is the reason why a second ratio has been used: the Time Ratio $\frac{\mathrm{TL1}}{\mathrm{TL2}}$. The Time Ratio aims to represent the scale of increased travel time from one node to another. Hence, the ratio only takes into account the travel times between the nodes that remain accessible after the occurrence of the disruptive event.

As a consequence:

TL2 =

$$\sum_{i_{l2}=1}^{N}\left(\sum_{j_{l2}=1}^{n_{i_{l2}}} T_{i_{l2}j_{l2}}\right)$$

Where:

$T_{i_{l2}j_{l2}}$: Is the travel time for the fastest route from the node i_{l2} to the node j_{l2} , only if it remains possible to go from the node i_{l2} to the node j_{l2} after the occurrence of the disruptive event.
$n_{i_{l2}}$: Is the number of nodes that remain accessible from the node i_{l2} after the occurrence of the disruptive event.

TL2 is the sum of network's shortest possible travel times after the disruption.

TL1 =

$$\sum_{i_{l1}=1}^{N}\left(\sum_{j_{l1}=1}^{n_{i_{l1}}} T_{i_{l1}j_{l1}}\right)$$

Where:

$T_{i_{l1}j_{l1}}$: Is the travel time for the fastest route from the node i_{l1} to the node j_{l1} before the occurrence of the disruptive event, if this route remains accessible;
$n_{i_{l1}}$: Is the number of nodes that remain accessible from the node i_{l1} after the occurrence of the disruptive event.

$TL1$ is the sum of network's shortest possible travel times between the remaining accessible nodes after the disruption, but without the closure of the disrupted links so that for the calculation of $TL1$, the diverted routes are shorter than in the case of the $TL2$ calculation.

Thus, in this Time Ratio $\frac{TL1}{TL2}$ approach:

0: The disruptive event has resulted in a significant increase in the shortest route between the nodes.

1: The disruptive event has not resulted in a significant increase in the shortest route between the nodes.

The combination of the Connectivity Ratio with the Time Ratio (which complement one another) produces the WDTL. A WDTL Indicator value of 0 means the whole network has lost all accessibility: it has been completely impacted by the disruptive event. A WDTL Indicator value of 1 means the level of accessibility has been subject to no indirect impacts following the event. Therefore, the Regionalised Transport Disruption indicator is calculated as "one minus WDTL" to obtain a similar scale value as the other regionalised indicators (i.e. 1 means the whole network has lost all accessibility and 0 as no transport disruption).

The Regionalised Transport Disruption Indicator is then calculated for each simulation time, the different components of the network being repaired over time. The final Regionalised Transport Disruption indicator integrates the Indicator over the period of the simulation and provides a value between 0 and 1.

4.3.8.2 Application of the methodology within the model

The transport system is represented by an abstract network or graph composed of a set of nodes and links. The links represent either regional rail lines or main roads which connect nodes (either rail stations or road junctions). The first step is therefore to define this network. The Library of Coastal Vulnerability Indicators provides a 5 step-approach to support such analysis. The degree of information available to describe each node and link determines the degree of analysis that can be expected.

The transport network is imported in the model with a polyline shapefile. Only the first vertex and the last vertex are considered as junctions in the model. Therefore it is recommended that each polyline should represent a road/train from an "intersection" to another. This polyline shapefile provides information on the transport network (e.g. road, trains). Various information is required to run the model (Figure 4.25):

"Speed": speed on the considered roads/rail lines;

"Elevation": elevation of the considered roads/rail lines;

"L_Vcode" : vulnerability code of the roads/rail lines;

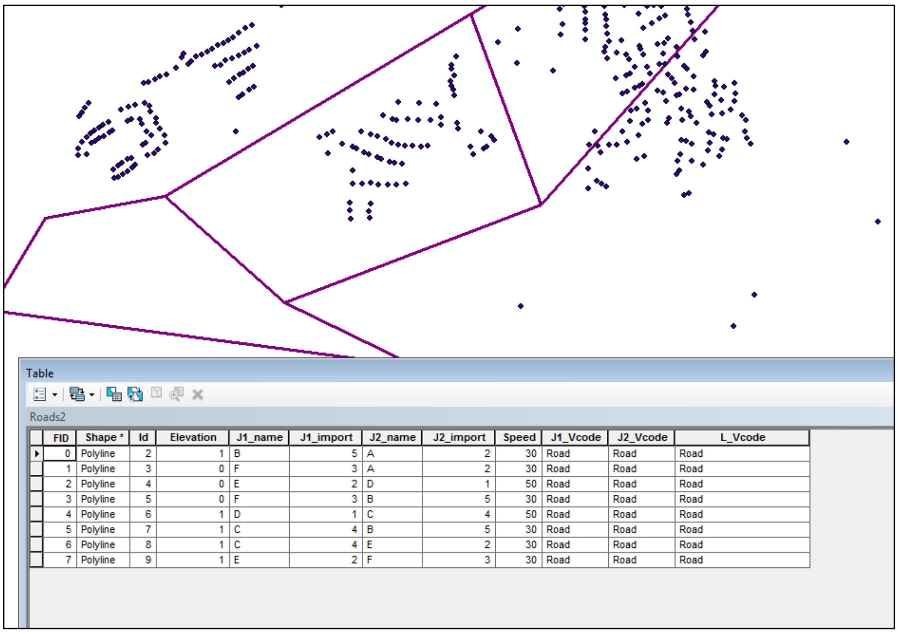
"J1_Vcode": vulnerability code of the starting junction (first vertex);

"J2_Vcode": vulnerability code of the ending junction (last vertex);

"J1_import": importance of the starting junction (first vertex);

"J2_import": importance of the ending junction (last vertex).

The vulnerability thresholds (flood, erosion) and associated reinstatement time for each vulnerability code should be recorded in the "CHT_ForINDRA.txt" file to calculate the level of impact and the disruption time.



FID	Shape *	Id	Elevation	J1_name	J1_import	J2_name	J2_import	Speed	J1_Vcode	J2_Vcode	L_Vcode
0	Polyline	2	1	B	5	A	2	30	Road	Road	Road
1	Polyline	3	0	F	3	A	2	30	Road	Road	Road
2	Polyline	4	0	E	2	D	1	50	Road	Road	Road
3	Polyline	5	0	F	3	B	5	30	Road	Road	Road
4	Polyline	6	1	D	1	C	4	50	Road	Road	Road
5	Polyline	7	1	C	4	B	5	30	Road	Road	Road
6	Polyline	8	1	C	4	E	2	30	Road	Road	Road
7	Polyline	9	1	E	2	F	3	30	Road	Road	Road

Figure 4.25: Example transport network in GIS

4.3.8.3 Limitations and assumptions

- Traffic flows are not considered in the model and these can significantly increase or decrease travel time as journey speeds change. Daily, weekly and seasonal variability in traffic numbers are also not considered.
- Transport disruption can lead to a change in user behaviour, as new routes are sought and alternative travel options taken. However, due to the large amount of complexity involved in such an analysis, these aspects are not considered in the current approach.
- The indirect impacts are assessed without considering the effects of an evacuation or

emergency announcement. As a consequence, the travel time values related to the system are for normal conditions. Indeed, the aim of the model is to assess the potential disruption to normal conditions.

Regionalised Transport Disruption Indicator

- **Indicates the potential degree of transport disruption (accessibility and increased travel time) at the regional scale and is based on a connectivity analysis technique;**
- **First, define the transport system (all types) and map the regional network in GIS shapefiles and then associate their speed and importance;**
- **Attribute the vulnerability indicator and reinstatement time for the networks component in the "CHT_ForINDRA.txt" file;**
- **The change in accessibility and travel time is calculated for each node and is compared to the situation prior to the event;**
- **The final Regionalised Transport Disruption Indicator provides the degree of disruption over time (0 no disruption; 1 complete loss of accessibility).**

4.3.9 Utility Disruption

Utility services such as water, power, gas or telecommunications play an essential role in maintaining the continuity of activities in our society. Whereas short disruptions to these services might be mitigated against by service providers or tolerated by customers, larger and longer disruptions cascade into other socio-economic impacts and in a reduction of public safety and security. Several recent flood events have highlighted such concerns, such as power failures (England in 2007[208] and 2013[209] or France in 2010[210]) or water disruption (England in 2007[211], Australia in 2011[212] or USA in 2005[213]). The scale of indirect effects from directly impacted utility assets to consumers depends largely on the role and the importance of these assets but also on the overall infrastructure network.

Although it might be difficult to assess the change in flow of these services and the consequences for individual consumers, an important first task when estimating disruption to critical infrastructure is to consider proportionality. As not all 'critical infrastructure' will lead to severe economic or social consequences, it is at least necessary to define which assets or locations might have the most severe consequences as the result of a coastal event. The main criteria for this are likely to be: the degree of disruption to an essential service, the extent of the disruption in terms of population impacted or geographical spread, and the length of disruption[214].

4.3.9.1 Selected Method

Examples of methodologies and models for assessing the vulnerability or the potential risk for utility networks are abundant in the literature. Most of them approach the problem by complex-based network analysis and flow modelling approach[215] [216] [217] [218] [219] [220]. Network theory is

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[208] Penning-Rowsell, E.C., Priest, S., Parker, D., Morris, J., Tunstall, S., Viavattene, C., Chatterton, J. and Owen, D.J. (2015) Flood and Coastal Erosion Risk Management: A Handbook for Economic Appraisal. Available under licence at: www.MCM-Online.co.uk (accessed 05.11.2015).

[209] McMillan, D. (2014) Disruption at Gatwick Airport, Christmas Eve 2013. Report by David McMillan to the Board of Gatwick Airport Limited, 26 February 2014. Available at: https://www.gatwickairport.com/globalassets/publicationfiles/business_and_community/all_public_publications/2014/mcmillan_report_feb14.pdf (accessed 05.11.2015).

[210] Kolen, B., Slomp, R., Jonkman, S.N. (2013) The impacts of storm Xynthia February 27-28, 2010 in France: lessons for flood risk management. Journal of Flood Risk Management, 6: 261-278.

[211] Severn Trent Water (2007) Gloucestershire 2007: the impact of the July Floods on the water infrastructure and customer service, Final Report. Available at: http://s3-eu-west-1.amazonaws.com/media.aws.stwater.co.uk/upload/pdf/The_Final_Gloucester_2007_Report.pdf (Accessed 01.02.2015).

[212] Espada, R.J.R., Apan, A. and McDougall, K. (2013) Using spatial modelling to develop flood risk and climate adaptation capacity metrics for vulnerability assessments of urban community and critical water supply infrastructure. Spatial modelling of flood risk and climate adaptation capacity metrics – 49th ISOCARP congress 2013. 12p.

[213] White House (2006) The Federal response to Hurricane Katrina: Lessons learned. Washington D.C.: Government Printing Office.

[214] Cabinet Office (2010) Strategic Framework and Policy Statement on Improving the Resilience of Critical Infrastructure to Disruption from Natural Hazards, London: Cabinet Office.

[215] Ouyang, M., Zhao, L., Pan, Z., Hong, L. (2014) Comparisons of complex network based models and direct current power flow model to analyse power grid vulnerability under national attacks. Physica A (403). 45-53.

[216] Shuang, Q., Zhang, M., Yuan, Y. (2014) Node vulnerability of water distribution networks under

mainly used as a screening process whereas flow modelling provides an in-depth analysis[221]. Indeed, flow modelling requires detailed information about the network and its components, the choice of appropriate physical laws for the considered systems and the required level of expertise and calculation time is high. In contrast, network theory provides simple techniques and indicators for analysing the network topology. As such, the technique is faster and less data-demanding, but a major limitation is that the dynamics within the system cannot be represented.

Network analysis is considered the most appropriate method for INDRA, considering its purpose (regional scale, screening process, transparency and stakeholder engagement) and certain limitations, i.e.:

- The level of information available will be limited to "non-confidential" information and not of great detail;
- The approach should be applicable in most cases despite the level of expertise of the end user;
- It should be able to represent different types of utilities (water, electricity, telecommunication, gas etc.) in a simple and similar manner revealing potential large failures due to extreme events.

In Graph Theory, a network is represented by a set of nodes and by a set of links between the nodes. The technique analyses the network's structural properties based on node and link characteristics such as the connectivity between two nodes (shortest pathways, level of connection, maximum flow) or the centrality of a node in a network (degree, closeness, "betweenness")[222] [223] [224]. The technique allows the identification of the most important nodes and links in the network and, therefore, the weakest parts of the network. The technique can also be used to compare geographically distinct networks or a partially functioning network following an event. In utility network assessment studies, attention is mainly focused on indicating the potential losses of connection (i.e. loss of service in the form of the number of

cascading failures. Reliability Engineering and System Safety (124). 132-141.

[217] Johansson, J., Hassel, H., Zio, E. (2013) Reliability and vulnerability analyses of critical infrastructures. Reliability Engineering and System Safety (120) 27-38.

[218] Ouyang M., Duenas-Osorio, L. (2014) Multi-dimensional hurricane resilience assessment of electric power systems. Structural Safety (48). 15-24.

[219] Winkler, J., Duenas-Osorio, L., Stein, R., Subramanian, D. (2010) Performance assessment of topologically diverse power systems subjected to hurricane events Reliability Engineering and System Safety (95). 323-336.

[220] Arianos, S., Bompard, E., Carbone, A. and Xue, F. (2009) jhgf Power grid vulnerability: a complex network approach. Chaos (19).

[221] Eusgeld, I., Kroger, W., Sansavini, G., Schapfer, M., Zio, E. (2009) The role of network theory and object-oriented modelling within a framework for the vulnerability analysis of critical infrastructures. Reliability Engineering and System Safety (94). 954-963.

[222] Tanenbaum, A.S. (1981) Connectivity analysis. Computer Networks. 36-56.

[223] Stergiopoulos, G., Kotzanikolaou, P., Theocharidou, M., Gritzalis, D. (2015) Risk mitigation strategies for critical infrastructures based on graph centrality analysis. International Journal of critical infrastructrure protection (10). 34-44.

[224] Hu, J., Yu, J., Cao, J., Ni, M., Yu, W. (2014) Topological interactive analysis of power system and its communication module: a complex network approach Physica A (416). 99-111.

consumers disconnected from any source) and the reduction of redundancy (i.e. potential reduction of the supply by a reduction in network capacity) using connectivity analysis.

The level of disconnection can be easily estimated by considering the absence of a path between a node and any type of source. For instance, Ouyang et al. (2015)[225] assess a connectivity loss by considering the ratio of generators before and after an event connected to each individual load substation. The potential blackout extent is also calculated using another indicator considering the balance between supply and demand. Change in the number and length of pathways can also indicate variation in the performance of the system due to a reduction in redundancy and in flow capacity within the system[226] [227]. However, information on flow limits and flows analysis remains necessary in such a case.

Here, the objective is similar and tries to answer the following question: is the potential loss of services within the region greater due to an event happening in hotspot A or in hotspot B? Such circumstances might be induced by a large number of disconnections (high proportion of local distribution assets), by the loss of an essential source or an essential distribution asset (major pipes or a primary substation for instance).

The direct impact assessment identifies which assets of a network are damaged by the event. The approach here is the same as for any other assets, i.e. to define the four impact threshold levels and their associated reinstatement state. Once an asset is damaged, it can be considered as non-functional and, therefore, the network topology is modified accordingly and the extent of the disruption beyond the impacted areas can be estimated.

In the model two indicators using connectivity analysis were preferred as the most appropriate for the assessment needs:

- Indicator of connectivity loss (percentage loss of connection): for each demand node define it the source remains connected and therefore a service is still received (e.g. power and water);
- Indicator of imbalance: following disruption assess whether demand exceeds supply and therefore if there is a risk of services not being delivered (i.e. over demand and potential blackout).

Connectivity loss (percentage of loss of connection):

$$I_{Cl} = \frac{1}{d}\sum_{i=1}^{d}\frac{Cimp}{Cnorm}$$

Where:

I_{Cl}: Indicates the percentage of connectivity loss for the whole network;

[225] Ouyang, M., Zhao, L., Pan, Z., Hong, L. (2015) Comparisons of complex network based models and direct current power flow model to analyse power grid vulnerability under intentional attacks. Physica A: Statistical Mechanics and its Applications (403). 45-53.

[226] Winkler, J., Duenas-Osorio, L., Stein, R., Subramanian, D. (2010) Performance assessment of topologically diverse power systems subjected to hurricane events Reliability Engineering and System Safety (95). 323-336.

[227] Eusgeld, I., Kroger, W., Sansavini, G., Schapfer, M., Zio, E. (2009) The role of network theory and object-oriented modelling within a framework for the vulnerability analysis of critical infrastructures. Reliability Engineering and System Safety (94). 954-963.

d: Number of demand nodes;

C_{imp}: Sum of the total service capacity of all source nodes connected to the i^{th} demand node in an impacted network;

C_{norm}: Sum of the total service capacity of all source nodes connected to the i^{th} in a normal situation;

A I_{CI} value of 0 indicates that all demand nodes are disconnected, a value of 1 that the network is not impacted.

Indicator of imbalance:

$$I_{SI} = \frac{1}{s}\sum_{i=1}^{s}\frac{DSnorm}{DSimp}$$

Where:

I_{SI}: Indicates a variation in the balance of supply-demand within the system;

s: Number of source nodes still delivering services;

DS_{imp}: Sum of the demand-supply ratio of each demand node connected to the I^{th} source delivering services in the impacted network;

DS_{norm}: Sum of the demand-supply ratio of each demand node connected to the I^{th} source delivering services in a normal situation.

A I_{SI} value tending to 0 indicates that the imbalance of supply-demand limits the distribution of services and disconnections are expected for the majority, a value of 1 means the demand supply is balanced or that the demand is lower than the supply.

The two indicators are combined into one Regionalised Utility Disruption Indicator:

$$I_{Ud} = 1 - (\left(\frac{1}{d}\sum_{i=1}^{d}\frac{Cimp}{Cnorm}\right) * \left(\frac{1}{s}\sum_{i=1}^{s}\frac{DSnorm}{DSimp}\right))$$

The I_{Ud} is then calculated for each simulation time, the different components of the network being repaired over time. The Regionalised Utility Disruption Indicator integrates I_{Ud} over the period of the simulation and provides a value between 0 and 1.

4.3.9.2 Application of the methodology within the model

The model can consider a maximum of three different utility networks and each of the utilities should be scored separately.

Any analysis starts with a definition of the network, i.e. a classification of the different components of the network (nodes and links) and the structure of the network. The Library of Coastal Vulnerability Indicators provides a 5 step-approach to support the analysis. The degree of information available to describe each node and link determines the degree of analysis that can be expected.

For the current application, “capacity” is only required for source and demand nodes, a similar unit should be used for both. As the flows are not modelled, an indication of the population served (e.g. per inhabitant equivalent) is recommended as the easiest method.

Information about the vulnerability of different assets to the considered hazards and associated reinstatement time has to be provided in the vulnerability input file (“CHT_ForINDRA.txt”).

The input, the output and the uniqueness characteristics are defined by the network layout in the form of a polyline shapefile entered into the model (Figure 4.26). The polyline should always follow the direction of the service flow, i.e. the first vertex should indicate the origin of the flow (asset) and the last vertex the destination of the flow (next connected asset). If the service flow happens to be in both directions, two separate polylines should be created. The following information is also required:

"InType": The “first vertex”/asset type – 3 codes are used (D for demand node, S for source node and T for Transmission node);

"InName": A unique string code for identifying the “first vertex”/asset;

"InValue": The capacity of the “first vertex”/ asset (only required for source and demand nodes);

"InVcode": The vulnerability code of the “first vertex”/asset (as a reference for the “CHT_ForINDRA.txt”);

"InElev": The elevation of the “first vertex”/asset;

"outType": The “last vertex”/asset type – 3 codes are used (D for demand node, S for source node and T for Transmission node);

"outName": A unique string code for identifying the “last vertex”/asset;

"outValue": The capacity of the “last vertex”/asset (only required for source and demand nodes);

"outVcode": The vulnerability code of the “last vertex”/asset (as a reference for the “CHT_ForINDRA.txt”);

"outElev": The elevation of the “last vertex”/asset;

"LinkVcode": The vulnerability code of the asset line e.g. pipeline, powerline (as a reference for the “CHT_ForINDRA.txt”);

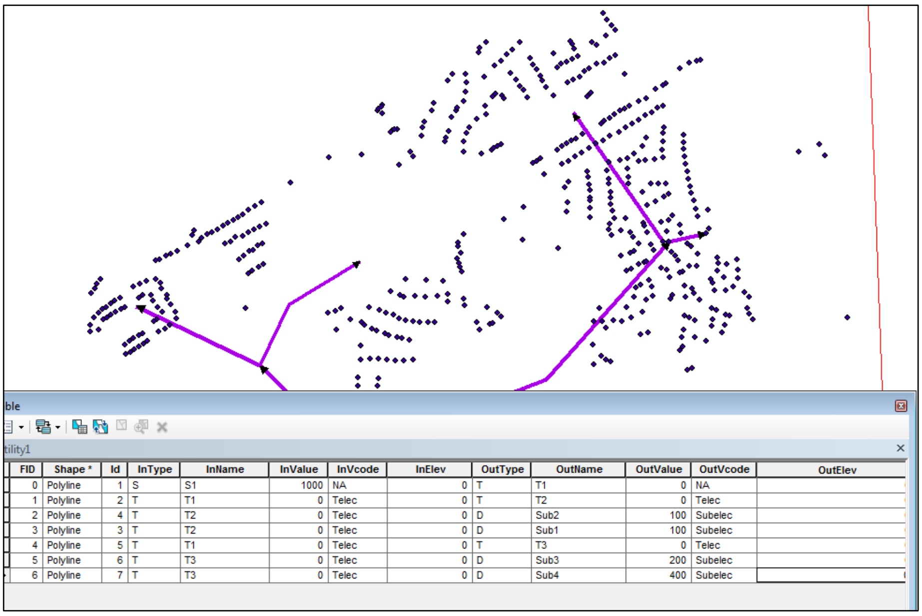
"LinkElev": The elevation of the asset line.

The geographic location of any asset is only required if that asset is considered vulnerable to the hazard. In the case of a water pipe, for instance, it might be difficult to define their exact location. If it is considered that they are not vulnerable to flooding for instance, then a link can simply be traced between two assets to indicate the existence of a connection. But if the pipe network follows the coastline and might be exposed to erosion, then its layout should be correctly identified[228].

If source nodes and the associated utility network are outside of the regional boundary, their geographical location can be ignored, however they still have to be represented in the assessment and, as such, by locating them outside the exposed area.

The demand nodes are not representing those individual properties serviced, but the final distribution asset (such as an electricity sub-station). However, individual properties can be related to these by indicating the name of the sub-station or other demand nodes in the land use shapefile (field “Util1” “Util2” “Util3”).

[228] If in some cases this is unknown the road network can be used as a good indicator of their location as essential pipes are often buried alongside the road system.



FID	Shape *	Id	InType	InName	InValue	InVcode	InElev	OutType	OutName	OutValue	OutVcode	OutElev
0	Polyline	1	S	S1	1000	NA	0	T	T1	0	NA	
1	Polyline	2	T	T1	0	Telec	0	T	T2	0	Telec	
2	Polyline	4	T	T2	0	Telec	0	D	Sub2	100	Subelec	
3	Polyline	3	T	T2	0	Telec	0	D	Sub1	100	Subelec	
4	Polyline	5	T	T1	0	Telec	0	T	T3	0	Telec	
5	Polyline	6	T	T3	0	Telec	0	D	Sub3	200	Subelec	
6	Polyline	7	T	T3	0	Telec	0	D	Sub4	400	Subelec	

Figure 4.26: Utility shapefile and table

4.3.9.3 Limitations and assumptions

The approach adopted here is the result of a number of simplifications meaning the assessment can be undertaken with low data input. As such, the approach does not quantify the loss of services *per se*, but rather indicates the potential for the loss of services.

It should also be acknowledged that:

- The approach does not consider the propagation of damages from one asset to another, i.e. the propagation of short-circuits, water hammer effects;
- The approach does not include flow analysis. As such, differences in flow capacity between links are not considered. The reduction in redundancy and the reduction in flow capacity are therefore not indicated, although these could subsequently lead to more disconnections;
- The potential for utility managers to redistribute the services from one area to another is not considered to prioritise service provision;
- The existence of resilience measures (generators, local water reserves) for specific properties is not considered.

Regionalised Utility Disruption Indicator

- **Indicates the potential level of utility service loss (disconnection and imbalance between supply and demand) at the regional scale based on a connectivity analysis technique;**
- **First, define the services considered (up to three utility networks, e.g water, electricity, gas), map the regional network in GIS polyline shapefiles and then associate a capacity to each asset node of the network;**
- **Attribute the vulnerability indicator and reinstatement time for the networks' component in the "CHT_ForINDRA.txt" file;**
- **The change in service loss is calculated for each demand node and compared to the situation prior to the event;**
- **The variation in the balance of supply-demand within the system is calculated for each source node;**
- **The final Regionalised Utility Disruption Indicator provides the degree of service loss over time (0 no disruption, 1 full loss of services) for the selected network. Up to three indicators can be calculated and input into the MCA.**

4.4 Multi-Criteria Analysis (MCA)

The impact assessment process provides various indicators to compare hotspots (Figure 4.3). These indicators have to be combined in order to rank the hotspots in a way to reflect the perspectives of various stakeholders' and to reach a consensus on the selected hotspot(s). Multi-Criteria Analysis (MCA) techniques are considered to be an appropriate methodology to conduct this type of assessment in CRAF Phase 2, as MCA improves the transparency and analytic rigour of the decision-making process through the involvement of as many stakeholders as possible[229] [230]. They include "decision models" which contain "a set of decision options which need to be ranked or scored by the decision maker; a set of criteria, typically measured in different units; and a set of performance measures, which are the raw scores for each decision option against each criterion"[231].

The literature on MCA guidance is vast and has grown considerably over the last decade. General reviews have been undertaken, including Figueira et al. (2005)[232] who conducted a detailed state of the art of different methods. Velasquez and Herster (2013)[233] performed a literature review of common Multi-Criteria Decision-Making methods, examining advantages and disadvantages. In addition, Papadopoulos (2011)[234], who, in the context of a European project, conducted an overview of multi-criteria evaluation methods for mitigation and adaptation policy instruments. The Manual of the Department of Communities and Local Government in England is another example of a generic review, which provides government guidance on the application of MCA, and also has an extensive review of different MCA techniques[235].

MCA approaches are widely used in environmental management, water resources planning, as well as flood risk and coastal management. Specific literature reviews on the application of MCAs on environmental management were conducted by many authors in the last decade[236] [237].

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[229] Dunning, D. J., Ross, Q. E., and Merkhofer, M. W. (2000) Multiattribute utility analysis for addressing Section 316 (b) of the Clean Water Act. Environmental Science and Policy, 3, 7-14.

[230] Brown, K., Adger, W. N., Tompkins, E., Bacon, P., Shim, D., and Young, K. (2001) Trade-off analysis for marine protected area management. Ecological Economics, 37(3), 417-434.

[231] Hajkowicz, S. and Collins, K. (2007) A Review of Multiple Criteria Analysis for Water Resource Planning and Management. (2007) 21:1553–1566, p.1554.

[232] Figueira, j., Greco, S., Ehrgott, M. (2005) Multiple criteria decision analysis: state of the art surveys. Kluwer Academic Publishers. Boston.

[233] Velasquez, M., and Hester, P. T. (2013) An Analysis of Multi-Criteria Decision Making Methods. International Journal of Operations Research Vol. 10, No. 2, 56–66.

[234] Papadopoulos, A. and Konidari, P. (2011) Overview and selection of multi-criteria evaluation methods for mitigation / adaptation policy instruments. PROMITHEAS– 4. Knowledge Transfer and research needs for preparing mitigation/adaptation policy portfolios. European Commission - Seventh Framework Programme.

[235] DCLG (2009) Multi Criteria Analysis. A manual. Department of Communities and Local Government. London.

[236] Huang, I. B., Keisler, J., and Linkov, I. (2011) Multi-criteria decision analysis in environmental sciences: ten years of applications and trends. Science of the total environment, 409 (19), 3578-3594.

[237] Mendoza, G. A., and Martins, H. (2006) Multi-criteria decision analysis in natural resource management: a critical review of methods and new modelling paradigms. Forest ecology and management, 230(1), 1-22.

Hajkowicz and Higgins (2008)[238] made a comparison of MCA techniques, applying MCA to six water management decision problems, testing different methods in order to compare results, and they arrived to the conclusion that in most of cases, "as long as ordinal and cardinal data are handled appropriately, the ranking of decision options is unlikely to change markedly by using different MCAs techniques".

Many papers have been published on the applications of MCA for the specific field of flood risk and coastal management[239] [240] [241] [242] [243] [244]. The usefulness of MCA for encouraging public participation in flood risk management was highlighted by Kenyon (2007)[245] who developed a new participant-led multi-criteria method to evaluate flood risk management options in Scotland, and by Levy (2005)[246], developing a decision support system architecture integrating MCA techniques remote sensing, GIS, hydrologic models and real time information systems for the Yangtze River in China.

MCAs are used to decide, among many options, which is the most convenient for most stakeholders in terms of a set of criteria (i.e. in flood and coastal risk management decisions can involve the construction of a flood alleviation channel or dredging a river, or harder engineering solution like the construction of barriers or dams). However, in the case of the MCA developed for INDRA, it is not the aim to assess options as would typically be assessed in an MCA, but to identify critical hotspot areas by analysing impacts in relation to different criteria. Hence the MCA will not be used in the strict sense to choose an option, but to decide from a distinct number of the impacted areas.

The main reasons for including the use of an MCA in the CRAF are:

- Multi-stakeholder engagement and community participation: To obtain as many opinions in deciding which hotspots are most impacted. MCA techniques can be used to identify shared solution space from multiple perspectives[247] hence they provide transparency

[238] Hajkowicz, S. and Higgins, A. (2008) A comparison of multiple criteria analysis techniques for water resource management. European Journal of Operational Research 184: 255–265, p.263.

[239] Meyer, V., Scheuer, S., and Haase, D. (2009) A multicriteria approach for flood risk mapping exemplified at the Mulde river, Germany. Natural Hazards, 48(1), 17-39.

[240] Papaioannou, G., Vasiliades, L., and Loukas, A. (2015) Multi-criteria analysis framework for potential flood prone areas mapping. Water Resources Management, 29(2), 399-418.

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[242] Ellis, J. B., Lundy, L., and Revitt, D. M. (2011) An integrated decision support approach to the selection of sustainable urban drainage systems (suds). In SWITCH Conference: The Future of Urban Water; Solutions for Liveable and Resilient Cities.

[243] Scholes, L., Ellis, J. B., and Revitt, D. M. (undated) The Development of Multi-criteria Analysis for the Evaluation of Urban Surface Drainage Options.

[244] Sieker, H., Peters, C., and Sommer, H. (2008) Modelling stormwater and evaluating potential solutions. In SWITCH report presented at 3rd SWITCH Scientific Meeting. Belo Horizonte, Brazil.

[245] Kenyon, W. (2007) Evaluating flood risk management options in Scotland: A participant-led multi-criteria approach. Ecological Economics 64: 70–81.

[246] Levy, J. (2005) Multiple criteria decision making and decision support systems for flood risk management. Stoch Environ Res Risk Assess 19: 438–447.

[247] Cai et al. (2004) in Hajkowicz, S. and Collins, K. (2007) A Review of Multiple Criteria Analysis for Water

and accountability within the process;

- MCA uses formal principles of decision theory[248] to inform choice, ensuring the analysis is logical and robust[249];
- In order to identify hotspots, different criteria, usually measured in different units, need to be evaluated; MCA enables this using a process of normalisation or standardisation.

4.4.1 Classification of MCA techniques

MCA methods can be classified as Multi Objective Decision Making (MODM) and Multi Attribute Decision Making (MADM) approaches. MODM approaches work with an indefinite set of possible scenarios, and they start with a set of principles (e.g. maximizing efficiency, reducing costs) and result in an optimized scenario. MADM approaches work with a finite set of scenarios or options which are further scrutinized about how well they fit a set of principles[250]. Since the CRAF also considers a finite set of options from the result of the impact assessment; the MADM approach is considered to be more appropriate for this purpose.

MADM can be further divided into value measurement models[251] [252] [253]; goal, aspiration, and reference-level models[254] [255]; and outranking models[256] [257], a classification widely reviewed for MCA techniques[258] [259] [260] [261]. Table 4.17 shows a combination of MADM techniques which are

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Resource Planning and Management. Water Resources Management 21: 1553–1566, p.1554.

[248] For a comprehensive overview of decision theory, see: Peterson, M (2009) An Introduction to Decision Theory. Cambridge University Press, Cambridge.

[249] Hajkowicz, S. and Collins, K. (2007) A Review of Multiple Criteria Analysis for Water Resource Planning and Management. Water Resources Management, 21: 1553–1566, P. 1554.

[250] Belton, V. and Stewart, T. (2002) Multiple Criteria Decision Analysis: An Integrated Approach. Springer Science and Business Media. Boston.

[251] Keeney, R. & Raiffa, H. (1976) Decisions with multiple objectives: preferences and value trade–offs. Wiley: New York.

[252] Van Herwijnen, M. (undated) Multi Attribute Value Theory (MAVT). Available at: http://www.ivm.vu.nl/en/Images/MCA1_tcm234-161527.pdf (accessed: 05.11.2015).

[253] See Hajkowicz, S. and Higgins, A. (2008) A comparison of multiple criteria analysis techniques for water resource management. European Journal of Operational Research 184 (2008), 255–265.

[254] Hwang and Yoon (1981) in Huang, I. B., Keisler, J., and Linkov, I. (2011) Multi-criteria decision analysis in environmental sciences: ten years of applications and trends. Science of the total environment, 409 (19), 3578-3594.

[255] Benayoun et al. (1971) in Løken, E. (2007) Use of multicriteria decision analysis methods for energy planning problems. Renewable and Sustainable Energy Reviews 11: 1584–1595.

[256] See Huang, I. B., Keisler, J., and Linkov, I. (2011) Multi-criteria decision analysis in environmental sciences: ten years of applications and trends. Science of the total environment, 409 (19), 3578-3594.

[257] See Hajkowicz, S. and Collins, K. (2007) A Review of Multiple Criteria Analysis for Water Resource Planning and Management. Water Resour Manage, 21: 1553–1566, p.1554.

[258] Buchholz, T., Rametsteiner, E., Volk, T. and Luzadis, V. (2009) Multi Criteria Analysis for bioenergy systems assessments. Energy Policy (37) 484–495.

[259] Løken, E. (2007) Use of multicriteria decision analysis methods for energy planning problems. Renewable and Sustainable Energy Reviews 11: 1584–1595.

[260] Papadopoulos, A. and Konidari, P. (2011) Overview and selection of multi-criteria evaluation methods for mitigation / adaptation policy instruments. PROMITHEAS– 4. Knowledge Transfer and research needs

easy to develop and stakeholder friendly, classified according to the types of MCA proposed by Belton and Stewart (2002)[262].

4.4.2 Selecting an MCA method

Hajkowicz and Higgins (2008: 263)[263] argue that "sometimes, the ease of understanding an MCA technique will be a primary concern in the choice of whether or not it is used". Using more complicated techniques should not be necessary if the method is going to confuse users or if it will not be understood by stakeholders. The same authors agree with Janssen (2001)[264] who states that the selection of MCA techniques is less important than the initial steps, such as the selection of criteria, the selection of decision options, the weighting of criteria and obtaining performance measures (see below) to populate the matrix. For the purpose of the MCA in the CRAF, the most suitable MADM approach should be easy to understand by all stakeholders and end users as well as straightforward to develop.

Value measurement models assign a numerical score to each scenario or option, thus ranking them depending on how they score according to a weighted list of criteria[265]. This type of MCA approach is good for decision makers and stakeholders helping them to obtain greater understanding of their own values and to justify decisions if required[266]. The most commonly used techniques within this type are Multi Attribute Utility Analysis (MAUA) by Keeney and Raiffa (1976)[267], Multi Attribute Value Analysis (MAVA)[268] Weighted Summation and Multiplication (a type of MAVA) by Howard (1991)[269] and Analytic Hierarchy Process (AHP)[270].

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for preparing mitigation/adaptation policy portfolios. European Commission - Seventh Framework Programme.

261 Mendoza, G. A., and Martins, H. (2006) Multi-criteria decision analysis in natural resource management: a critical review of methods and new modelling paradigms. Forest ecology and management, 230(1), 1-22.

262 Belton and Stewart in Mendoza, G. A., and Martins, H. (2006) Multi-criteria decision analysis in natural resource management: a critical review of methods and new modelling paradigms. Forest ecology and management, 230(1), 1-22.

263 Hajkowicz, S. and Higgins, A. (2008) A comparison of multiple criteria analysis techniques for water resource management. European Journal of Operational Research 184 (2008), 255–265.

264 Janssen, R. (2001) On the use of multi-criteria analysis in environmental impact assessment in the Netherlands. Journal of Multi-Criteria Decision Analysis 10, 101-109.

265 Buchholz, T., Rametsteiner, E., Volk, T. and Luzadis, V. (2009) Multi Criteria Analysis for bioenergy systems assessments. Energy Policy (37) 484–495.

266 Belton and Stewart in Mendoza, G. A., and Martins, H. (2006) Multi-criteria decision analysis in natural resource management: a critical review of methods and new modelling paradigms. Forest ecology and management, 230(1), 1-22.

267 Keeney, R. & Raiffa, H. (1976) Decisions with multiple objectives: preferences and value trade–offs. Wiley: New York.

268 Van Herwijnen, M. (undated) Multi Attribute Value Theory (MAVT). Available at: www.ivm.vu.nl/en/Images/MCA1_tcm234-161527.pdf (accessed: 05.11.2015).

269 See Hajkowicz, S. and Higgins, A. (2008) A comparison of multiple criteria analysis techniques for water resource management. European Journal of Operational Research 184 (2008), 255–265.

270 Kasperczyk, N. and Knickel. K. (undated) Analytical Hierarchy Process (AHP). Available at: http://www.ivm.vu.nl/en/images/mca3_tcm53-161529.pdf (accessed 05.11.2015).

The most commonly applied value measurement models could all be used for selecting hotspots in CRAF Phase 2 in terms of the methodology, with most being stakeholder-friendly in the sense they are easy to understand. However, due to the nature of the problem to be solved and the time available, a simple model is preferred rather than a complex one where a higher number of specialists are needed. One simple and straightforward method used widely in water management, and the method selected for the CRAF, is **weighted summation**. Here, all criteria are transformed onto a commensurable scale (usually 0 to 1, where 1 usually represents best performance), multiplied by weights and finally summed to attain overall utility[271]. An important advantage of this method against the other value measurement models is that it allows using compensatory and non-compensatory criteria. Non-compensatory methods do not permit trade-offs between attributes. This means that an unfavourable attribute cannot be offset by another favourable one. The calculation of weighted summation is simple, but the difficulty lies in the standardization of the data (how the scores of each criterion are converted into a common denominator) and the assignment of weights.

[271] Hajkowicz, S. and Higgins, A. (2008) A comparison of multiple criteria analysis techniques for water resource management. European Journal of Operational Research 184 (2008), 255–265.

Table 4.17: Classification of Multi Attribute Decision Making MCA techniques

Classification of approaches	Technique/ Approach	Information	Result	Transparency	Stakeholder friendly?	Appropriate for the purpose of choosing scenarios or hotspot areas?
Value measurement models	Multi Attribute Utility Analysis (MAUA) Keeney and Raiffa (1976)	Quantitative	Performance scores / ranking		No	Yes
	Multi attribute Value Analysis (MAVA)			High	Yes	Yes
	AHP Saati 1994 (in Huang et al. 2011)	Qualitative		Low	Not in all cases. Undertaking the comparisons and ensuring consistency becomes increasingly complex as the numbers of criteria and options increases	Yes
	Weighted summation and multiplication Howard 1991 (in Hajkowicz and Higgings 2008)	Quantitative		High	Yes	Yes.

Classification of approaches	Technique/ Approach	Information	Result	Transparency	Stakeholder friendly?	Appropriate for the purpose of choosing scenarios or hotspot areas?
Goal, aspiration and reference level models	Ideal point method (e.g. TOPSIS) Hwang and Yoon, 1981 (in Huang et al. 2011)	Quantitative	Distance to target	Medium	Yes.	No. Not our purpose to design goals. They are not design for handling qualitative data.
	STEM or STEP approach (Benayoun et al. 1971)					
Outranking methods	PROMETHEE (Brans et al. 1986) in Huang et al. 2011)	Quantitative	Ranking / Incomplete ranking	Low	No. Difficult to explain to non-specialists	Yes. Although they are good for a first screening process, and then another method is needed to get a full ranking or actual recommendations among the alternatives (Loken 2007)
	ELECTRE (Roy 1968, in Hajkowicz and Collins 2007)					

4.4.3 Steps to follow for applying weighted summation

In order to conduct an MCA, an evaluation matrix is first developed by the user where the options (hotspots in this case), criteria and performance measures are included. The following steps are then usually followed for any assessment, although for the selection of hotspots these were tailored in accordance with the goals of the analysis.

Step 1 - Define decision options: The CRAF screens and ranks the potential risk of different hotspots along the coastline. The ranking should guide the user in their decision to prioritise efforts in directing resources and modelling. Therefore the 'options' are the potential hotspots identified in CRAF Phase 1 (see Figure 2.1).

Step 2 - Identify the evaluation criteria (impact categories): The criteria for the CRAF MCA are predefined in the INDRA model: household displacement, household financial recovery, risk to life, regional business disruption, business financial recovery, ecosystem recovery, regional utilities service disruption and regional transport service disruption.

Step 3 - Obtain impact valuation for the evaluation matrix and transform into commensurate units (standardise): The values for the matrix may be either ordinal or cardinal, and can be sourced from expert judgement or other environmental and economic models. Impact scores can be measured on a quantitative scale such as ratio, interval or monetary scale or a qualitative scale such as ordinal, binary or +++/---, the latter being good for expert judgement. It can be mixed depending on the nature of the criteria[272]. In the INDRA, each impact indicator is automatically converted into a value ranging from 0 to 1 (see previous sections), a value of 0 indicating no disruption, a value of 1 maximum disruption.

Step 4 - Weight the criteria: Criteria are rarely of equal importance to the decision maker and a variety of methods are available to assign weights at either cardinal or ordinal levels of measurement. Allocating weights can be controversial and criticised, as the selected method reveals stakeholder subjectivity which may influence the final outcomes. It is, therefore, essential to report the methods and the narrative of the process which led to the final outcomes. The choice of which stakeholders to involve should also be explained and any limitations acknowledged. Weights can be applied by experts on the basis of generally accepted knowledge, by politicians on the basis of political interests or by local residents on the basis of personal interests[273].

There are two different methods to assign weights[274]:

- Swing weighting, based on comparisons of differences. E.g.: how does the swing from 0 to 100 on one preference scale compare to the 0-100 swing on another scale? In order "to

[272] van Herwijnen, M., and Janssen, R. (2006) Software support for multi-criteria decision making. In: Giupponi, C., Jakeman, A., Karssenberg, D. and Hare, M. (Eds.) Sustainable management of water resources: an integrated approach, Fondazione Eni Enrico Mattei. Edward Elgar, Cheltenham, Northampton, 131-150.

[273] van Herwijnen, M., and Janssen, R. (2006) Software support for multi-criteria decision making. In: Giupponi, C., Jakeman, A., Karssenberg, D. and Hare, M. (Eds.) Sustainable management of water resources: an integrated approach, Fondazione Eni Enrico Mattei. Edward Elgar, Cheltenham, Northampton, 131-150.

[274] Van Herwijnen, M. (undated) Weighted summation. Available at: http://www.ivm.vu.nl/en/Images/MCA2_tcm53-161528.pdf (accessed 05.11.2015).

make these comparisons, it is recommended to take into account both the difference between the least and most preferred options, and how much they care about that difference". Hence the weight represents both the range of the difference and how much all stakeholders care about this difference;

- Direct estimation of the relative importance of the weight by assigning a value to each criterion. A scale 0-1 or 0-100 can be used. If the ranges of each criterion are taken into account, this method can be very effective and has been selected for CRAF Phase 2.

Different techniques can be used to engage with the stakeholders. Amongst these, three are proposed (World Café, Fish Bowl, Focus Group) and these are discussed in Appendix D.

Step 5 - Rank the options: At this stage the weights are combined with the performance measures by the INDRA to attain an overall performance rank or score for each decision option, scaled from 0 to 1.

4.4.4 Application of the methodology within the model

The MCA is integrated within the model. At the bottom of the interface, the user can perform the MCA by, first, indicating the preference of stakeholders[275] for each indicator (the total of their weights being equal to 100), and then by clicking the "MCA_score" button (Figure 4.27). The scores for each indicator are then displayed in a histogram plot and the results (score * weight) displayed in the text box below (Figure 4.28). It should be noted that the same process has to be repeated separately for each hotspot and therefore the same weight should be assigned in every case in order to rank the hotspots. To avoid errors, the text can be copied or exported in order to record the results of the current assessment by right-clicking on the text box.

For certain impact indicators, it is necessary to inform the model of which receptors to consider. To do this an MCA code should be attributed in the receptor point shapefile (field "MCAcat") as follows:

- For Household Displacement, household financial recovery: "Household";
- For Regional Business Disruption, business financial recovery: "Business";
- For Ecosystem Recovery: two codes could be used "Agriculture" or "Ecosystems";
- Any land use not associated with a code will not be considered except for the Risk To Life Indicator.

[275] The process could be repeated with the stakeholders to highlight how the preference values they assign may change the final outcome. It is up to the users to decide if this should be repeated. However, the initial preference should be undertaken prior to discussion of the impacts to avoid introducing bias.

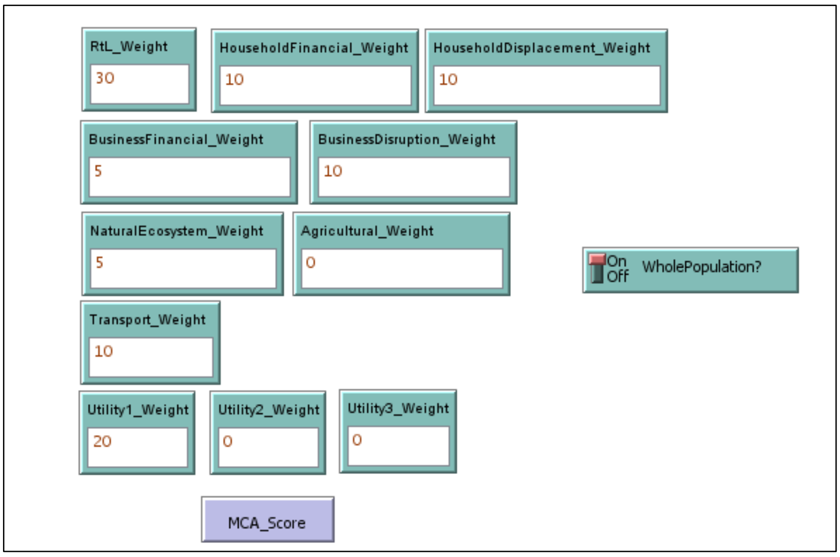

Figure 4.27: Inputting MCA preferences in the model

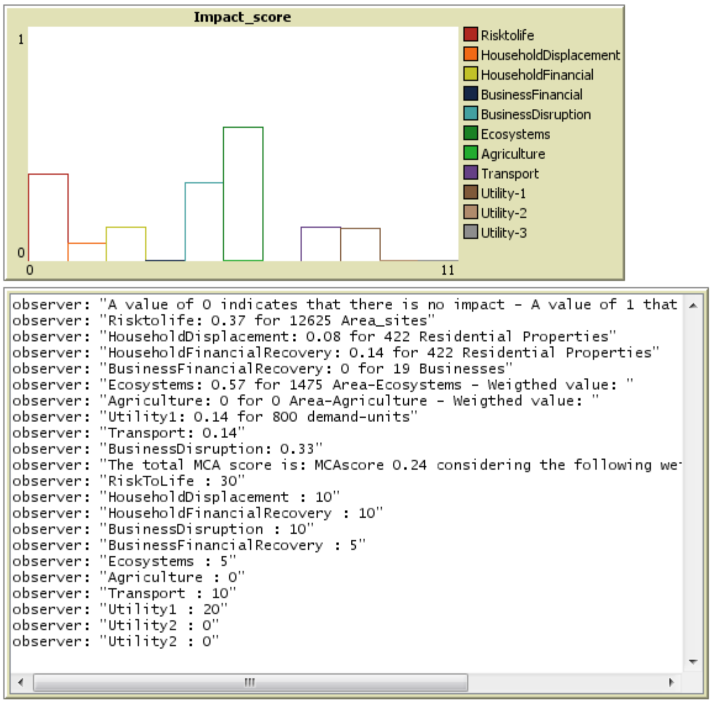

Figure 4.28: Impact scores and MCA final result for a hotspot

5 Appendices

5.1 Appendix A

Coastal ecosystem services mapping
Dr Åse Johannessen, Stockholm Environment Institute

The INDRA model indicates the potential changes within the regional ecosystems and their recovery time. To do so, the user is required to review all ecosystems potentially exposed within the region. Even if the oceans, seas and coastal zones are estimated to contribute more than 60% of the total economic value of the biosphere, the knowledge of the services they provide is not as substantial as for their terrestrial counterparts. In particular, their mapping is lagging behind (European Commission, 2014). The importance of the ecosystems within the region has also to be expressed by the stakeholders' preferences in the MCA process. A good understanding and assessment of the level of ecosystems services should be provided to support it and used for further analysis. This appendix presents to the user some key concepts and information on selected ecosystems which could help with the task (see separate file: "EcosystemServicesINDRA_Appendix.xlsx"[276]).

Some important concepts

Ecosystem services

The main aim of the service-concept is to communicate to other human beings the use of an ecosystem function. A common practice is to adopt the broad definition of the Millennium Ecosystem Assessment (MEA, 2005) that "ecosystem services are the benefits people obtain from ecosystems." The distinction between ecosystem functions and services can therefore be made as detailed below, separating the 'functions of' the ecosystem and the 'functions for' humans, which they generate. In short, if an ecosystem function has a human use or a value as a commodity it can be regarded as an ecosystem service.

Ecosystem services vs functions

The distinction between ecosystem services and functions is controversial and inconsistent (Roe and van Eeten, 2002). Some observers have explicitly equated functions with services (Callicott et al., 1999; Ekins et al., 2003), while some insist that the terms are at best ill-defined buzzwords with little empirical content on their own (Goldstein, 1999). The differences could be explained with ecosystem functions referring variously to the habitat, biological or system properties or processes of ecosystems, whereas ecosystem services are yielded by ecosystem functions and focus on the usefulness for humans. One single ecosystem service can be the product of two ecosystem functions, whereas in other cases the contrary may be true (Costanza et al., 1997).

Ecosystem functions have been classified in a number of ways which have developed since their introduction (e.g. see the oft-quoted work by De Groot, 1992). The Millennium Ecosystem Assessment (MA) popularized the term ecosystem services. During the 1990s, a need was identified by a number of international environmental organisations for a global ecosystem

[276] Available at the Public Deliverables section of the RISC-KIT website: http://www.risckit.eu/np4/8/

assessment. There had been advances in fields such as resource economics but the new findings had little effect on environmental policy. This led to the launch of the MA in 2001 and carried out over a period of four years. The RISC-KIT project has adopted the functions first described by the MA distinguishing four broad benefit streams: **provisioning services, cultural services, supporting services** and **regulating services** (Perrings, 2010) which initially grouped the supporting and regulating services into one category (MEA, 2005). This division of four main functions is also used by The Economics of Ecosystems and Biodiversity (TEEB). TEEB was initiated by the German government and endorsed by the G8+5. It therefore has a strong backing by the established governance system, including the UN. It is a study to assess the global economic costs of ecosystem degradation and biodiversity loss, and to recommend solutions to policymakers, administrators, businesses and individuals.

1. *Provisioning services* are the natural products generated by ecosystems and cover the products of renewable biotic resources including foods, fibres, fuels, water, biochemicals, medicines, pharmaceuticals, as well as the genetic material of interest to the CBD. The production, processing and consumption of these all have consequences both for the net emission of greenhouse gases, and for the capacity of the system to accommodate the effects of climate change.

2. *Supporting services* comprise the main ecosystem processes that are necessary for all other services, such as soil formation, photosynthesis, primary production, nutrient, and water cycling. The concern over climate change is primarily a concern over the atmospheric consequences of changes in the carbon cycle. These services play out at very different spatial and temporal scales, extending from the local to the global, and over time periods that range from seconds to hundreds of years.

3. *The Regulating services* are the benefits obtained from the regulation of ecosystem processes, defined by the MA to include air quality regulation, climate regulation, hydrological regulation, erosion regulation or soil stabilization, water purification and waste treatment, disease regulation, pest regulation and natural hazard regulation. More generally, they comprise the benefits of biodiversity in moderating the effects of environmental variation on the production of those things that people care about directly. They limit the effect of stresses and shocks to the system. As with the supporting services they operate at widely differing spatial and temporal scales. So, for example, the morphological variety of plants in an alpine meadow offers strictly local benefits in terms of reduced soil erosion, while the genetic diversity of crops in global agriculture offers a global benefit in terms of a lower spatial correlation of the risks posed by climate or disease. Both macro- and micro-climatic regulation are examples of the regulating services.

4. *Cultural services* comprise a range of largely non-consumptive uses of the environment including the spiritual, religious, aesthetic and inspirational wellbeing that people derive from the ‘natural’ world; the value to science of the opportunity to study and learn from that world; and the market benefits of recreation and tourism. While some of these activities—particularly recreation and tourism—have significant implications for GHG emissions, many have relatively little impact (Perrings, 2010).

Table 1: How to compare the common classification systems of ecosystem services (Liquete et al., 2013)

	This paper	MA	Beaumont	TEEB	CICES
Provisioning	**Food provision**	Food	Food provision	Food	Terrestrial plant and animal Freshwater plant and animal Marine plant and animal
	Water storage and provision	Fresh water	N/A	Water	Potable water Water flow regulation Water quality regulation
	Biotic materials and biofuels	Ornamental resources Genetic resources Biochemicals Fiber	Raw materials	Ornamental resources Genetic resources Medicinal resources Raw materials	Biotic materials Renewable biofuels
Regulating and maintenance	**Water purification**	Water purification and waste treatment Nutrient cycling	Bioremediation of waste Nutrient cycling	Waste treatment	Bioremediation Water quality regulation Dilution and sequestration of wastes
	Air quality regulation	Air quality regulation	Gas and climate regulation	Air quality regulation	
	Coastal protection	Natural hazard regulation Water regulation Erosion regulation	Disturbance prevention	Moderation of extreme events Regulation of water flows Erosion prevention	Mass flow regulation Water flow regulation Air flow regulation
	Climate regulation **Weather regulation**	Climate regulation	Gas and climate regulation N/A	Climate regulation	Atmospheric regulation
	Ocean nourishment	Soil formation Nutrient cycling	Nutrient cycling	Maintenance of soil fertility	Pedogenesis and soil quality regulation
	Life cycle maintenance	Pollination	Biologically mediated habitat	Maintenance of life cycles of migratory species Maintenance of genetic diversity Pollination	Lifecycle maintenance and habitat protection Gene pool protection
	Biological regulation	Pest regulation Disease regulation	N/A	Biological control	Pest and disease control
Cultural	**Symbolic and aesthetic values**	Spiritual and religious values Cultural heritage values Cultural diversity Sense of place Aesthetic values	Cultural heritage and identity Feel good or warm glow	Spiritual experience Aesthetic information	Spiritual Aesthetic, heritage
	Recreation and tourism	Recreation and ecotourism Social relations	Leisure and recreation	Opportunities for recreation and tourism	Recreation and community activities
	Cognitive effects	Inspiration Knowledge systems Educational values	Cognitive effects	Inspiration for culture, art and design Information for cognitive development	Information and knowledge

Ecosystems vs habitat

In the UK and much of Europe, the classification of ecosystems can be considered as significantly overlapping with that of habitats. A definition of a habitat is an ecological or environmental area that is inhabited by a particular animal or plant species. In Europe, Annex I of the EU Habitats Directive[277] lists 231 European natural habitat types, including 71 priority types (i.e. habitat types in danger of disappearance and whose natural range mainly falls within the territory of the European Union).

However, whilst the classification and management of habitats is centred on the populations of species of interest, the concept of an ecosystem is centred on the interactions between its components and its properties as a system. This systems perspective logically extends to include people as part of ecosystems. We simultaneously depend upon and influence ecosystems with incentives in the social structures for developing integrated land and water management (Kates et al., 2001).

Some important habitat classifications:

The EUNIS habitat classification is a comprehensive pan-European system to facilitate the harmonised description and collection of data across Europe through the use of criteria for habitat identification. It is hierarchical and covers all types of habitat types from natural to artificial, from terrestrial to freshwater and marine. (5283 types) (European Environment Agency, 2015). A good interactive hierarchical view is available at the EUNIS website[278].

The EU Habitats Directive lists 231 European natural habitat types. It is useful to provide the EU code for natural habitat types listed in the Habitats Directive.

The IUCN red data species list[279] uses another habitat classification

Classification systems

Different classification systems are used in parallel which can cause confusion. A key to how to compare these is found below in table 1 (Liquete et al., 2013).

Millennium Assessment (MA)

The Millennium Ecosystem Assessment (MA) popularized the term ecosystem services. During the 1990s, a need was identified by a number of international environmental organisations for a global ecosystem assessment. There had been advances in fields such as resource economics but the new findings had little effect on environmental policy. This led to the launch of the MA in 2001 and carried out over a period of four years (Millennium Ecosystem Assessment, 2015).

The economics of ecosystems and biodiversity

The economics of ecosystems and biodiversity (TEEB) was initiated by the German government and endorsed by the G8+5. It therefore has a strong backing by the established governance system, including the UN. It is a study to assess the global economic costs of ecosystem degradation and biodiversity loss, and to recommend solutions to policymakers, administrators, businesses and individuals.

Common International Classification of Ecosystem Services (CICES v4.3)

CICES is linked with the Framework of the UN System of Environmental Economic Accounts (SEEA) (European Commission, 2014). In terms of ecosystem service classifications by adopting

[277] See: http://ec.europa.eu/environment/nature/legislation/habitatsdirective/index_en.htm

[278] http://eunis.eea.europa.eu/habitats-annex1-browser.jsp?expand=1,11#level_1100

[279] http://www.iucnredlist.org/technical-documents/classification-schemes/habitats-classification-scheme-ver3

the CICES general structure, the MCES classification can be directly linked with the framework of the UN System of Environmental-Economic Accounts (SEEA) and with several standard product and activity classifications, namely the International Standard Industrial Classification of All Economic Activities, the Central Products Classification, and the Classification of Individual Consumption by Purpose which is relevant for future progression of MCES work.[280]

European efforts in mapping of ecosystem services

The Biodiversity Information System for Europe (BISE) is a single entry point for data and information on biodiversity supporting the implementation of the EU strategy and the Aichi targets in Europe. Here, Mapping and Assessment of Ecosystems and their Services (MAES) is one part[281]. A first outcome is the development of a coherent analytical framework to be applied by the EU and its Member States in order to ensure consistent approaches are used (see Figure 1).

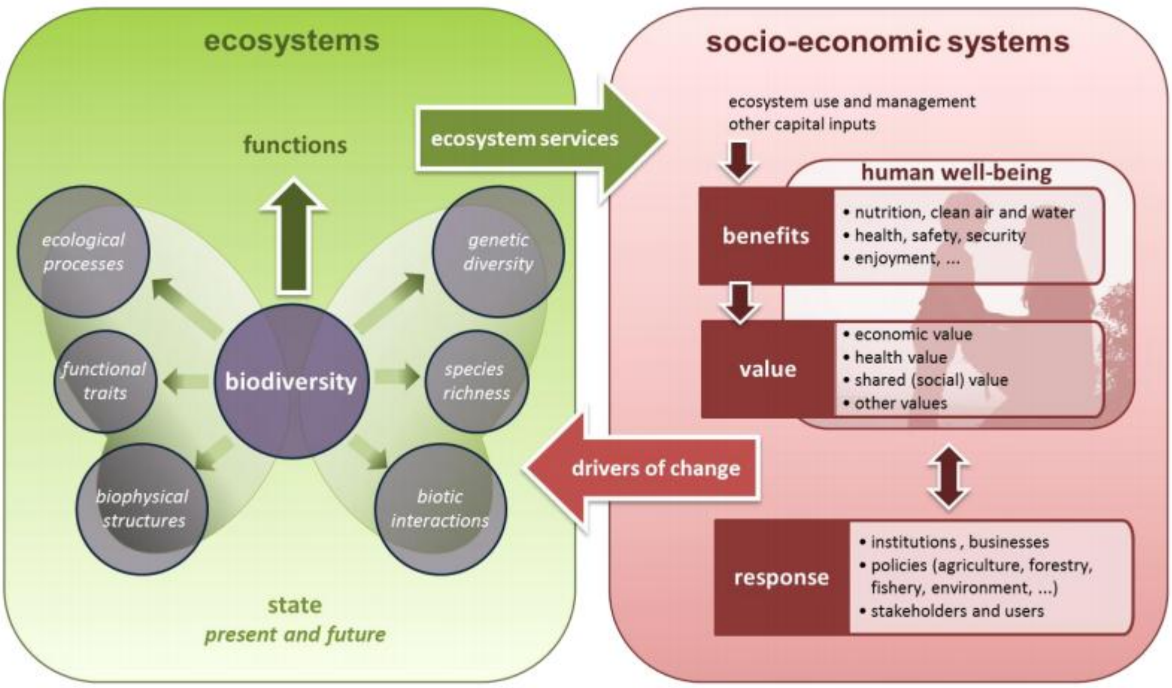

Figure 1: MAES conceptual framework[282].

The pilot on natural capital accounting aims to explore the potential for valuation and natural capital accounting at EU and national level. This builds on the biophysical mapping and assessment of the state of ecosystems and of their services in the context of the EU 2020 Biodiversity Strategy. This uses the latest developments on ecosystem accounts at global and EU level and concrete examples in Member States. The EU pilot is among the first to address indicators to map and assess marine ecosystem services (European Commission, 2014).

[280] See: http://cices.eu/

[281] See: http://biodiversity.europa.eu/maes

[282] ibid.

National ecosystem assessments

Countries have done national ecosystem assessments following the MEA/MA. For example the UK has carried out one, building its methodology on work published since the MA[283], including post MA reviews (Carpenter et al., 2009) and The Economics of Ecosystems and Biodiversity's (TEEB) Scoping the Science report (Balmford et al., 2008). Also Japan, Spain, and Portugal have carried out assessments (Wilson et al., 2014).

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[283] See: http://uknea.unep-wcmc.org/Resources/BackgroundDocuments/tabid/85/Default.aspx

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5.2 Appendix B

Households – Coastal Flood

		Direct impact on property			
		Low	**Medium**	**High**	**Very High**
Characteristics of receptor related to financial recovery	**Impact scenario**	**Low financial damages sustained - minor damages to contents and or building.**	**Medium financial damages sustained**	**High financial damages sustained - severe damage to the structure temporary relocation likely**	**Very high financial damages are sustained - including partial/total collapse of property.**
Household with no insurance	**NoI**	2	3	4	5
Household with no insurance, but resident has self-insured	**NoIself**	1	2	3	4
Household with no insurance, but which are able to access a small/medium amount of government compensation	**NoIScomp**	1	2	3	4
Household with no insurance, but which are able to access a large amount of government compensation	**NoILcomp**	1	1	2	3
Partly insured household	**PartI**	1	2	3	4
Household with full coverage for buildings and contents insurance	**FullI**	1	1	1	2

Impact categories

1	**Full financial recovery** – households will recovery with no/few adverse impacts.
2	**Partial financial recovery – medium duration -** households will achieve partial financial recovery that will take many months to achieve.
3	**Partial financial recovery – long duration -** households will achieve partial financial recovery that will take over a year to achieve.
4	**Low degree of financial recovery** possible for households and/or will take many years/decades to achieve.
5	**Very low financial recovery is possible** – the household suffers major and permanent changes to their way of life.

Households – Coastal Erosion

		Direct impact on property			
		Low	**Medium**	**High**	**Very High**
Characteristics of receptor related to financial recovery	**Impact scenario**	Activities disrupted before and during event for monitoring	Direct impact on property	n/a	Very high financial damages are sustained - including partial/total collapse of property.
Household with no insurance	NoI	1	1	n/a	5
Household with no insurance, but resident has self-insured	NoIself	1	1	n/a	4
Household with no insurance, but which are able to access a small/medium amount of government compensation	NoIScomp	1	1	n/a	4
Household with no insurance, but which are able to access a large amount of government compensation	NoILcomp	1	1	n/a	3
Partly insured household	PartI	1	1	n/a	4
Household with full coverage for buildings and contents insurance	FullI	1	1	n/a	2

Impact categories

1	**Full financial recovery** – households will recovery with no/few adverse impacts.
2	**Partial financial recovery – medium duration -** households will achieve partial financial recovery that will take many months to achieve.
3	**Partial financial recovery – long duration -** households will achieve partial financial recovery that will take over a year to achieve.
4	**Low degree of financial recovery** possible for households and/or will take many years/decades to achieve.
5	**Very low financial recovery is possible** – the household suffers major and permanent changes to their way of life.

Business Properties – Coastal Flood

		Direct impact on property			
		Low	**Medium**	**High**	**Very High**
Characteristics of receptor related to financial recovery	**Impact scenario**	Low financial damages sustained - minor damages to contents and or building.	Medium financial damages sustained	High financial damages sustained - severe damage to the structure requiring business owners to move out of the business premises.	Very high financial damages are sustained - including partial/total collapse of property.
Non-insured/self-insured smaller to medium sized business - a business which has no or very little insurance coverage.	BNoI	2	3	4	5
Non-insured/self-insured larger businesses or business corporations	BMNCself	1	1	1	2
Non-insured/self-insured business – but the health of the business or access to resources, such as business loans or government assistance (e.g. tax breaks) tide the business through the difficult recovery period.	BNoISelf	1	2	3	4
Partly Insured business – but some elements may not be fully insured (i.e. may only have structural, contents or business interruption insurance/not all elements may be eligible for coverage; may have some degree of underinsurance.	BStateown	1	2	3	4
Fully insured business - with Structural, Contents and Business Interruption insurance.	BPartI	1	1	1	2
State owned businesses -the circumstances and duration of recovery will depend upon the specific state involved.	BFullI	1	1	2	2

Impact categories

1	**Full financial recovery** - business able to continue with little impact on the running of the business and overall profits.
2	**Partial financial recovery** – with a medium duration. Businesses will be able to achieve a partial recovery (the business may shrink in the short to medium term) that will take many months to achieve.
3	**Partial financial recovery with a long duration.** Businesses will be able to achieve a partial recovery (the business may shrink in the medium to long term) from flooding but this will take over a year to achieve.
4	**Low degree of financial recovery** and/or will take many years/decades to recover. The business may shrink significantly as a result of the flooding, It may be necessary to relocate the business and it would require significant rebuilding.
5	**Very low financial recovery is possible.** This means that the business would shrink significantly. This would change the nature of the business and in many situations the business would not be able to recover, leading to permanent closure.

Business Properties – Coastal Erosion

		Direct impact on property			
		Low	**Medium**	**High**	**Very High**
Characteristics of receptor related to financial recovery	**Impact scenario**	Activities disrupted before and during event for monitoring	Activities disrupted before, during and after event for monitoring	n/a	Very high financial damages are sustained - including partial/total collapse of property
Non-insured/self-insured smaller to medium sized business - a business which has no or very little insurance coverage.	BNoI	1	1	n/a	5
Non-insured/self-insured larger businesses or business corporations	BMNCself	1	1	n/a	2
Non-insured/self-insured business – but the health of the business or access to resources, such as business loans or government assistance (e.g. tax breaks) tide the business through the difficult recovery period.	BNoISelf	1	1	n/a	4
Partly Insured business – but some elements may not be fully insured (i.e. may only have structural, contents or business interruption insurance/not all elements may be eligible for coverage; may have some degree of underinsurance.	BStateown	1	1	n/a	4
Fully insured business - with Structural, Contents and Business Interruption insurance.	BPartI	1	1	n/a	2
State owned businesses -the circumstances and duration of recovery will depend upon the specific state involved.	BFullI	1	1	n/a	2

Impact categories

1	**Full financial recovery** - business able to continue with little impact on the running of the business and overall profits.
2	**Partial financial recovery** – with a medium duration. Businesses will be able to achieve a partial recovery (the business may shrink in the short to medium term) that will take many months to achieve.
3	**Partial financial recovery with a long duration.** Businesses will be able to achieve a partial recovery (the business may shrink in the medium to long term) from flooding but this will take over a year to achieve.
4	**Low degree of financial recovery** and/or will take many years/decades to recover. The business may shrink significantly as a result of the flooding, It may be necessary to relocate the business and it would require significant rebuilding.
5	**Very low financial recovery is possible.** This means that the business would shrink significantly. This would change the nature of the business and in many situations the business would not be able to recover, leading to permanent closure.

5.3 Appendix C

Format of the different input files for the INDRA model

Various files are required to run the models. They are of two types: Geographic Information System .shp files and .txt files.

GIS files (.shp): Geographic Information System files are used to import spatial information on the hazard and the receptors. The user can inform the model of their names and availability. CSboundary, flood, erosion, overwash map, receptors, transport, utilities map.

If certain fields are required, please double-check that the field name is correctly spelt including capital letters.

<u>CSboundary map</u>

This polygon shapefile defines the boundary of the case study - any data contained in other shapefiles outside this boundary will not be imported. It has to represent the regional boundary and shall be used for each assessment.

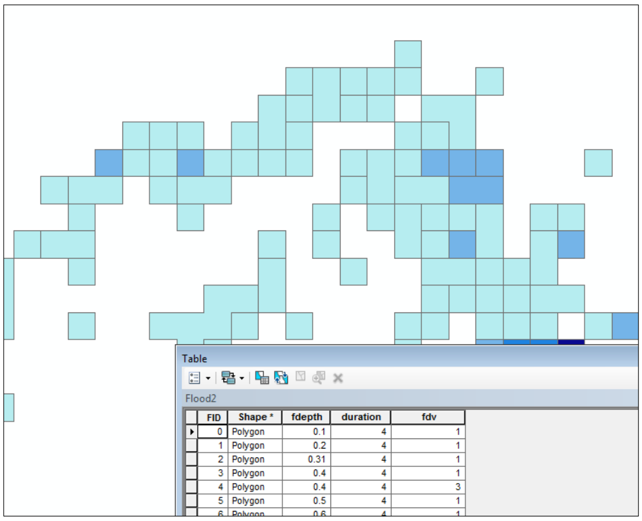
<u>Flood map or overwash map</u>

This polygon shapefile provides the flood hazard information. Required fields are:

"fdepth" : flood depth;

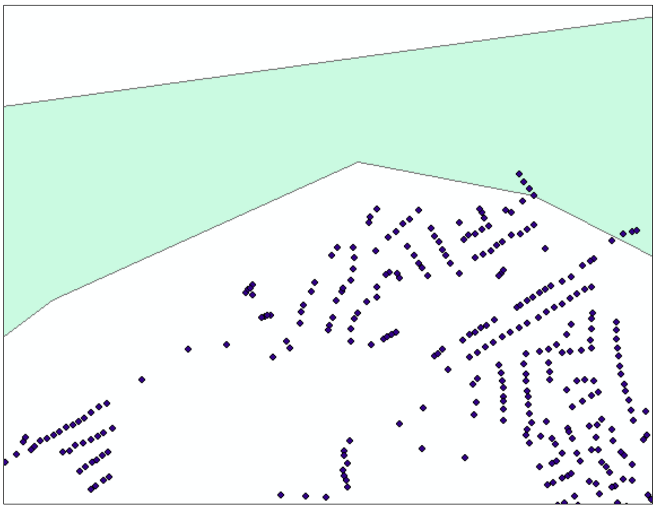
"fdv": flood depth velocity;

"duration": flood duration;



<u>Erosion map</u>

This polygon shapefile provides the delimitation of the seaside (the polygon being the sea).



<u>Landuse</u>

This point shapefile provides the information for the land use only (e.g. buildings, ecosystem etc.).

Required fields are:

“LUid”: a unique reference value for the land use;

"Rcode": the vulnerability land use code;

"Nb": the number of assets associated with the points (1 or more if grouped);

"elevation": the elevation in metres of the land use compared to the ground level;

"area": the associated surface (the metrics can be defined by the user as long as it is consistent for all land uses);

"NatArea": the vulnerability of the area (risk to life);

"Util1": the name of the utility asset (belonging to utility network 1) associated with the land use if any;

"Util2": the name of the utility asset (belonging to utility network 2) associated with the land use if any;

"Util3": the name of the utility asset (belonging to utility network 3) associated with the land use if any;

"Util1d": indicates if the land use is dependent on the utility 1 asset (0 if not, 1 if yes – used for business disruption calculation);

"Util2d": indicates if the land use is dependent on the utility 2 asset (0 if not, 1 if yes – used for business disruption calculation);

"Util3d": indicates if the land use is dependent on the utility 3 asset (0 if not, 1 if yes – used for business disruption calculation);

"Inscode": the associated insurance area code;

"MCAcat": the associated MCA category;

"BS_ref": the associated supply chain node (for business);

"BS_cap": the business capacity;

"BS_scap": the business spare capacity;

“NonExp”: indicates if the land use is potentially exposed (0 if not, 1 if yes).

<u>Transport</u>

This polyline shapefile provides information on the transport network (e.g. road, trains).

Required fields are:

"roadId”: a unique reference value for the polyline;

“J1_name”: the name of the starting junction;

“J2_name”: the name of the final junction;

“Speed": speed on the considered roads/rail lines;

"elevation": elevation of the considered roads/rail lines;

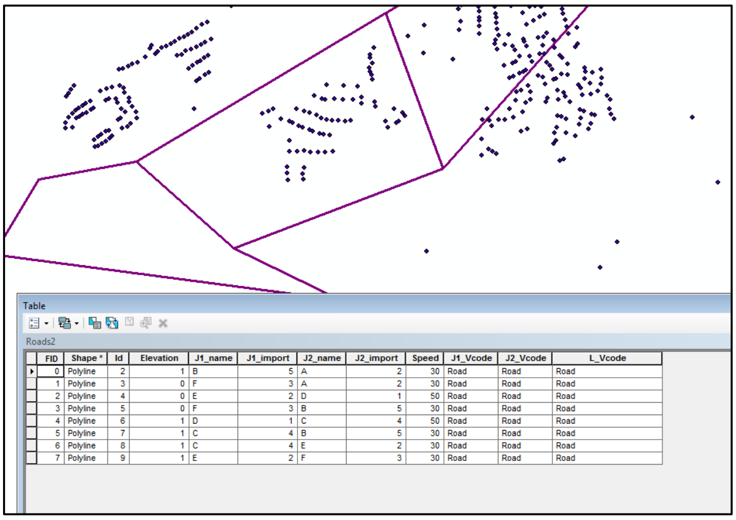
"L_Vcode" : vulnerability code of the roads/rail lines;

"J1_Vcode": vulnerability code of the starting junction (first vertex);

"J2_Vcode": vulnerability code of the ending junction (last vertex);

“J1_import": importance the starting junction (first vertex);

"J2_import": importance of the ending junction (last vertex).



FID	Shape *	Id	Elevation	J1_name	J1_import	J2_name	J2_import	Speed	J1_Vcode	J2_Vcode	L_Vcode
0	Polyline	2	1	B	5	A	2	30	Road	Road	Road
1	Polyline	3	0	F	3	A	2	30	Road	Road	Road
2	Polyline	4	0	E	2	D	1	50	Road	Road	Road
3	Polyline	5	0	F	3	B	5	30	Road	Road	Road
4	Polyline	6	1	D	1	C	4	50	Road	Road	Road
5	Polyline	7	1	C	4	B	5	30	Road	Road	Road
6	Polyline	8	1	C	4	E	2	30	Road	Road	Road
7	Polyline	9	1	E	2	F	3	30	Road	Road	Road

<u>Utility</u>

This polyline shapefile provides information on the utility networks. Up to 3 shapefiles can be used for different utility networks. The direction of the polyline should respect the flow direction within the network.

Required fields are:

“Ut_id”: a unique reference value for the polyline;

"InType": the “first vertex”/asset type – 3 codes are used (D for demand node, S for source node and T for Transmission node);

"InName": a unique string code for identifying the “first vertex”/asset;

"InValue": the capacity of the “first vertex”/ asset (only required for source and demand nodes);

"InVcode": the vulnerability code of the “first vertex”/asset (as a reference for the CHT_forINDRA.txt);

"InElev": the elevation of the “first vertex”/asset;

"outType": the “last vertex”/asset type – 3 codes are used (D for demand node, S for source node and T for Transmission node);

"outName": a unique string code for identifying the “last vertex”/asset;

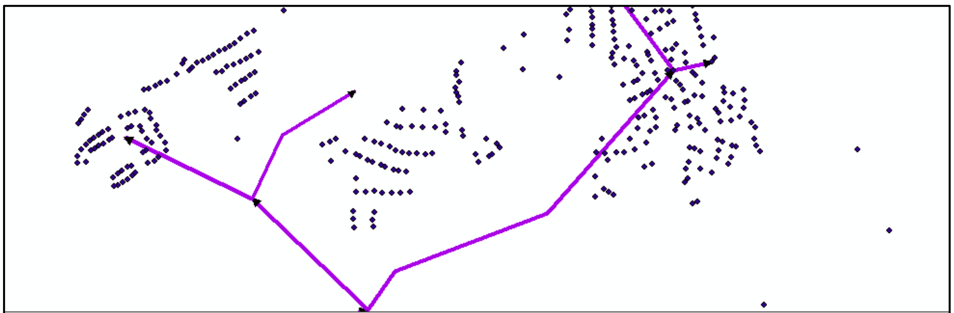
"outValue": the capacity of the “last vertex”/asset (only required for source and demand nodes);

"outVcode": the vulnerability code of the “last vertex”/asset (as a reference for the CHT_forINDRA.txt);

"outElev": the elevation of the “last vertex”/asset;

"LinkVcode": the vulnerability code of the asset line e.g. pipeline, powerline (as a reference for the CHT_forINDRA.txt);

"LinkElev": the elevation of the asset line.



Table

Utility1

FID	Shape	Id	InType	InName	InValue	InVcode	InElev	OutType	OutName	OutValue	OutVcode	OutElev	
0	Polyline	1	S	S1	1000	NA	0.1	T	T1	0	NA	0.1	Subele
1	Polyline	2	T	T1	0	Telec	0.1	T	T2	0	Telec	0.1	Subele
2	Polyline	4	T	T2	0	Telec	0.1	D	Sub2	100	Subelec	0.1	Subele
3	Polyline	3	T	T2	0	Telec	0.1	D	Sub1	100	Subelec	0.1	Subele
4	Polyline	5	T	T1	0	Telec	0.1	T	T3	0	Telec	0.1	Subele
5	Polyline	6	T	T3	0	Telec	0.1	D	Sub3	200	Subelec	0.1	Subele
6	Polyline	7	T	T3	0	Telec	0.1	D	Sub4	400	Subelec	0.1	Subele

Text files: text files are used as input files in the models: CHT_forINDRA.txt, Insur_ forINDRA.txt, SC_ forINDRA.txt.

<u>CHT_forINDRA.txt</u>

The file provides information on the vulnerability thresholds.

```
comments CodeHazardThresholds  threshold_1 threshold_2 threshold_3 threshold_4 "recovery" T1Rtime T1Rfactor T2Rtime T2Rfactor
"dd curves for prop anytype flooding" "Prop_fd" 0 0.25 0.90 9999 "recovery" 3 1 15 0.8 180 0.5 9999 9999
"building collapse for prop any type flooding" "Prop_fdv" 9999 9999 3 7 9999 "recovery" 9999 9999 9999 9999 180 0.7 1000 1
"dd curves for prop anytype overwash" "Prop_od" 0 0.25 0.90 9999 "recovery" 3 0.5 15 0.4 180 0.2 9999 9999
"building collapse for prop any type overwash" "Prop_odv" 9999 9999 3 7 "recovery" 9999 9999 9999 9999 100 0.5 1000 1
"Erosion for any prop" "Prop_er"  10 5 9999 0 "recovery" 0 1 10 0.2 9999 9999 5000 1
"Risk to life for LowVulneSite" "N1_fdv" 0 0.5 9999 7 "recovery" 9999 9999 9999 9999 9999 9999 9999
"Risk to life for MediumVulneSite" "N2_fdv" 0 0.25 1.1 7 "recovery" 9999 9999 9999 9999 9999 9999 9999
"Risk to life for highvulsite" "N3_fdv" 0 0.25 0.5 1.1 "recovery" 9999 9999 9999 9999 9999 9999 9999
"Sanddunes floodduration" "Sd_fdur" 0 9999 1 2 "recovery" 9999 9999 9999 9999 9999 9999 9999
```

The first line is not considered by the model but indicates the file contents.

Each following line informs about the vulnerability of a receptor, space is used to delimitate the variables and quotations are used for string variables. Each line should provide the following variables:

A comment in quotations introducing the considered vulnerability indicator (e.g. “dd curves for prop anytype flooding”): not used in the model but required;

A CodeHazardThresholds in quotations: the code comprises two elements separated by an underscore. The first element is the referent code for the receptor (see receptor vulnerability code). The user is free to use a code of their choosing provided that it matches those used in the different receptor shapefiles. This is not the case for the hazard code. The following code should be used if applicable (i.e. the hazard is considered in the assessment): fd (flood depth), fdv (flood depth-velocity), fdur (flood duration), od (overwash depth), odv (overwash depth-velocity), odur (overwash duration), er (erosion);

4 numbers indicating the threshold value for Low, Medium, High, Very High impact. If a threshold is not applicable, a value of 9999 should be used. For instance, Very High impact is not considered for flood damages and Low and Medium impact for building collapse;

"Recovery" comments are used only to improve readability, e.g. describing what the value represents;

4 values indicating the recovery time value. Each value represents the recovery time value associated with the threshold value of impact in sequence. 9999 can be used to indicate that a value is not applicable for the considerer threshold. Values are mainly expected for non-residential properties and infrastructure assets.

Insur_forINDRA.txt

The file provides insurance information (impact and insurance related financial recovery).

The first line of the input file is not considered by the model but indicates the file contents.

Each following line informs about the insurance of an area (the receptors are related to the area within the receptor shapefile), a space is used to delimitate the variables and quotations are used for string variables. Each line should provide the following variables:

A comment in quotations introducing the considered insurance and sector area (e.g. "dd curves for prop anytype flooding"): not used in the model but required;

An Area_InsuranceCode in quotations: the code comprises two elements, separated by an underscored. The first element is the referent code for the area and the receptor type-category (see receptor insurance code). The user is free to use a code of their choosing provided that it matches those used in the different receptor shapefiles. This is not the case for the insurance code. The following code should be used if applicable (i.e. the hazard is considered in the assessment): NoI_F, NoIself, NoIScomp_F, NoILcomp_F, PartI_F, FullI_F, BNoI_F, BMNCself_F, BNoIself_F, Bstateown_F, BPartI_F, BFullI_F (please refer to insurance section for equivalent. A similar series is used for erosion (E replace the F));

A value between 0 and 1 for the proportion of properties with the insurance scheme;

4 numbers indicating the financial impact for Low, Medium, High, Very High impact. If a threshold is not applicable, a value of 9999 should be used;

```
Comments Area_InsuranceCode RatioOfPropertyUnderTheInsurance HazardlowImpact HazardMedImpact HazardHighImpact HazardVeryHighImpact
"theNorthAreaforHouseholds_withnoinsurance_Flooding" "ResNorthin_NoI_F" 0.15 2 3 4 5
"theNorthAreaforHouseholds_withSelfinsurance_Flooding" "ResNorthin_NoIself_F" 0.0 1 2 3 4
"theNorthAreaforHouseholds_withSmallGovCompensation_Flooding" "ResNorthin_NoIScomp_F" 0.0 1 2 3 4
"theNorthAreaforHouseholds_withLargeGovinsurance_Flooding" "ResNorthin_NoILcomp_F" 0.0 1 1 2 3
"theNorthAreaforHouseholds_withPartinsurance_Flooding" "ResNorthin_PartI_F" 0.355 1 2 3 4
"theNorthAreaforHouseholds_withFullinsurance_Flooding" "ResNorthin_FullI_F" 0.495 1 1 1 2
"theNorthAreaforBusiness_withNoinsuranceOrSelfinsuredsmall_Flooding" "BusNorthin_BNoI_F" 0.1 2 3 4 5
"theNorthAreaforBusiness_withNoinsuranceOrSelfinsuredLarge_Flooding" "BusNorthin_BMNCself_F" 0.0 1 1 1 2
"theNorthAreaforBusiness_withNoInsurselfinsur_Flooding" "BusNorthin_BNoIself_F" 0.1 1 2 3 4
"theNorthAreaforBusiness_StateOwned_Flooding" "BusNorthin_Bstateown_F" 0.0 1 2 3 4
"theNorthAreaforBusiness_withPartinsurance_Flooding" "BusNorthin_BPartI_F" 0.65 1 1 1 2
"theNorthAreaforBusiness_withFullinsurance_Flooding" "BusNorthin_BFullI_F" 0.15 1 1 2 2
"theNorthAreaforHouseholds_withnoinsurance_Erosion" "ResNorthin_NoI_E" 0.15 9999 9999 9999 5
"theNorthAreaforHouseholds_withSelfinsurance_Erosion" "ResNorthin_NoIself_E" 0.0 9999 9999 9999 4
"theNorthAreaforHouseholds_withSmallGovCompensation_Erosion" "ResNorthin_NoIScomp_E" 0.0 9999 9999 9999 4
"theNorthAreaforHouseholds_withLargeGovinsurance_Erosion" "ResNorthin_NoILcomp_E" 0.0 9999 9999 9999 3
"theNorthAreaforHouseholds_withPartinsurance_Erosion" "ResNorthin_PartI_E" 0.355 9999 9999 9999 4
"theNorthAreaforHouseholds_withFullinsurance_Erosion" "ResNorthin_FullI_E" 0.495 9999 9999 9999 3
"theNorthAreaforBusiness_withNoinsuranceOrSelfinsuredsmall_Erosion" "BusNorthin_BNoI_E" 0.1 9999 9999 9999 5
"theNorthAreaforBusiness_withNoinsuranceOrSelfinsuredLarge_Erosion" "BusNorthin_BMNCself_E" 0.0 9999 9999 9999 2
"theNorthAreaforBusiness_withNoInsurselfinsur_Erosion" "BusNorthin_BNoIself_E" 0.1 9999 9999 9999 4
"theNorthAreaforBusiness_StateOwned_Erosion" "BusNorthin_Bstateown_E" 0.0 9999 9999 9999 4
"theNorthAreaforBusiness_withPartinsurance_Erosion" "BusNorthin_BPartI_E" 0.65 9999 9999 9999 2
"theNorthAreaforBusiness_withFullinsurance_Erosion" "BusNorthin_BFullI_E" 0.15 9999 9999 9999 2
```

<u>SC_forINDRA.txt</u>

The file provides information on the supply chains (business disruption impact).

The first line of the input file is not considered by the model but indicates the file contents.

Each following line until the line "LINKAGE" informs on the different supply nodes, space is used to delimitate the variables and quotations are used for string variables. Each line should provide the following variables:

The supply node code in bracket;

A description of the supply node in bracket;

The type of node in bracket: "S" for supply, "D" for Demand;

An importance weight for the node: a value;

The capacity of the node not case study dependant (e.g. not informed by one of the receptors);

After the line "LINKAGE" each line should inform about the node's relationships by providing the supplier node code and then the supplied node code;

```
"Supplynode" "description" "type" "ImportanceWeight" "OutBoundaryCapacity"
"A" "ProducerGoodA" "S" 1 0
"B" "Distributor" "S" 1 10
"C" "ProducerGoodA" "S" 1 10
"D" "ServicesD" "S" 3 10000
"E" "customers" "D" 0 20
"F" "Site Attractiveness" "A" 0 80
"LINKAGE"
"A" "B"
"C" "D"
"B" "D"
"D" "E"
"F" "E"
```

5.4 Appendix D

Examples of stakeholders' engagement techniques for MCA
Dr Nico Stelljes, Ecologic Institute

World Café

Focusing on the facilitation of a collaborative dialogue and the sharing of knowledge, the World Café method creates an ambiance of a café, where participants discuss questions or issues provided in small groups. These small groups (usually 4 to 8 persons) are grouped around a café table and hosted by a team member. The table is covered with a table cloth; which the participants are asked to write their ideas on. To imitate a café atmosphere, snacks and drinks should be available and also background music (for example classical music) can improve the atmosphere. At regular intervals the participants move to a new table where a different topic is discussed. The host remains at the table and summarizes the results to the new table guests. The new starting conversation can be based upon the discussions from the former participants. At the end of the process, the main ideas are summarized in a plenary session and follow-up possibilities are discussed.

The method is particularly useful to engage larger groups of workshop participants in a dialogue process with the goal to generate input, share knowledge and discuss different options. It also helps to deepen the relationships between the participants and creates a meaningful interaction between the workshop hosts and audience. The method is less suited for groups containing fewer than 12 persons, where the conveyance of one-way information with an already determined solution or answer is the objective. For the success of the method it is important not to under estimate the importance of the café atmosphere. By creating a feeling of both informality and intimacy, the outcome of the café can be very creative and productive.

Fishbowl

To facilitate a dialogue between experts, the fishbowl method can be an appropriate method. For the set-up, a small circle of chairs is surrounded by a larger circle of chairs. In total, these numbers of chairs should be slightly more than participants, to ensure mobility. In the inner circle, a small number for experts (the fish) discuss a series of directional questions. In the outer circle (the bowl), the participants observe quietly the discussion in the inner circle. The inner circle is the only place for discussion and contributing. There are two different kinds of fishbowls: the open and the closed format.

In the open fishbowl, several (2 to 3) empty chairs are placed in the centre circle. After the first discussion, any member of the audience can join the discussion by occupying an empty chair at any time. For balancing reasons one 'fish' must leave the inner circle when a free seat is taken. The discussion continues with participants frequently entering and leaving the Fishbowl. It is possible to join the inner circle more than one time.

The closed format, all chairs are occupied and participants are not allowed to join and leave the circle. Only when the moderator signals, a complete change of participants will take place and this change is determined beforehand. The new group will discuss the previous issue. There will be a few changes so all participants will be at some point part of the inner circle and therefore contributing to the discussion. This approach is only appropriate when all participants have at least some level of prior knowledge of the subject.

The outer circle must always observe the discussion silently but should prepare questions and comments so they can move into the inner circle. When the time is over, or all topics have been covered, the inner circle is removed and the floor is open for a debriefing. The moderator will review key points, reflect on interesting comments and the groups feelings regarding particular issues.

The fishbowl method should be planned for 1.5 hours including 10 minutes of introduction, 20 minutes of debriefing and 60 minutes for the actual fishbowl discussion.

Focus Group

To obtain information about various people's preferences and values in smaller groups (4-12 persons), a focus group might be a useful method. It is a planned discussion, facilitated by a skilled moderator. A focus group can be seen as a combination of a focused interview and a discussion group. It is useful for initial concept exploration and generating creative ideas.

To implement a focus group, which usually lasts for a few hours, firstly the questions to be addressed must be determined. The moderator leads the group through a semi-structured discussion to draw out the views of all participants and then summarises the main issues. To ensure a productive discussion, a friendly and respectful atmosphere has to be created.