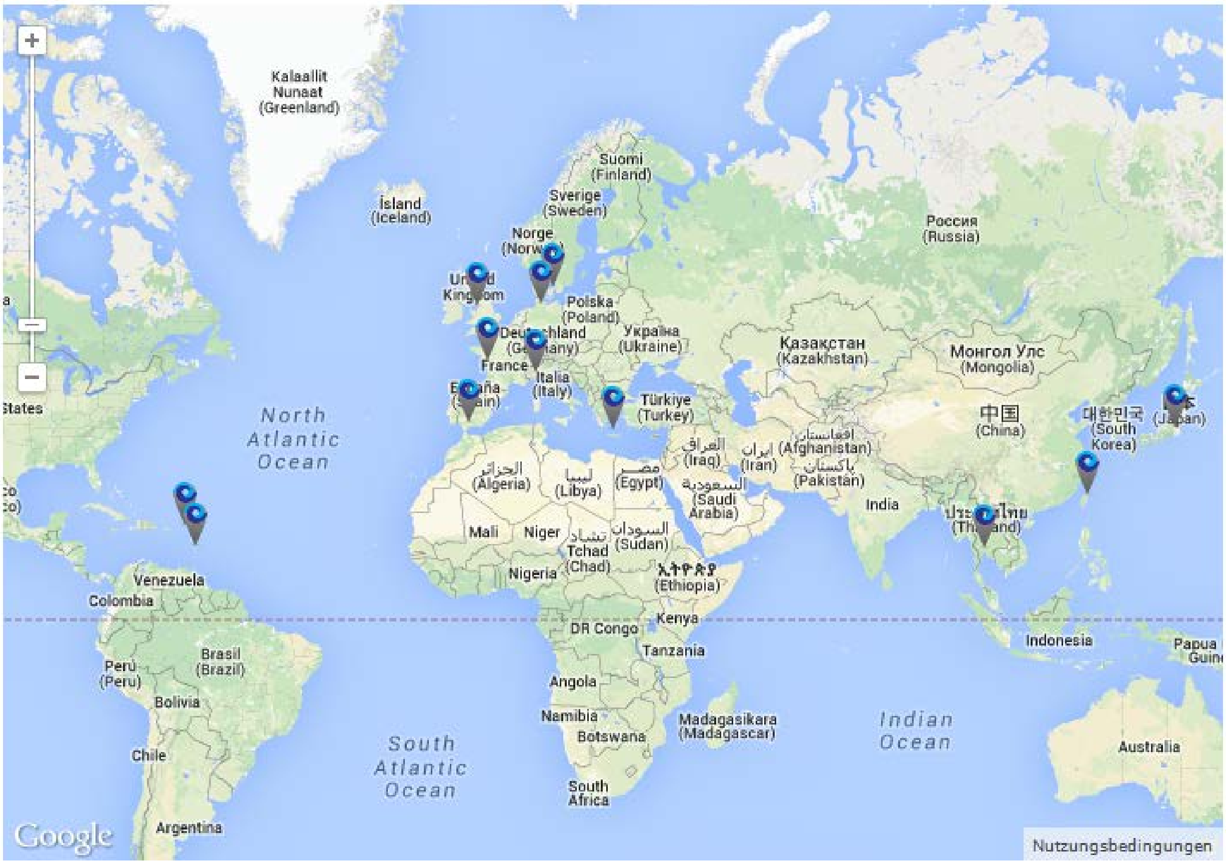
pearl

Preparing for Extreme And Rare events in coastal regions

D6.3 Report

Synthesis report evaluating the outcomes in all case studies and cross-linking of findings



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Abstract (for dissemination, 100 words)	The report summarises the research activities in the European case studies as well as in the international case studies. It goes beyond a mere summary of the work done but also delivers an evaluation of the outputs based on their potential tod uptake of the PEARL methodology for holistic risk management and governance in the study areas as well as their cross-linking.
Keywords	Holistic risk management, case study areas, cross-linking

Disclaimer

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Summary

The present report “Synthesis report evaluating the outcomes in all case studies and cross-linking of findings” (D6.3) has been produced as a deliverable of the Work Package 6 on Case Study Areas. This work package aims at enabling efficient managment anf conduction of the flood risk assessment and management tasks (given in WP1-WP5) to be performed in the case study areas.

The report summarises the research activities in the European case studies as well as in the international case studies. It goes beyond a mere summary of the work done but also delivers an evaluation of the outputs based on their potential tod uptake of the PEARL methodology for holistic risk management and governance in the study areas as well as their cross-linking.

In this report, the work performed in each case study area is briefly described and is linked to the reports and publications where the reader can find more information. Research activities and available results in the relevant work packages have been summarised.

Although the presented case study exhibit a high variety of the challenges and the key issues of concerns, a variety in the deployed methodologies and tools, their common ground is a step forward the holistic view on the flood risk and its consideration for the development of the flood risk mitigaiton strategies in the selected areas.

Contents

1 Introduction

This report reflects the main outputs and achievements in the PEARL case study areas to uptake the holistic flood risk management. It outlines the work performed in the case study areas with the main lessons learned. Further, this report cross-links the main outcomes from the cases study areas and assesses their potential for further upscaling and exploitation.

The PEARL holistic risk management approach is based on the following three premises:

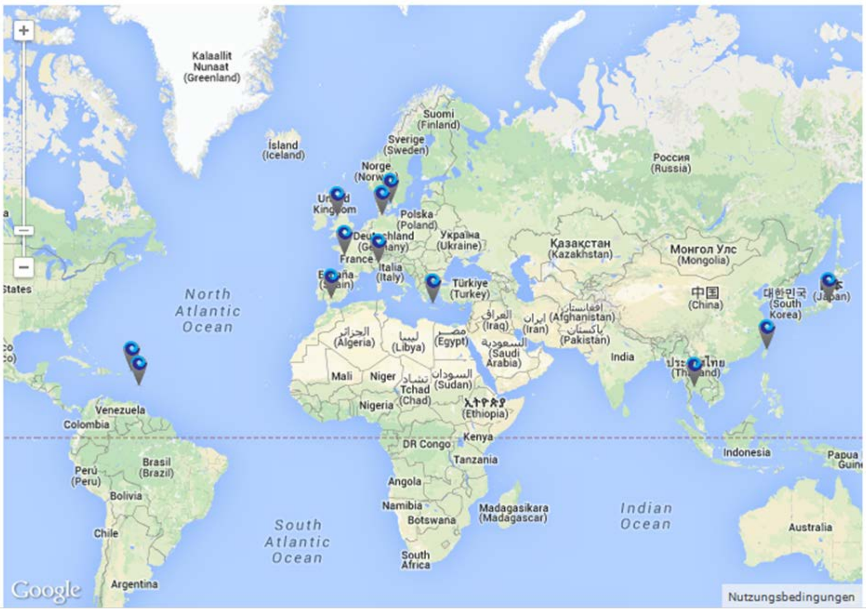
- Risk management is a sociotechnical process, which cannot be studied by separating social and technical processes (i.e., parts) and designing them in isolation.
- The relationships between the parts are mutual, emergent, dynamic and nonlinear and are guided by the self-organising capacities of each part and the (unpredictable) dynamics of their coevolution.
- The process of strengthening any kind of flood risk mitigation measure (such as forecasting, prediction and early warning capabilities) should be understood and studied within the context of the larger flood management process which depends on interactions with other sub-processes at different levels.

In order to demonstrate and test the potential for implementation of this approach and the associated methods and tools developed in PEARL, a portfolio of case study areas has been selected covering a range of geographic and climatic conditions, data availability and quality, extreme events typologies, existing governance structures and stakeholder participation activities.

The overview and the geographic spread of the PEARL case studies is given in Table 1.

Table 1 Overview of the PEARL Case study areas

Case study area		
1.	Greve	Denmark
2.	The Elbe Estuary	Germany
3.	Les Boucholeurs	France
4.	Genova	Italy
5.	Marbella	Spain
6.	Rethymno	Greece
7.	Tainan	Taiwan
8.	St. Lucia	The Caribbean
9.	St. Maarten	The Caribbean



1 0.	Ayutthaya	Thailand	*Figure 1 Geographic spread of the PEARL case study areas*

The case studies had different baselines (as summarised in the corresponding sections in this report) and the main challenge of PEARL has been to identify, define and demonstrate the set of methods and tools that can contribute to the implementation and adoption of the holistic approach in flood risk management.

Further, the level of this implementation has been analysed, evaluated and cross linked based on the following key points:

1. Which of the implemented methods and tools were successful, which one not? What is/might be the reason for it?
2. Acceptance of the stakeholders (usability, clarity, reliability, accessibility of the PEARL products assessed by the key stakeholders)
3. What is the main achievement in the context of the PEARL holistic approach in the study area i.e. how PEARL advanced the existing flood risk management practices including the legacy aspects
4. Transferability and scalability of the approaches, methods and tools

2 Case Study – Greve, Denmark

2.1 A brief description of the case study area

The coastal area of Greve Municipality in Eastern Denmark is a case study area in the PEARL project. It is a sub-urban area located 20 km southwest of the Danish capital, Copenhagen. The municipality is around 60 km^2 in size, with 9 km of coast to the southeast bordering the Baltic Sea at Køge Bay (Figure 1).

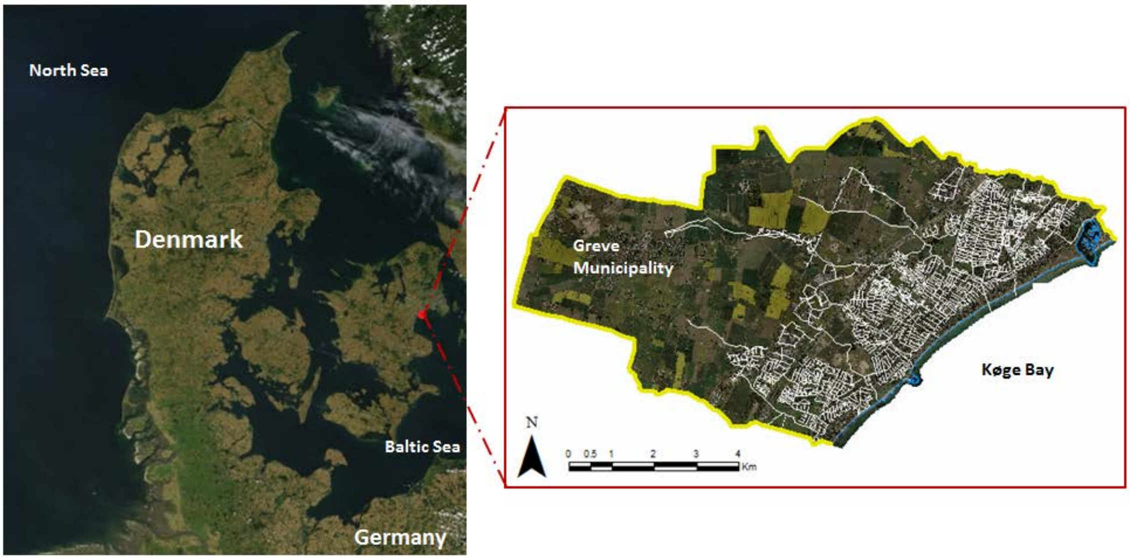


Figure 2 Location of the Greve Case Study Area in eastern Denmark

The case study area is centred on the coastal part of Greve. The coast is the most densely built-up region of the municipality, characterized by relatively flat and low-lying terrain with elevations of just between 2-6 m MSL (Figure 2).

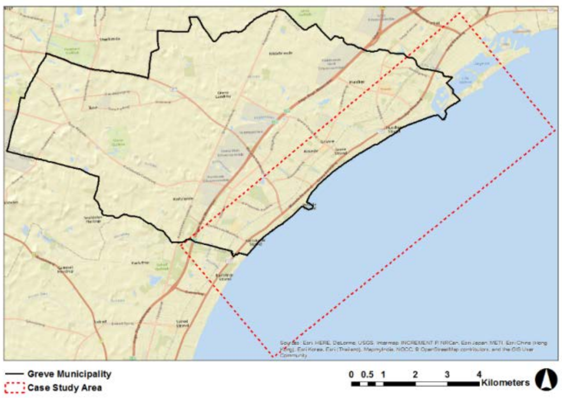


Figure 3 Coverage of the case study area (red dotted line) within Greve Municipality

The coastal area along Køge Bay, with its sandy beaches and natural ecosystems, is highly attractive to local and tourist populations alike, leading to the development of numerous holiday homes and residential houses in the area. In addition, Greve is part of an industrial area in the south of

Copenhagen. However, Greve is considered one of the most flood-prone areas in Denmark (EC, 2009). It is under threat of flooding from:

- Extreme rainfall
- Storm surges

Greve has been seriously affected by flooding due to extreme rainfall in the past – in 2002, and again in 2007 (Greve Kommune, 2007; Sto. Domingo et al., 2010). The region is also at risk from coastal flooding due to storm surges and general sea level rise because of its location in Køge Bay (Vestergaard, 2011). There have been 28 documented high sea level events in Køge Bay with magnitudes greater than 1.52 m—the highest water level observed in the area in 1955-2002. The highest sea level ever recorded in Køge Bay was in October 1760 estimated to have reached 3.7 m. In addition, in November 1872, sea levels reached 2.8 m causing widespread storm surge flooding in the area (Madsen, 2008; Colding, 1881).

Within the project aim of developing a holistic risk reduction framework against extreme events in coastal regions, Greve was used as a case study area under several Work Packages working towards this central objective.

In Work Package 2 –Understanding formation of hazards under extreme events, Greve was used as a test and application area to:

- (O2.5) Develop a set of extreme event scenarios, and to test the framework, concepts, and tools developed for estimation of hazards under extreme events.

Also, under Work Package 4 –Flood forecasting and early warning systems for coastal regions, Greve was used as a case area to:

- (O4.1) Improve the speed of state-of-the-art modelling tools for early warning, in order to achieve sufficient lead times for emergency actions.
- (O4.2) Develop new, and customise existing methods and concepts for fast flood simulations in areas with combined flood risks.
- (O4.3) Develop and evaluate methods for uncertainty propagation and its impacts on early warnings and real-time decision-making.

2.2 Understanding the formation of hazards under extreme events (WP2)

Under this work package on understanding the formation of hazards under extreme events (WP2), several tasks were performed around the Greve case area, such as the development of new methods to simulate extreme event drivers/phenomena, and modelling of individual and concurrent coastal flood hazards under extreme event conditions.

2.2.1 Description of the key activities performed in the case study area

A new coupled global (GCM) and regional (RCM) climate model was developed and used to investigate regional sea level rise and changes in extreme sea level event statistics in European

coasts, including Køge Bay in Greve. The output of the climate model are subsequently used to drive high-resolution models to analyse changes in extreme storm events.

A high-resolution atmospheric model was developed, which will be used to investigate extreme precipitation events for a few of the PEARL case study areas, including Greve. The variability and changes of rainfall and storm surge frequencies will also be analysed in Greve using observed precipitation data.

As part of the activity on developing extreme event scenarios, a method for generating storm surge hydrographs, based on statistical analysis, was developed. The method was then implemented in a storm surge simulator, which can be used to generate storm surge hydrographs of various return periods. In addition, an integrated hazard-modelling framework focusing on wave modelling has been developed for Køge Bay in Greve.

Finally, flood hazard modelling considering extreme rainfall and sea surge events, occurring individually and concurrently, was performed in the Greve case study using a coupled 1D/2D flood modelling, as well as an open source integrated 2D/3D adaptive mesh modelling approach (PEARL, 2017c).

2.2.2 Lessons learned from the case study work

Data availability was a crucial consideration in the viability of an area as a test case in the development of tools and methods for modelling extreme event drivers, and subsequent analysis of resulting flood hazards. Long periods of atmospheric and sea level data were required, which were not uniformly available among the various case study areas in the project.

In addition, the timing of the various tasks within the work package was a challenge to integrated/holistic application of the different methods and tools developed. The work package spans both the phenomenon/driver modelling and hazard modelling stages, wherein results from one stage fed into the other within the assessment process. Thus, some task delays were exacerbated as they affected modelling stages down the line. Boundary input from other sources/studies, were then sometimes used for timely development and test application of some methods, e.g. flood hazard modelling.

2.3 Flood forcasting and early warning systems for coastal regions (WP4)

Case study work for Greve under this work package centred on the development, implementation, and enhancement of an online real-time coastal flood forecasting system for the area (Figure 3). Greve was used as a test case in the development of methods and techniques for online flood forecasting, achieving faster model simulations, and considering uncertainty in flood forecasting.

2.3.1 Description of the key activities performed in the case study area

Greve was a test application area for modelling tools and techniques for online flood forecasting developed in the PEARL project. These techniques have been reported in Deliverable D4.1 “Report on novel online modelling tools and techniques for early warning systems” (PEARL, 2016).

An online site was built for the case area, where flood map and flood level forecasts are routinely computed and published (see Figure 3). The operational system employs a hydrodynamic flood model that calculates potential flooding in the area using forecasted rainfall and sea water levels.

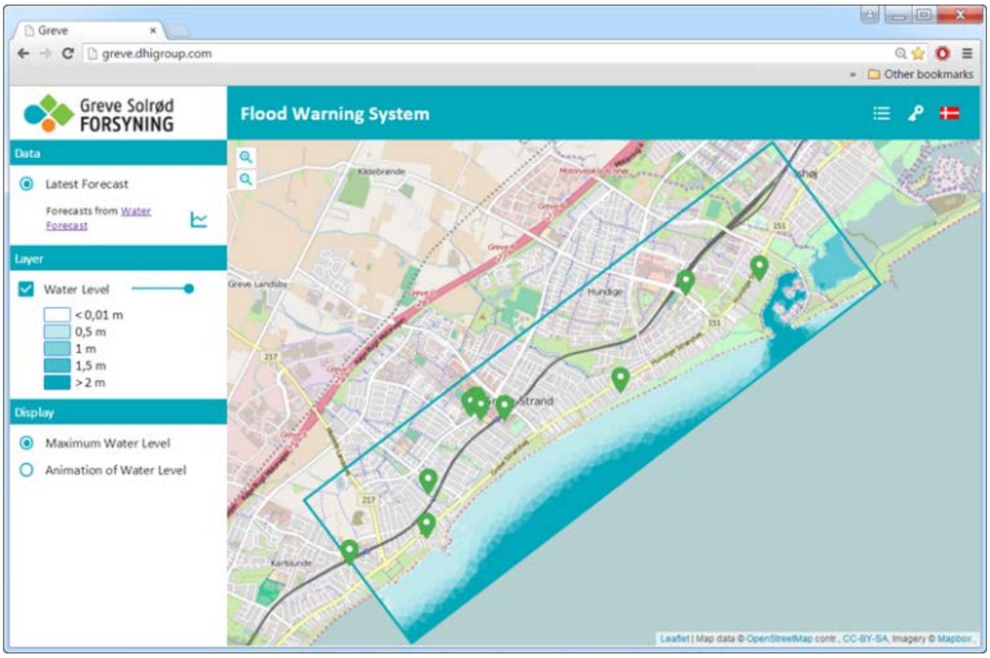


Figure 4 Homepage for the online coastal flood warning system in Greve, Denmark (www.greve.dhigroup.com) (Source: PEARL, 2016).

The flood model operating behind the forecasting site has gone through several iterations of model types and setups for optimisation geared towards achieving a fast and accurate flood model appropriate for real-time forecasting. The following model speed-up techniques were tested and evaluated in the Greve case study:

- Modification of computational grid type
- Optimisation of computational grid size
- Parallelisation of computations
- Use of Graphics Processing Unit (GPU) computing

The first two techniques relate to computational load optimisation, while the last two concern maximisation of hardware capabilities. These techniques were described in Deliverable D4.2 “Guidelines on achieving faster simulations for early warning” (PEARL, 2017a). The report contains details on further analysis and description on models, and applied methodologies along with discussion on extracted results.

A method for probabilistic flood forecasting and mapping, which considers the various uncertainties in the hazard assessment process, has also been developed, and will be implemented in the Greve flood-forecasting site as additional enhancement. This activity relates to the task of developing advanced uncertainty methods and tools for early warning (T4.3), which has been reported in the Deliverable D4.3 “Guidelines for uncertainty propagation analysis”.

2.3.1 *Lessons learned from the case study work*

A variety of options is available for establishing a real-time forecasting system for an area. Each component of a typical system (i.e. Data Acquisition, Flood Forecasting, Decision Support, and Dissemination (PEARL, 2016)) may be customised according to forecasting needs, stakeholder concerns, and data availability, and can thus be as streamlined or as sophisticated as appropriate. In Greve, good availability of data with respect to forecasted model boundary inputs as well as flood model setup requirements allowed the development of a coupled 1D/2D hydrodynamic coastal flood model for the system. The model simulates spatially distributed flows and water levels in 1D (i.e. underground sewers) and 2D (i.e. urban surface), as well as flow exchanges between the two systems, and allows analysis of individual as well as concurrent hazards that are highly relevant for urban coasts.

Application of several speed-up techniques also enabled the use of this type of integrated 1D/2D flood model in real-time forecasting applications. Information dissemination needs in the case area were limited following stakeholder requirements. Therefore, although facilities for automatic dissemination of forecast results were in place, the case study focused more on optimisation of the hydraulic forecast model with respect to simulation speed and accuracy, and on the development of a method for considering model uncertainty in the forecast system and result presentation.

2.4 Concluding remarks

The case study of Greve is a very data rich case, which made it possible to carry out many new development and analyses. I.e. the case was found very suitable for developing and improving new tools for early warning systems for storm surges, and the lead-time is approx. one day, which is rather good for preparation of an emergency response. The system was tested during the storm in January 2017, where the prognosis for the storm surge water level was within the predicted uncertainty (15 cm). Further, the Greve case was found very suitable for developing methods for uncertainty propagation and with analyses of its impacts on early warnings and real-time decision-making.

Further, Greve was used for the development of new methods to simulate extreme event drivers/phenomena, and modelling of individual and concurrent coastal flood hazards under extreme event conditions. Research have been carried out concerning:

1. A new coupled global (GCM) and regional (RCM) climate model was developed and used to investigate regional sea level rise and changes in extreme sea level event statistics in European coasts, including Køge Bay in Greve.

2. A high-resolution atmospheric model was developed, which will be used to investigate extreme precipitation events for a few of the PEARL case study areas, including Greve.

3. As part of the activity on developing extreme event scenarios, a method for generating storm surge hydrographs, based on statistical analysis, was developed. The method was then implemented in a storm surge simulator, which can be used to generate storm surge hydrographs of various return periods.

4. Finally, flood hazard modelling considering extreme rainfall and sea surge events, occurring individually and concurrently, was performed in the Greve case study using a coupled 1D/2D flood modelling, as well as an open source integrated 2D/3D adaptive mesh modelling approach.

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As for item 1-4 above the value of the research still needs to be compared to traditional methods applied in Greve.

3 Case Study – Elbe Estuary / Hamburg, Germany
(contribution: TUHH)

3.1 A brief description of the case study area

The German case study area is located in the Estuary of the River Elbe with the emphasis on its largest urban area being the City of Hamburg (Figure 4).

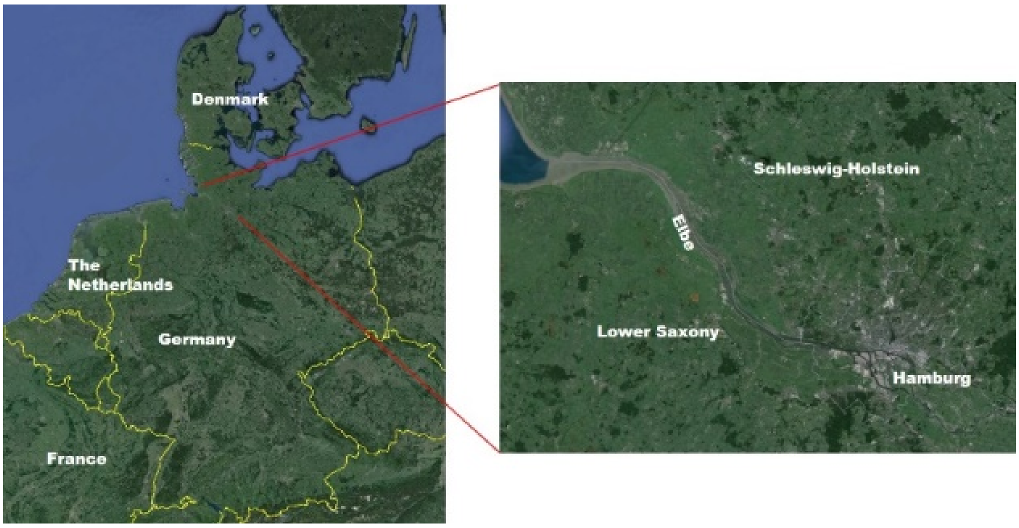


Figure 5: Location of the Elbe Estuary and the City of Hamburg

The case study area encompasses the tidal influenced section of the Elbe (tidal Elbe) between the weir in Geesthacht (Elbe km 586) and the navigational mark Kugelbake at Cuxhaven (Elbe km 728) as depicted in *Figure 5*. This section is called Low Elbe (*Unterelbe*) and has a length of 142 km.

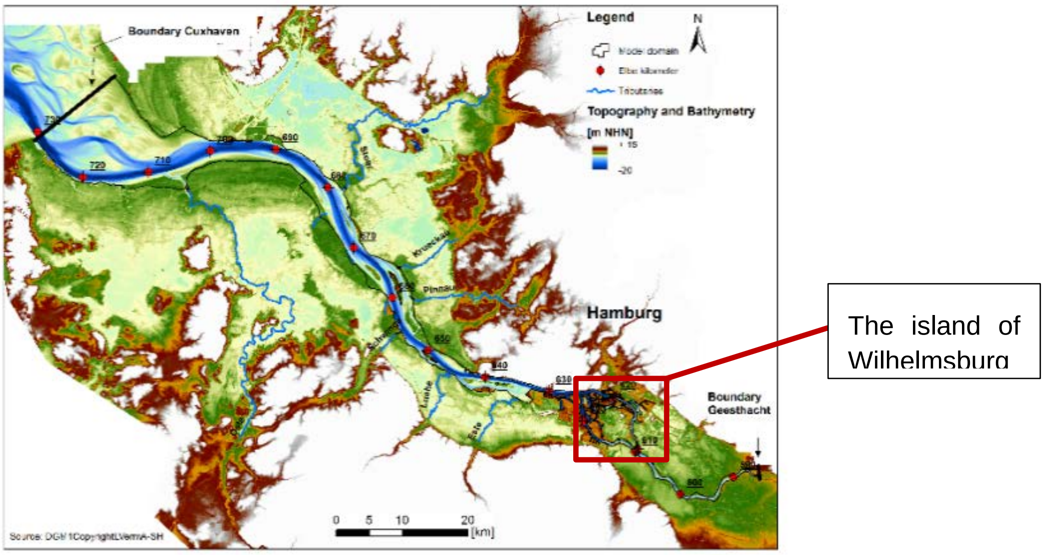


Figure 6: Overview of the Elbe estuary/Hamburg case study area

In the Elbe Estuary, the most significant urban area is the Free and Hanseatic City of Hamburg, located in the North German Plain approx. 100 km upstream of the mouth of the river Elbe in the North Sea (Figure 4). Hamburg counts approx. 1.76 Mio inhabitants (31.12.2014) covering the total urban area of 755.3 km², resulting in the population density of 2,334 inhabitants/km² (31.12.2014).

Due to its low terrain elevations, the City of Hamburg is prone to flooding due to storm surges or even normal high tides. In the island of Wilhelmsburg, which is a densely populated (1532 inhabitants/km²) area located between the Norderelbe and the Süderelbe (indicated in *Figure 5*), the terrain elevation is below the mean tidal level. Without its ring dikes the island of Wilhelmsburg would be inundated twice a day.

The climatic and meteorological conditions of the metropolitan area of Hamburg and the Elbe estuary are significantly characterized by the proximity of the North Sea and the Baltic Sea with their maritime weather influences. Nevertheless, continental climate conditions get more important with rising distance from the North Sea and in south-easterly direction.

From a climatic, resp. meteorological point of view the case study areas covers both coastal areas and inland areas. In that sense, both the wind conditions over the North Sea in the German Bight and wind condition of the inland area have to be considered for the analysis of the extreme hydro-meteorological events. In general, wind velocities in coastal areas are higher than in inland areas. The annual average wind velocity on the island Helgoland (in the North See) is 8m/s, whereas the annual average wind velocity decreases to 4,5 m/s in Hamburg. Additionally, wind velocities vary with the seasons. In the winter season, wind velocities are 1 m/s - 2 m/s, on the island of Helgoland more than 3 m/s higher than the wind velocities in summer (Rosenhagen and Schatzmann, 2011).

As the wind velocities over the German Bight are high during the winter season, storms are likely to occur. In case of westerly to north-westerly wind directions, strong storm winds can create extreme storm surges moving upstream into the Elbe estuary (Gönnert, 2003). Storm winds creating storm surges in the North Sea evoke from extratropical cyclones, developing along the polar front over the Atlantic Ocean. The strength of the storm winds are depending on the temperature difference of the air masses of the subtropical high pressures belt and the subpolar trough. The higher the temperature differences the stronger the storm winds (Weischet, 2002).

Before PEARL, the level of the development of the individual tools and their application in the case study area was at a high level. However, within PEARL a major improvements have been achieved that are paving the road to the holistic flood risk management in the Elbe Estuary.

For the first time the complexity of the flood situation in the Elbe estuary was looked at through a FORIN lens, the early warning system has been upgraded to enable the spatial distribution of the forecasted water level involving the key stakeholders, the tailored approach to stakeholder involvement has been applied to pursue the necessity of the holistic approach for the whole Elbe Estuary. The existing flood risk assessment procedures and results have been extended to analyse the temporal evolution of the flood risk, focusing on an urbanised and intensively developing area of Wilhlemsburg.

3.2 Understanding the formation of vulnerability and risk in coastal regions (WP1)

3.2.1 Description of the activities performed in the case study area with the key outcomes

The approach taken in this study follows the method developed by UNU-EHS and adapted by the World Risk Index. The methodology, however, is modified with exposure and risk excluded and not measured for

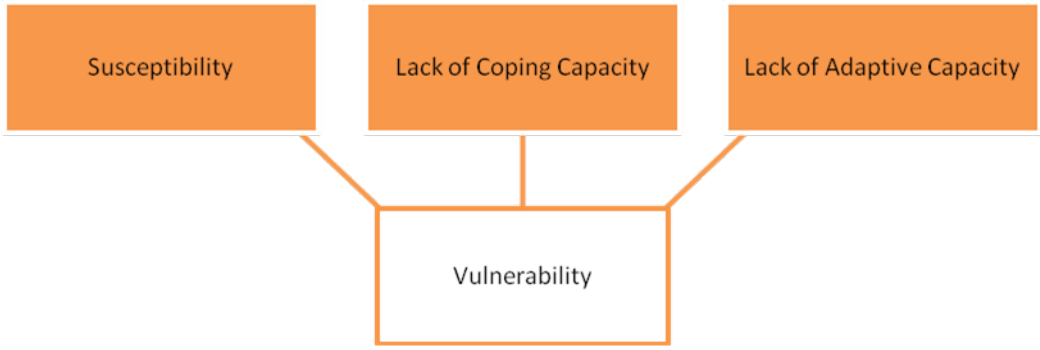


Figure 7: Measuring Social Vulnerability

Limiting the focuses to the internal risk factor, vulnerability, the susceptibility, lack of coping capacity and lack of adaptive capacity indices has ben calculated, which in turn will result to the vulnerability of an area. Further investigation may be done to compute for the risk index, by analysing the exposure to natural hazard and combining it with the vulnerability results.

All three components, susceptibility, lack coping capacity and lack of adaptive capacity, had been calculated separately to assess the vulnerability of a Wilhelmsburg (Figure 7), a sub area in the Elbe Estuary in the City of Hamburg. Then to derive the vulnerability, susceptibility, lack of coping capacities and lack of adaptive capacities were aggregated using two different formulas.

In the first approach, the calculation has been performed with equal weighting of the components of susceptibility, lack of coping capacities and lack of adaptive capacities, while in the second the more weight has been placed on the first two components – susceptibility and lack of coping capacity. The reasoning for this is that there are more contributing indicators for these two components, compared to lack of adaptive capacity, which only has the indicator Green Infrastructure. The first formula consequently gives 33.3% of its weight purely to Green Infrastructure, which is a large percentage of the result for a single indicator to carry. The largest percent that any other indicator weighs is 11% (Turnout of Local Elections and Economic Coverage). It was decided to modify the percentage of each component to balance the weight contribution per indication. Ninety percent is placed to the first two components, with 45% each for susceptibility and lack of coping capacity, while lack of adaptive capacity receives 10% of the weight. Thus, analysis for both formulas were done and compared with each other (see also Table 1).

Figure 8: The River Island of Wilhelmsburg (U.S. Geological Survey und NASA 2011)

Table 2 Indicator Contribution per Vulnerability Formula

	Vulnerability Formula 1	Vulnerability Formula 2
Susceptibility	*33%*	*45%*
Demography (50%)		
Vulnerable Age Groups (25%)	4%	6%
Elderly Living Alone (25%)	4%	6%
Population Density (25%)	4%	6%
Language Ability/ Origin (25%)	4%	6%
Poverty & Income (50%)		
Dependency Ratio (50%)	8%	11%
Unemployment Rate (50%)	8%	11%
Lack of Coping Capacity	*33%*	*45%*
Government & Authorities (33.3%)		
Turnout at Local Elections (100%)	11%	15%
Social Networks (33.3%)		
Households with Children (50%)	6%	7%
Households with Single Parents (50%)	6%	7%
Economic Coverage (33.3%)		
Social Security Recipients	11%	15%
Lack of Adaptive Capacity	*33%*	*10%*
Environmental Status (100%)		
Green Infrastructure (100%)	33%	10%

Total Vulnerability	100%	100%

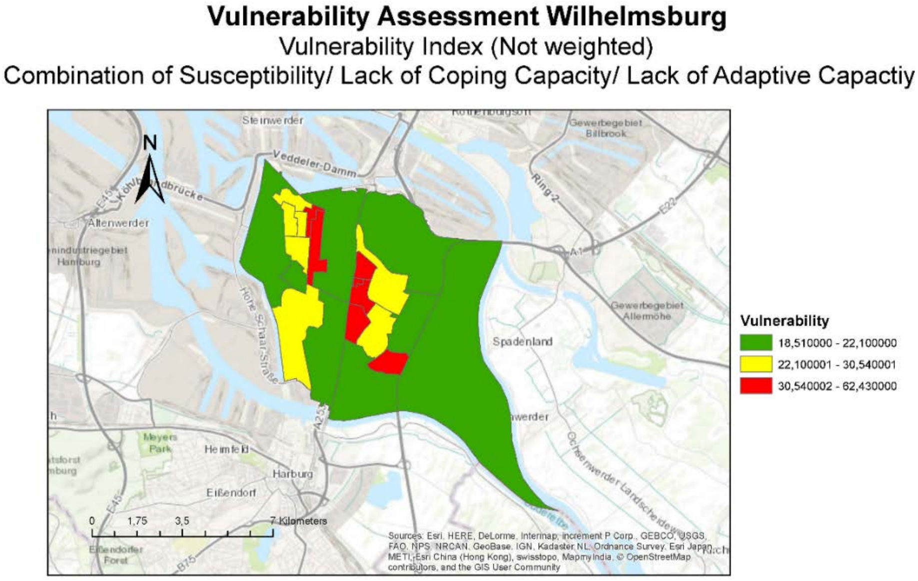


Figure 9: Vulnerability Map (with equal weights to Susceptibility, Lack of Coping Capacity and Lack of Adaptive Capacity)

The second vulnerability map illustrates the second formula used, where Susceptibility, Lack of Coping Capacity contribute 45% each and Lack of Adaptive Capacity, contribute 10% in computing for the vulnerability, as seen in Figure 45. Comparing the two different results, it can be seen that the areas with low vulnerability maintain, regardless of which formula was used. As for the areas with medium and high values, most of the areas maintain with the formula change, except for statistical areas 16009, 16010, 16011, 16013 and 16014 – either moving from medium to high vulnerability or from high to medium vulnerability.

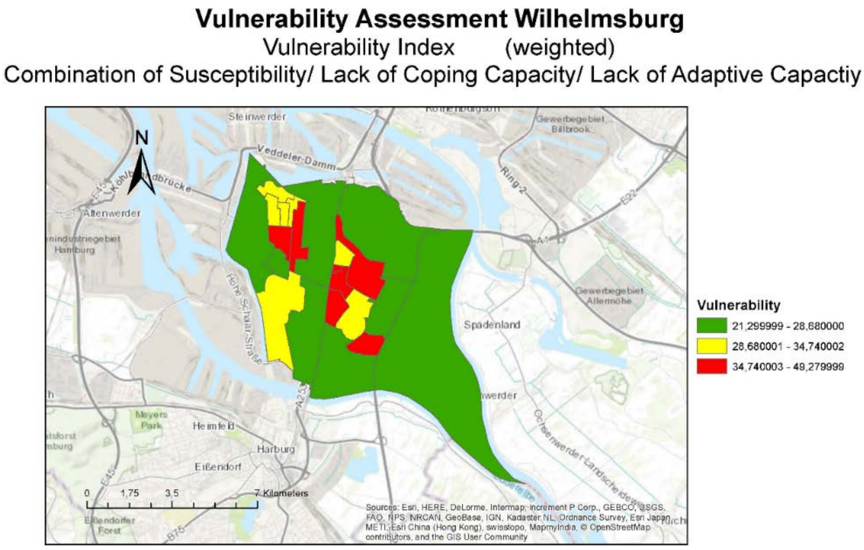


Figure 10: Vulnerability Map (45% to Susceptibility, 45% to Lack of Coping Capacity and 10% Lack of Adaptive Capacity)

Although it may appear at first glance that majority of the areas are under the low vulnerability group, the visual aspect of the spatial vulnerability map may be misleading. It could seem a greater bulk of Wilhelmsburg has low vulnerability, area-wise, with the green colour standing out. However, when population is taken into consideration and ranked, the results show that only 16.3% of the total population of Wilhelmsburg fall under the low vulnerability category. For the medium and high vulnerability, the values change depending on which formula is used. But when summed, the percentage of the population belonging under the medium and high vulnerability combined is at 83.7%.

Table 3 Percentage of the Population under Low, Medium, High Vulnerability

Vulnerability to Population	**Vulnerability Formula 1** (Equal weight per component)	**Vulnerability Formula 2** (45% to Susceptibility, 45% to Lack of Coping Capacity and 10% Lack of Adaptive Capacity)
Low Vulnerability	16.3%	16.3%
Medium Vulnerability	38.5%	44.6%
High Vulnerability	45.2%	39.2%

In order to initiate the risk analysis in the Elbe Estuary in a holistic manner, a preliminary socio-technical analysis has been performed utilising the PEARL MAIA meta-model, following the steps as given in Figure 10.

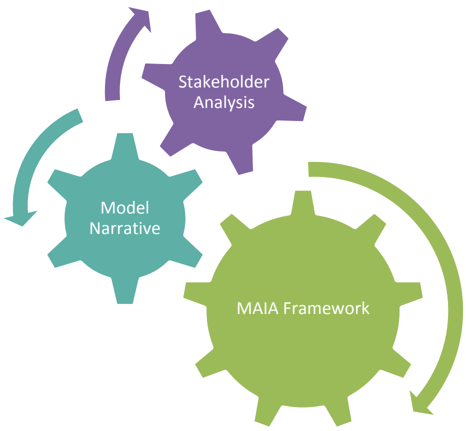


Figure 11: Methodology for the Socio-technical Analysis

The focus of the study has been to analyse the benefits of flood proofing in the area of Wilhelmsburg, considering to major scenarios:

1. Insurance coverage of flood damage
2. Increased governmental initiatives

And how could these scenarios possibly change the public's perceptions and motivations towards protecting their own homes.

For the conceptualisation of the MAIA model three agents are defined based on the key stakeholders identified in the model narrative and stakeholder analysis, being Households, Government Agencies, and Insurance Companies, with the following roles:

- Home Owner – Household
- Policy Maker – Government Agencies
- Financer – Insurance Companies

Deriving the following institutional characteristics and physical connections

Table 4 Constitutional Structure: Institutions

Attribute	Deontic	Aim	Conditional	Or else	Type
Homeowner	may	Apply wet proofing measures	Located in unsafe area (below +7.5m NHN)		Informal
Homeowner	may	Purchase insurance with flood damage coverage		Not insured for flood damage	Informal
Financer	must	Provide coverage for flood damage			Formal
Financer	must	Pay for damages	If household insurance is purchased		Formal
Government	must	Reduce risk for citizens	For all citizens within risk-prone areas		Formal
Government	must	Provide communication and awareness	For all citizens within risk-prone areas		Formal

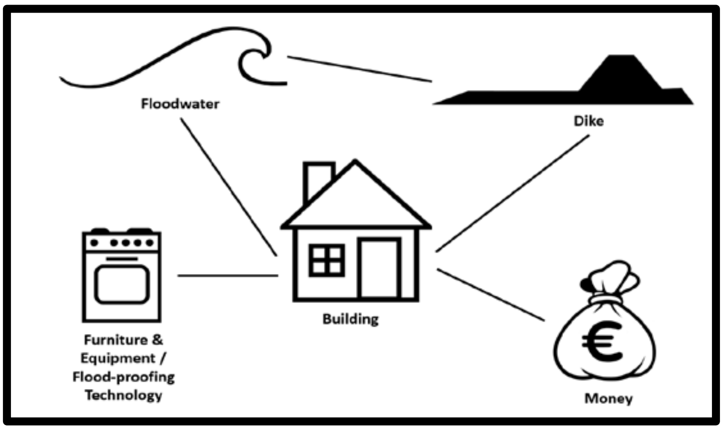


Figure 12: Physical Connection of Components

The parameters that will be the expected outcomes of the system are given as:

1. Number of insured households (P1)
2. Number of flood proofed households (P2)
3. Total saving of money from insurance coverage (P3)
4. Total saving of money from avoided damages (P4)

The relationship between each parameter and entity action may be direct (d) or indirect (i) and are given in Table 5.

Table 5: The relationship between each parameter and entity actions

		P1	P2	P3	P4
Risk Transfer	Insurance offers coverage for floodwater damage	d		i	
	Households purchase coverage and risk is transferred to the insurance company	d		i	
	Storm surge breaches dike and floods house	i		i	
	Insurance pays for damage	i		d	
Increase Government Initiatives	Government creates more initiatives to encourage flood proofing buildings		d		i
	Households implement wet proofing measures		d		i
	Storm surge breaches dike and floods house		i		i
	Damage is reduced and money is saved		i		d

The outcomes of this meta model will be used as an input to the agent-based model in a study that will go beyond PEARL.

3.2.2 Lessons learned from the case study work

The perfromed vulnerability assessment gives the preliminary assessment of the suceptible areas/ population groups and can contribute to the development of a plan for action. The indicators analysed were based on the data that was available. The results could be improved if the other indicators had corresponding data available. Further, some statistical data retrieved were from a different year compared to the rest of the data. Additionally, the data for the indicator, Green Infrastructures, was retrieved from a different source. Data from the same source and statistical year for all indicators would increase the consistency and accuracy of the results.

Following the World Risk Index method, the next step would be to calculate the risk index, given the outcome of vulnerability indices from this study. Exposure to hazards, the external risk factor, combined with vulnerability, the internal risk factor, would capture the overall risk index for each statistical area of Wilhelmsburg.

For socio technical analysis– understanding the dynamics in the flood protection system of Wilhelmsburg – the MAIA was a good stepping stone to establish the fundamentals of the complex socio-technical system. The tables and diagrams required a certain degree of detail, which obliged the researcher to fully investigate the case on hand. The chosen topic of wet flood proofing, which didn't have any existing regulation for Wilhelmsburg, was difficult to get around. Since no existing building regulations were present, the researcher had to create hypothetical scenarios in order to develop the framework. A lesson learned from this would be would to complete an initial stakeholder analysis and model narrative before deciding which particular measure to investigate into. This approach could be followed to improve on for future similar studies.

3.3 Understanding the formation of hazards under extreme events (WP2)

3.3.1 Description of the case study work

In order to characterize the extreme hydro-meteorological events such as storm surges, statistical analyses have been performed. A storm surge can be described by a combination of different parameters, which might be interdependent and therefore not representable by univariate statistical models (Salecker et.al. 2012). Rather, multivariate statistical approaches need to be applied. In tidal influenced coastal areas and estuaries, storm surges can be regarded as a superposition of the regular astronomical tide and an increased wind set-up (Figure 6).

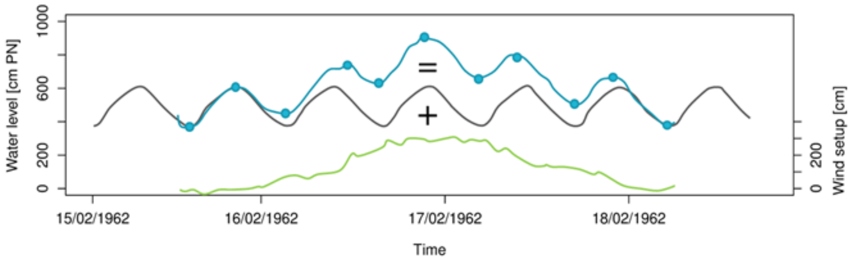


Figure 13 Storm surge hydrograph (blue line) as a superposition of the mean tide (grey line) and a storm induced wind set-up (green line)

The approach of the multivariate statistical analyses of the wind set-up applied to the Elbe Estuary is briefly described in Salecker et.al. 2012, Fröhle et.al. 2014 and D 2.2. Using the best fitting univariate distribution function, different water level and precipitation events have been derived (Table 5)

Table 6: Water levels and precipitation events for different return periods at the considered gauges

Return period [a]	Cuxhaven		Hamburg St. Pauli	
	Water Level [cm]	Precipitation [mm]	Water Level [cm]	Precipitation [mm]
10	433,34	10,66	1074,54	10,12
25	463,65	15,03	1134,61	15,07
50	484,36	18,55	1179,18	19,56
100	503,74	21,69	1223,41	24,86
200	522,18	25,04	1267,49	31,13
500	454,43	29,48	1325,64	41,23

Since, both parameters (water level and precipitation) are statistically independent the concurrent probability of occurrence can be obtained by multiplying the probability of occurrence of the individual parameters.

Extreme events are used as boundary conditions in **hydrodynamic numerical** models to simulate the impacts on the area under investigation. The unstructured triangular 2D model domain consists of approx. 100.000 elements with a mesh resolution of 3 m² up to 400.00 m² (Shaikh et.al. 2016). For simulation of (coastal) estuaries with a 2D or 3D numerical model approach, two different boundary conditions have to be applied at the model boundaries. At the upstream boundary at the weir in Geesthacht (see), a discharge boundary is applied. For the 2D-HDN model the discharges are based on daily data of the discharge gauge Neu Darchau (Figure *11*, black line). At the downstream boundary a water level boundary condition is applied based on the water level data of the gauge Cuxhaven-Steubenhöft (see, blue line).

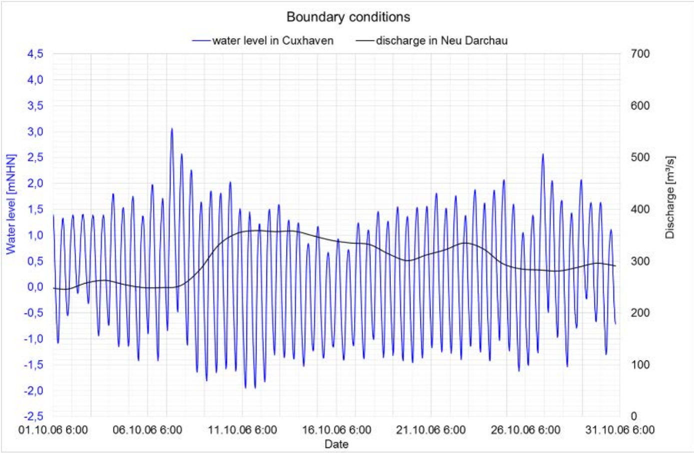
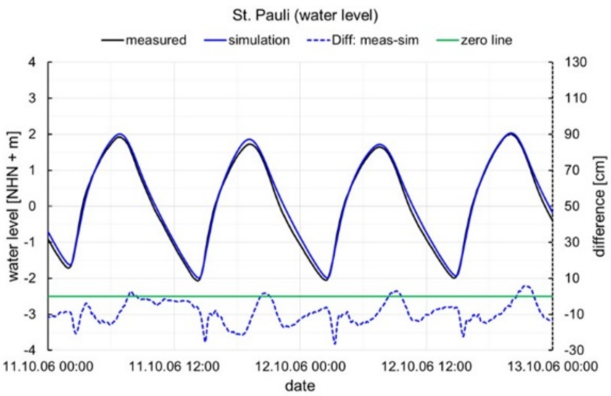


Figure 14: Hydrodynamic boundary conditions of the 2D-HDN model (water level - blue, discharge – black)

The 2D-HDN model has been calibrated with a focus on the hydro-dynamical characteristics water level and flow velocities (Shaikh et. al. 2016) based on a typical spring-neap cycle (see Figure 13). Figure 14 shows the results of the calibration process for the considered hydrodynamic characteristics.



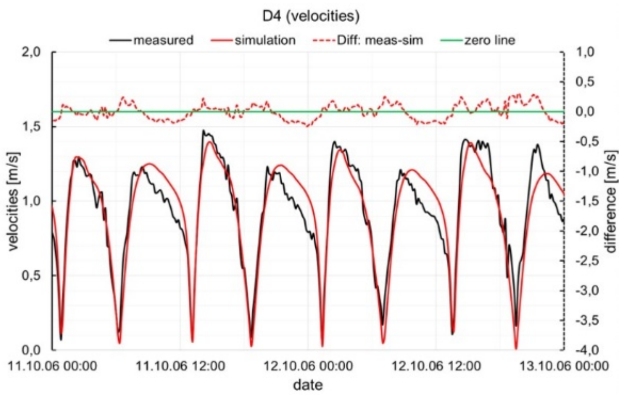


Figure 15 Measured and simulated water levels (left) and flow velocities (right) (Shaikh et.al., 2016)

3.3.2 Lessons learned from the case study work

As the statistical analysis showed that there is no any statistical dependance between water level and precipitation the concurrent probability of occurrence has been obtained by multiplying the probabilities of the individual parameters. In the context of PEARL we observed the flood types individually and focused on the storm surges rather than the pluvial floods. The hydrodynamic model of the Elbe Estuary has been enhanced within PEARL, mainly by updating and performing an extensive calibration of the existing model. Due to the complexity of the model, the delivery of the full and plausible model was achievable mainly because the data and know how availability in the team.

This hydrodynamic model has been further used to develop the operational and forecasting model for the Elbe Estuary, which is seen as its major contribution to the PEARL holistic framework.

3.4 Holstic and multiple risk assessment (WP3)

3.4.1 Description of the case study work

The impact and risk assessment is focused on the flood prone area of the largest urban area in the Elbe Estuary being the city of Hamburg (Figure 1, marked in blue) and encompass the following activities:

- **temporal evolution of the flood risk:** potential damages to the built environment focusing on a densely populated Hamburg district of Wilhelmsburg, which is undergoing an intensive urbanisation process in the recent years (IBA, 2012). Here, PEARL is building upon the research outcomes from the EU project CORFU and the project XtremeRisK funded by the German Ministry for Education and Research, in which the impact assessment has been performed as of the year 2010. This is taken as a baseline for the investigations described in this report. Due to the development of the urban area of Wilhelmsburg, which mainly took place after 2010 (see chapter 1.5.2) it is the objective of this study to assess the temporal development of the impacts and flood risk in the area, mainly triggered by an intensive urban development process.

- **direct and indirect damages for critical infrastructure**, for the port of Hamburg and the public and private transportation sector (are still an ongoing research, where the activities so far the intermediate results are thoroughly documented in Gkliati (2015), Blaj (2016), Zhamo (2016). (In further text: Critical Infrastructure)

A overview of the impact assessemnt activities for the City of Hamburg is given in Figure 12.

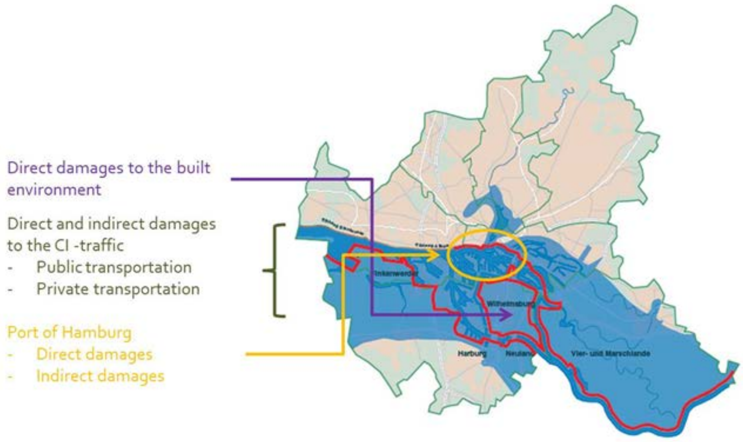


Figure 16 Actual overview of the research activities for the Elbe estuary/Hamburg case study (red line indicates the public flood protection infrastructure)

The methodology for the assessment of the temporal development of the potential damage is summarised in *Figure 16* and described in detail in Gruhn et al., 2017).

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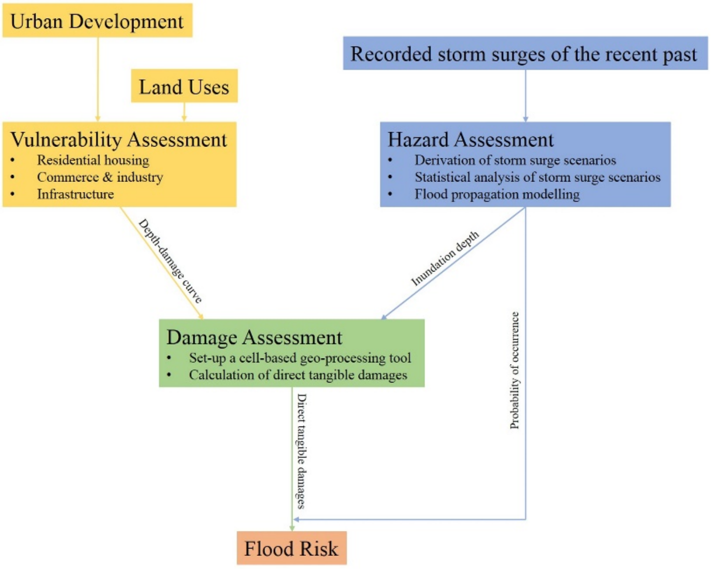


Figure 17 Overview of the methodolgy

The obtained results are summarised in Figure 17.

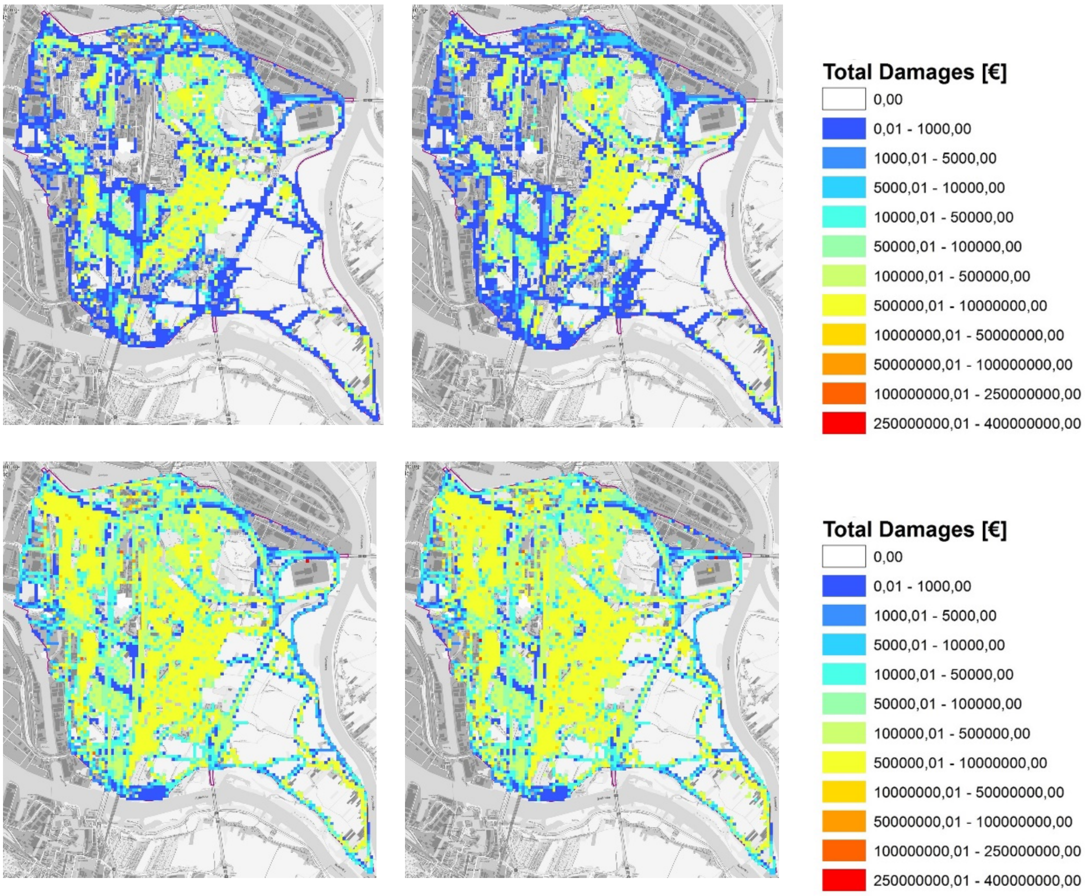


Figure 18: top: Total Damages of the scenario 2010A (2010 - left, 2016 - right); bottom: Total Damages of the scenario 2010C (2010 - left, 2016 - right)

The comparison of the results (2010 and present) shows the temporal evolution of the flood damages and the flood risk over time for the both time horizons 2010 and 2016. In the overall picture, it can be seen that the flood damages increase up to approx. 17%. The corresponding flood risk increase up to approx. 17%.

Public Transportation: Flood impacts to the public transportation sector has been carried out in the collaboration and exchange with the Columbia University, New York, USA and making use of the post-Sandy (2012) assessments and lessons learned. Two different approaches, which have been used to assess the flood damage to the transportation system of New York City as a result of the hurricane Sandy, have been applied to assess direct and indirect impacts on the public transportation (U-Bahn) of the City of Hamburg. The first approach, by Jacob et.al. (2011) connects costs from the direct physical damages and costs for restoration of the transportation system depending on the time which is needed to reach 90% of its capacity before the event to calculate the total losses (Figure 21).

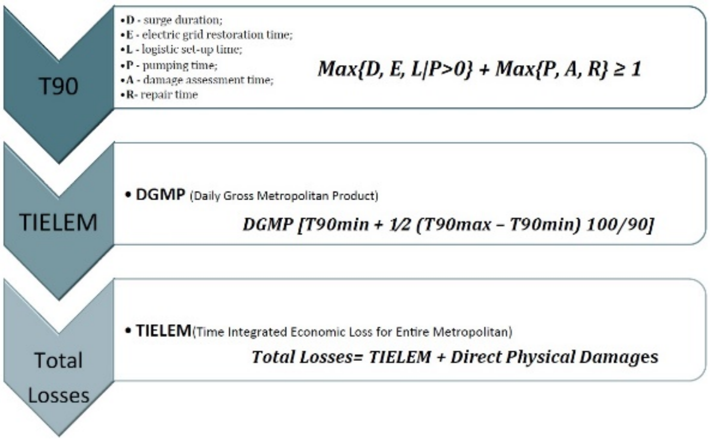


Figure 19: Approach of Jacob et.al. 2011 for the assessment of direct tangible flood damages (Zhamo, 2016)

The second approach, by Compton et.al. (2009), calculates direct tangible flood damages assuming a direct relationship between the length of track flooded and the resulting direct damages (Figure 22).

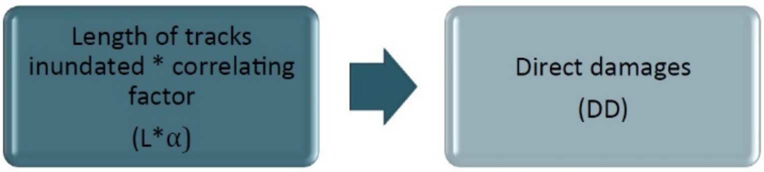


Figure 20: Approach of Compton et.al. 2009 for the assessment of direct tangible flood damages (Zhamo, 2016)

The correlating factor αis derived from the statistical analysis of recorded subway/railway flood incidents.

The approach to estimate indirect tangible damages is based on the statistics of people travelling through the floodplain area and derives the compensations in case of delay/cancellation of service (FHRC, 2008) (Figure 23).

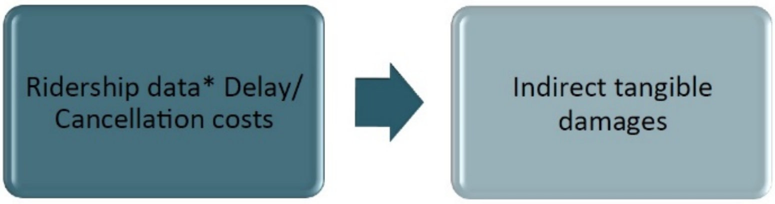


Figure 21: Approach to estimate indirect tangible damages due to service interruption in case of flood

The table below summarises the results of the investigations and gives a summarizing overview of the applied approaches.

	DIRECT TANGIBLE DAMAGES (Jacob et al., 2011)	(Compton et al., 2009)	INDIRECT TANGIBLE DAMAGES (FHRC, 2008)
The main factor to consider	Damage to physical infrastructure added to the time needed for the economy to restore to 90% of its functionality.	Damage is directly related to the length of tracks inundated.	Cancellation/delay of service
Clear boundary between direct/indirect damages	No	Yes	
Accuracy of data	High	Medium	High
Transferability	Yes	Yes	Yes
Knowledge gaps	"Worst case" scenario leads to overestimation of results. No defined relationship between each type of asset and damage caused by flooding.	Oversimplified approximation leads to uncertainties in the results. Lack of recorded flood damage assessments leads to errors in the correlating factor	Estimations and surveys conducted in the UK where governance of railway systems is private rather than public. Latest available surveys were conducted in 2009.
Considerations for improvement	Estimations based on more realistic scenarios Infrastructure-damage relationship for each different type of asset	Inclusion of existing flood protection measures in the estimations Creation of a digital database Increasing the number of case studies included in the regression analysis	Conduct surveys and post-damage assessment based on the ridership data and subway fare of the urban area to be studied
New York results (US$)	56 billion	587.3 million	343 million
Hamburg results (€)	908 million	209-269 million	39 million

The port facilities: The direct impacts of the notional storm surge scenarios has been calculated on the basis of the derived depth-damage curves and the inundation depths corresponding to the storm surge scenarios. Figure 22 shows exemplarily the direct damages to the general facilities (left) and handling equipment (right).

Figure 22: Initial rough estimation of the direct damages to general facilities (left) and handling equipment (right) of the Eurogate Container Terminal (Gkliati, 2015)

In the initial investigation the indirect damages have been obtained using the approach of Hallegate (2014), which connects the indirect damages (ΔY) and the direct damages (ΔK) (Eq. 2)

$$\Delta Y = (1+\alpha)\frac{3}{2}r\Delta KN \qquad \textit{Eq. 1}$$

Figure 20 shows the indirect damages resulting from the respective scenarios.

Figure 23: Indirect damages for different scenarios based on the approach of Hallegate (2014) (Gkliati, 2015)

3.4.2 Lessons learned from the case study work

The analysis of the temporal evolution of the flood risk generated tengible results and estimations of the impacts of the urban development in the area of Wilhelmsburg. They are a valuable input and discussion point with the key stakeholders when discussing further urban development and flood risk management strategies in the area. Within PEARL, a high level resolution of the impact assessment has been performed, which at the same time required considerable resources and high resolution data, mainly when analysing the building typologies and land uses. This could not be applied for the whole Elbe Estuary within the project lifetime, still leaving the room for improvement of its scalability.

The collaboration with the Columbia University, USA, has been assessed as beneficial,a s we could apply and test the methods and tools that have been deployed to analyse the impacts of the hurricane Sandy, 2012 to the affected areas and infrastructure in New York City. In reverse, the US partnrs become aware of the PEARL methods and tools, which micht be considered for further joint projects.

3.5 Flood forcasting and early warning systems for coastal regions (WP4)

3.5.1 Description of the case study work

A water level forecast systems based on real-time simulations has been developed on the basis of the multi-regression gauge based forecast system developed and implemented by BSH, the German Federal Maritime and Hydrographic Agency (BSH). The so-called MOS-forecast (MOS – Model Output Statistics) system provides pointwise water level forecasts for up to 6 days for several locations (gauge stations) along the Elbe River (Müller-Navarra, 2012). Since it is a pointwise forecasting system, no information about the spatial distribution and the spatial development of the water level along the river exists. This information together with flow velocities and wave information

is necessary to assess the safety of the constructions and is generated within the TUHH forecast approach in order to derive the spatial distribution of the water level.

The early warning system for the Elbe estuary is based on the 2D-HNM of the Elbe Estuary, which is described in chapter 2.2.1. This early warning system calculates the current status and a forecast over up to 3 days of the temporal and spatial development of the water level and respective currents along the Elbe estuary and to detect potentially endangered sections of the flood protection infrastructure.

Figure 25 shows the operational sequence and the data flow of the developed early warning system.

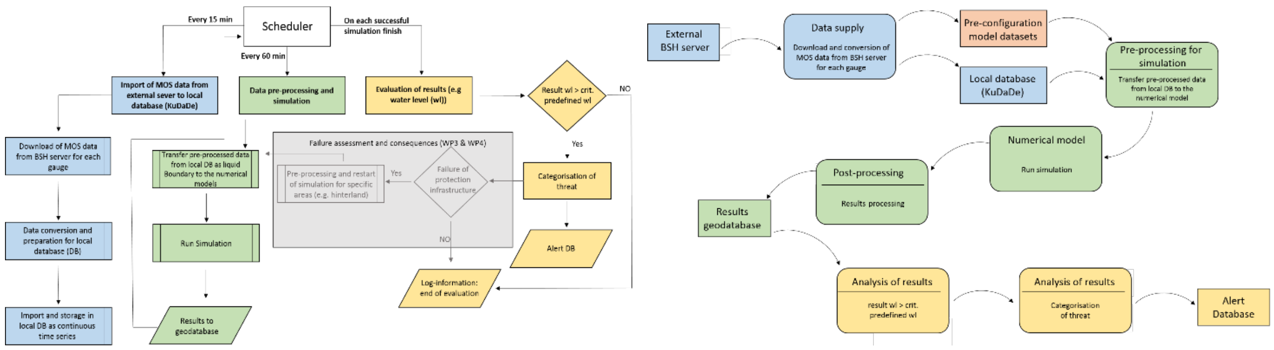


Figure 41: Flow chart (left) and data flow chart (right) of the early warning system for the Elbe estuary

The summarized results are stored in a geodatabase and processed for visualization on a web site (see Figure 24). The web site content includes a background map, the entire model domain of the Elbe estuary and the forecasted water level for different time step within the current simulation (forecast) period. Time series of forecasted water level for selected locations are shown on the web site (http://pearl.wb.tu-harburg.de/forecast/).

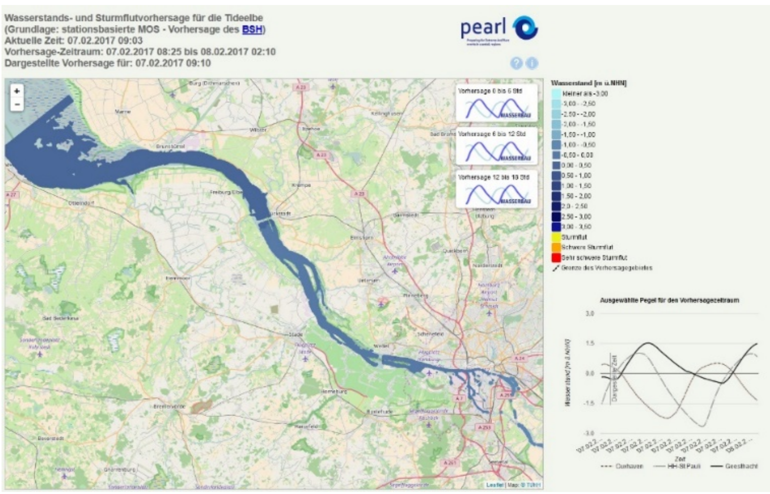


Figure 24: Screen shot of the visualization of the water level forecasts on the web site

For validation purposes the result of the numerical model of the Elbe estuary are compared with the water level forecasts of the BSH and measured water level time series for the available location,

within each sub-model. Figure 25 shows exemplarily the comparison the water levels at the tide gauge Hamburg St. Pauli.

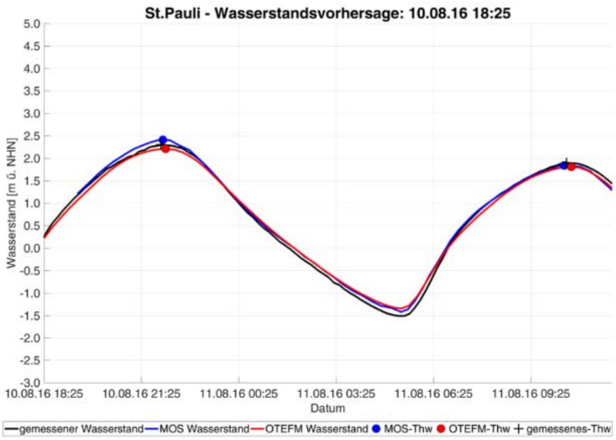


Figure 25: Comparison of the BSH water level forecast (blue line), TUHH simulated water level (red line) and the measured water level (black line) at the tide gauge Hamburg St. Pauli

Furthermore, statistical analyses have been performed in order to verify the model results. The results are given in the report D6.2 and in the publicaiton (Shaikh et al., 2016).

The application of the innovative technology of CPU/GPU computing especially for the realization of an evacuation module within the Kalypso model suite is explored by the TUHH aiming at the development of an evacuation model which can be run on an average NVIDIA®CUDA enabled desktop computer. A prototype for such an evacuation module is developed and applied to the Hamburg district Wilhelmsburg.

The overall evacuation concept encompasses pedestrian evacuation, evacuation by public transport, evacuation by private cars and the vertical evacuation. At present, the evacuation model covers the pedestrian evacuation to collecting points (bus stops) or to safe places (refuges) (Figure 26). The evacuation model will be extended during 2017.

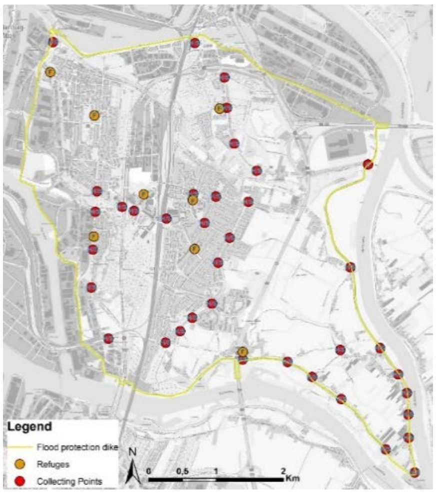


Figure 26: Collecting points and refuges in Wilhelmsburg

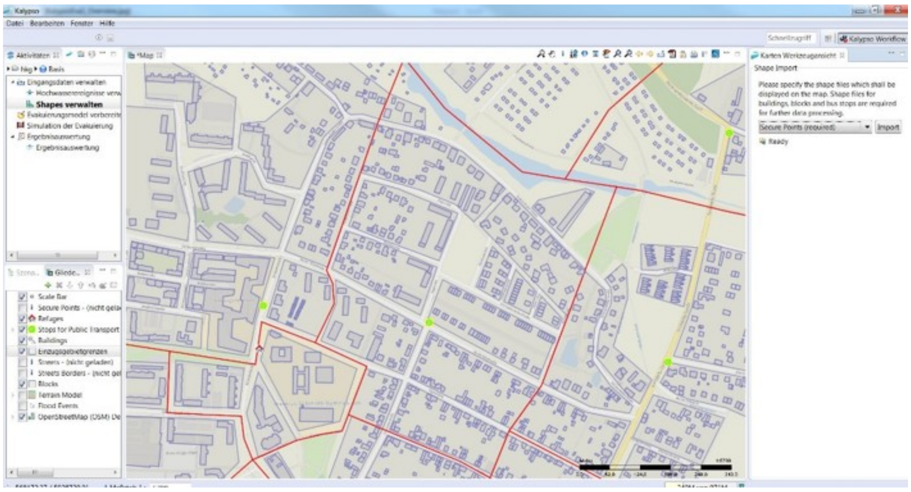


Figure 27: Screen shot from the Kalypso GUI showing "catchment areas" (red polygons), building polygons (small blue polygons) and aggregated building blocks (bigger blue polygons)

The mathematical-physical model, mentioned above, describes the movement of the pedestrians from the initial positions (building blocks) to the targets (collecting points or refuges) and is currently being tested with the local stakeholders.

3.5.2 Lessons learned from the case study work

Enhancement of the forecasting capabilties can be considered as one of the major improvements of the existing methods and tools in the Elbe Estuary witin PEARL. Apart from the technical expertise, it was mainly possible due to the close contact and exchange between the key stakeholders (in this case the Federal Maritime and Hydrographic Agency) and the PEARL researchers. This collaboration enabled an effective delivery of the tool that is needed by the practitioners and the affected public stakeholders, considering both, its technical capability and the usability.

3.6 Stakeholder involvement for strengthening resilience of coastal regions (WP5)

3.6.1 Description of the case study work

An adapted LAA model has been applied to the Elbe Estuary (described in D5.1) in order to involve the key stakeholders in the development of the holistic flood risk management practices and is composed of the following main phases:

1. Stakeholder analysis- who is (should be) involved? - Reassessment of the key stakeholders, their relations, interdependences… (desk study and interviews, link to WP1 (FORIN Desk study))
2. Tailored approach to the selected stakeholder groups and individuals addressing their specific interest (face to face sessions)
3. Towards the joint planning - 'from the parts to the whole' analysing the interactions of the key stakeholders (mutual and with the PEARL methods and tools) - (the final plenary discussions, final analysis)

The stakeholder roles and interrelations have been analysed in detail within PEARL and are summarised in Figure 21.

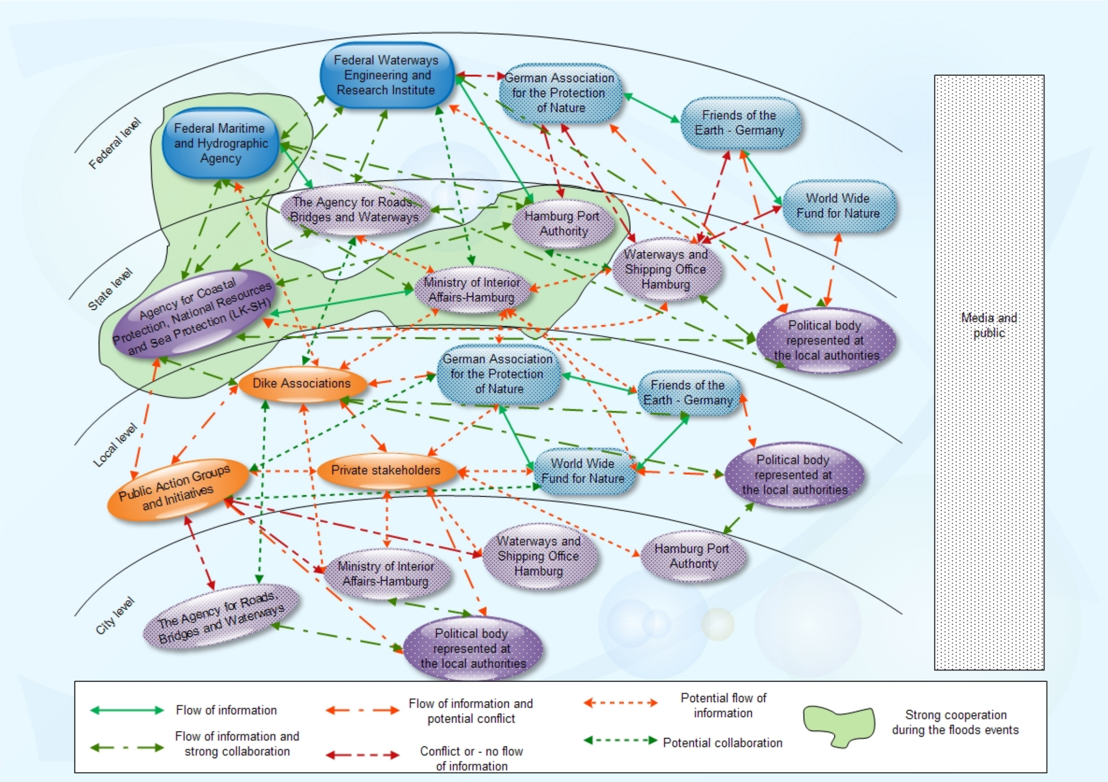


Figure 28: Rainbow diagram of the key stakeholder for the Elbe Estuary/ Hamburg

Out of the assessed key stakeholders, the following ones have been selected based on their influence and relevance for the flood risk management in the Elbe Estuary, existing contacts with the PEARL project team and declarative interest in the methods and tools being developed in PEARL. They are listed together with the way they of their engagement in Table 7.

Table 7: Key stakeholders ad their involvement within LAAs

Key stakeholder	Assessed Interest in PEARL	Way of engagement
The Agency for Roads, Bridges and Waterways (LSBG)	Hazard& risk assessment, modelling tools developed, EWS	Regular face-to-face meetings on a monthly basis with the key representatives
Ministry of Interior Affairs- Hamburg	Evacuation model	Regular meetings including the assessment of the needs and interests session related to the Evacuation model (D4.2)
Agency for Coastal Protection, National Resources and Sea Protection, Schleswig Holstein (LKN-SH)	Hazard& risk assessment for the Schleswig-Holstein area, modelling tools developed,	Occasional personalised meetings

Hamburg Port Authority (HPA)	Hazard& Risk assessment in the port of Hamburg area, EWS	Regular face-to-face meetings with the key representatives
Federal Maritime and Hydrographic Agency (BSH)	EWS	Active involvement and exchange of experiences; regular working meetings, joint publications
Ministry of environment and energy- BUE (the highest level administrative body)	Final results, policy briefs	Meetings with the officials Participants in the PEARL PCMs in January 2017 in the premises of the Ministry

All key stakeholders have been according to the plan as given above. The communicaiton and collaboraiton will go beyond PEARL.

The method for flood resilience assessment, developed by Batica et.al., 2013 and improved in the scope of the PEARL project has been applied to assess the Flood Resilience Index (FRI) for the Elbe Estuary, focusing on the City of Hamburg.

The evaluation of overall FRI has been followed by assigning values to each indicator with their corresponding weights. For the given conditions, the FRI for the Free and Hanseatic City of Hamburg is 3.96. The result in the form of table shows separate FRI for each dimension and the overall index.

Table 8: Overall FRI for the city/urban scale; for flood initiated by storm surges and the current status of the flood protection – Free and Hanseatic City of Hamburg, Germany

Free and Hanseatic City of Hamburg	Indicators	Dimension index Σ(xi*wi)/Σwi	"Importance" ∑wi/ ∑w	Overall FRI
Natural Dimension	2	4	0,03	3,96
Physical Dimension	36	3,87	0,39	
Social Dimension	10	3,96	0,09	
Economic Dimension	16	3,71	0,17	
Institutional Dimension	27	4,20	0,31	

Results obtained in this analysis demand an interpretation in order to address all current issues regarding flood resilience.

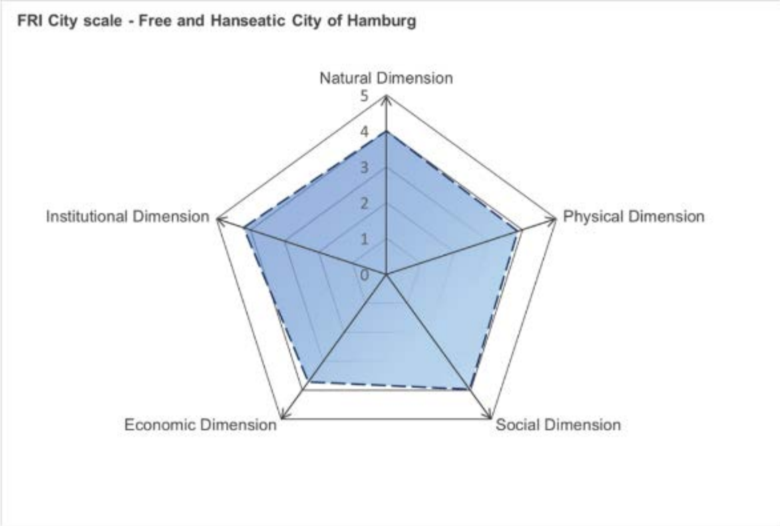


Figure 29: Radar chart presentation of FRI on city scale, for flood initiated by storm surges and the present status of the flood protection – Free and Hanseatic City of Hamburg, Germany

Results obtained using Matrix with 91 indicators give good interpretation about existing and needed assets and policies (laws, binding documents, etc.) that will contribute to increase flood resilience of analysed case study. The overall flood resilience index of 3.96 shows that the flood protection of the city of Hamburg is already at a considerable level, mainly due to the well-established flood management planning practices and efficiently assigned responsibilities and roles for different tasks of flood management. Still, flood management is a dynamic process and must be continuously adapted to the future conditions.

3.6.2 Lessons learned from the case study work

The rather specific situation in the Elbe Estuary case in comparison to the other case studies in PEARL mainly due to the high level of involvement and awareness of the key stakeholders in flood risk management, could be used as a chance to enahnce the existing LAAs concepts that are mainly developed to initiate the collaboraiton process. That was mainly done by tailoring the activities to the actual needs and interests of the key stakeholders. The collaborations and involvent activites that have been purshued within PEARL, will be maintained and further enhanced beyond PEARL. The novel methods and models developed within PEARL such as the socio-technical analysis, FRI assessment or the forecasting model contributed to this positive development.

3.7 Measures and strategies for strengthening flood resilience in coastal regions (WP5)

3.7.1 Description of the case study work

Witihn PEARL, the alternative or complementary measures and strategies, including the Nature Based Solutions (NBS) have been studies and their potential to mitigate the flood hazard and risk analysed. Those strategies are summaried in Table 9.

Table 9: Adaptation measure assessed with respect to their effect on an enhanced flood protection

Catalogue of adaptation measures					
Type of adaptation measure	Adaptation Measure		Description		Status
Static	M1	Narrowing of the cross section	M101	90% Narrowing near Brunsbüttel	In Progress
			M102	60% Narrowing near Brunsbüttel	In Progress
			M103	75% Narrowing near Brunsbüttel	In Progress
	M2	Re-aligment of dikes	M201	100m	In Progress
			M202	250m	In Progress
			M203	500m	In Progress
			M204	750m	In Progress
			M20X	>750m	In Progress
Dynamic	M3	Flood protection polder	M301	Location/Size A	
			M30X	Location/Size B	
	M4	Elbe flood barrier	M401	Closing time A	
			M40X	Closiing time B	
	M5	Integration of old tributaries	M501	Historical conditions (1930)	In Progress
			M502	Wischhafener Süderelbe	
			M503	Haseldorfer Binnenelbe	
			M504	Borsteler Binnenelbe	
			M505	Alte Süderelbe	
			M506	Dove-Elbe	
			M507	all	
	M6	Integration of tributaries	M601	Oste	
			M602	Stör	
			M603	Krückau	
			M604	Pinnau	
			M605	Schwinge	
			M606	Lühe	
			M607	Este	
			M608	all	

Re-alignment of the continuous dike line by 250 m and 500 m have been investigated (Figure 30) until the due date of the deliverable. The preliminary results shows that a re-alignment of the dikes lead to a decrease of the water levels (Figure 31).

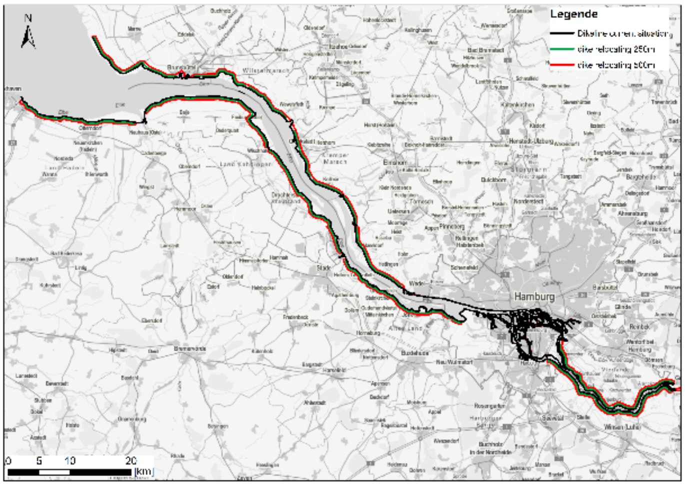


Figure 30: Investigated re-alignment scenarios i) 250 m – green line, ii) 500 m – red line

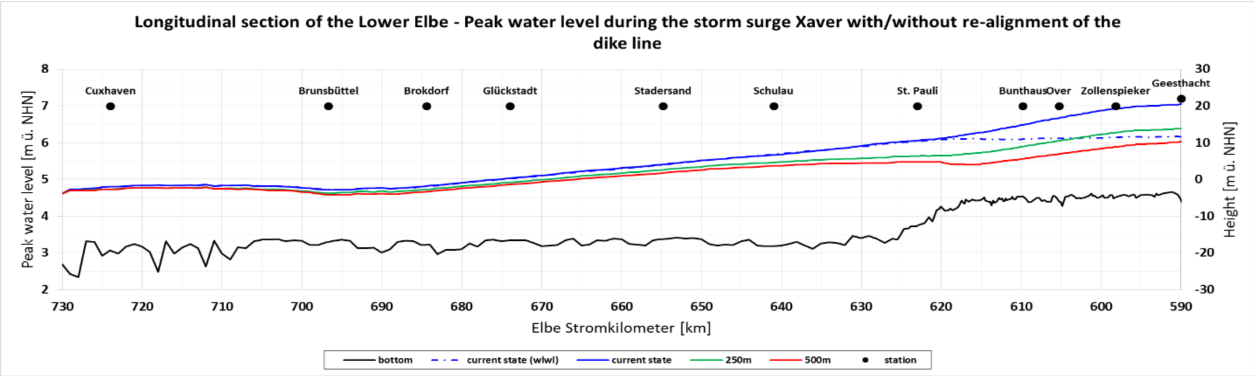


Figure 31: Longitudinal section of the Lower Elbe showing the peak water levels during the storm surge Xaver 2013

Further analysis of the strategies will be further performed, discussed and reassessed togehter with the key stakeholders within the LAA process beyond PEARL, some of them within the lately approved H2020 project RECONECT, TUHH is participating in.

3.7.2 Lessons learned from the case study work

The assessment of the in order to have a significant reduciton of the water level in the Elbe Estuary (*Figure 53*) it is necessary to relocate dikes for 500m which is difficult to achieve, due to the current landuse and the level of urbanisation in the area. That indicates the need that those measures and their combinaitons should be further investigated.

Moreover, those measures should be evalated in a broader context, considering hydrological, economic, ecologic or social aspects.

3.8 Concluding remarks

Although the Elbe Estuary case was considered to be at a high level of development in respect to flood risk management, PEARL brought new insights and methods that extends the existing approaches and practices. Apart from enhancing the technical capacity of the methods and tools developed and used in the Elbe Estuary, the initial application of the ‘holistic’ methods and tools such as MAIA framework, caught attention by the stakeholders and even not foreseen within PEARL, enabled conduction of in-depth interviews with the key ‘agents’ i.e. the representatives of the main actors and institutions of the developed meta model. This indicates that such tools can be used to enhance the stakeholder involvement process that before PEARL reached a saturation level and needed new methods and approached to keep the stakeholders involved in a long-term manner.

4 Study – Les Boucholeurs, France *(contribution: UNSA, ARTELIA)*

4.1 A brief description of the case study area

French case study, "Les Boucholeurs" is a district of Châtelaillon-Plage located on the limit of Yves, Charente-Maritime department. District count approximately 600 houses and have an important activity in oyster and mussel farming. The Atlantic coast is threatened by storm surges and potentially by the sea level rise. Those events could contribute to the failure mechanisms of the embankments and could generate some important water level on the rear part of this area, which is lower that the coast line itself.

Social situation is highly sensitive due to the difficulties and damages caused by Xynthis storm. Xynthia storm occurred in February, 2010 causing severe storm surge, demolition of the protection system and huge damages to both, people and assets.

"). After this event, in the hurry, the place "Les Boucholeurs" was designed as one of the main "Black Area" where all the houses should be destroyed. This impacted local community a lot due to their farming activities and living places. This causes huge social tensions and raised sensitivity of local community to any change.

Institutional framework of this area regarding flood protection is changed with the new protection plan, PAPI (Programmes d'action de prévention des inondations). Based on that change, the new protection system is build by now.

The main challenge for PEARL project is to try to apply holistic approach in 'helping' community to understand the risks, see all vulnerable spots and have possibility to discuss about different strategies and measures that will increase flood resilience of the area.

Since we had a good data to proceed with the analysis we managed to apply developed methodology for Flood Resilience Index on three different scales: micro, meso and macro. Even more, we were able to develop several scenarios for analysis in consultations with the local community.

4.2 Understanding the formation of vulnerability and risk in coastal regions (WP1)

4.2.1 Description of the activities performed in the case study area with the key outcomes

There were no activities within this work package. However, the vulnerability assessment has been done for the case study area based on following: data gathered from National Institute for Statistics and Economy studies (INSEE) and available flood map done by ARTELIA partner. The relevant data

for this analysis were: population number, gender distribution, income, number of elder persons, kids and handicapped.

While creating the framework for vulnerability the data availability is crucial. The framework for vulnerability is defined in order to have vulnerability mapping in Esri software. Based on available information about buildings following attributes are available:

- Building type - urban function
- Building height

The results are presented within WP3 under deliverable 3.4.

The reason for acting like this was already mentioned sensitivity of locals. Consequently, we could not gather data from survey or demand filling of any questionnaire.

4.2.2 Lessons learned from the case study work

4.3 Holistic and multiple risk assessment (WP3)

4.3.1 Description of the case study work

Within WP3 we developed risk assessment framework for case study. The research activities for Chantellailon-Plage case study focuses on holistic risk assessment and flood resilience evaluation. Therefore the activities were mainly on WP3 and WP5. The general objective after data collection and modelling phase was to focus on flood risk management with final goal to provide usable forms for communication with key stakeholders. The analysis and general definition of frameworks for vulnerability, risk and resilience needed to be applied within Arc GIS.

Research activities are focused on vulnerability and risk mapping. However, the additional requirement was to have availability to map both risk and vulnerability. The framework developed for vulnerability takes into account *population vulnerability, socio-economic vulnerability and vulnerability of build environment*. This was chosen in order to have possibility to have spatial representation of results. Each vulnerability parameter has associated impact element.

Lessons learned from the case study work

The results are presented within deliverable 3.4 and we also had an opportunity to present our results to stakeholders. We had a positive feedback. What was marked as very acceptable is the fact that we created spatial presentation of results. With the framework developed for vulnerability and risk we created the maps showing vulnerability and risk value for every building the in area.

In addition, we managed to crate maps for three different scenarios. In the figures below the result maps are shown for vulnerability and risk.

The developed scenarios are based on three different flood maps created after the Xynthia event. The scenario 1 is simulation effects of Xynthia storm, Scenario 2 is having better protection system were just overtopping is possible and Scenario 3 include openings in protection system.

Table 10: Scenarios applied for vulnerability, risk and flood resilience assssement

Scenario 1	Xynthia	Xynthia

Scenario 2	X20_2016_ssBreches_classesH	Xynthia + 20cm
Scenario 3	X20_2016_PPR_classesH	Xynthia + 20cm (PPR)

Figure 32: Vulnerability mapped for three different scenarios

Figure 33: Risk mapped fro three different scenarios

As an added value the damage assessment is done. The process is focused on development of depth damage curves for different building types. The principle is adopted from FP7 CORFU project and reused on this cases study. Also, the mapping of the results is done and shown in the figure bellow.

Table 11: recapitulation of scenarios and direct flood damages calculated

	Flood modeling	Vulnerability	Risk	Damage
Scenario 1	Xynthia	*	*	€ 14 974 616.91
Scenario 2	Xynthia + 20cm	*	*	€ 10 693 836.89
Scenario 3	Xynthia + 20cm (PPR	*	*	€ 21 311 024.79

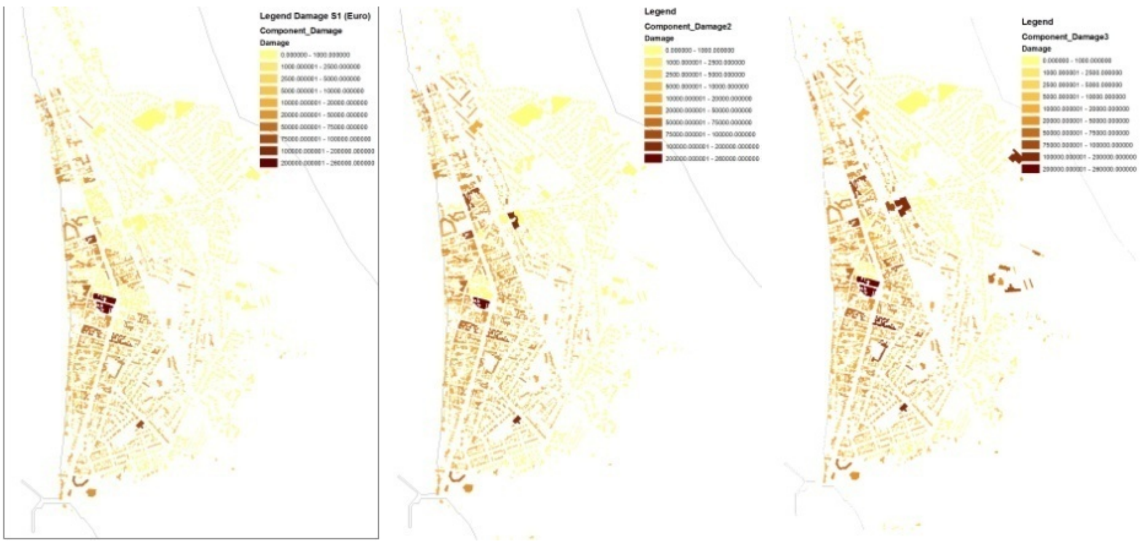


Figure 34: Mapped direct flood damage in € for every building in the case study area

The developed framework has a great acceptance from local community. Spatial representation of results is more understandable for non scientific or non engineering persons.

4.4 Stakeholder involvement for strengthening resilience of coastal regions (WP5)

4.4.1 Description of the case study work

The research within WP5 focuses on flood resileince assessment. The defined framework gathers multiscale assement and multidimension assessment. Case study area is analysed as urban system taking ino account different urban functions and services. The importance of these consideration is expalined within deliverable 5.2. The different scales for analysi are defined. based on available data, cases tudy Chantellailon-Plage is analised on three scales: building, block and city (urban scale). Developed framework for flood resilinece gives posibility to have flood resileince mapping for building and block scale. We used the oportunity and mapped cases study area. In the text below the short version of our analysis is presented as well as maps related to floor resileince evaulation.

A set of data give by our partner ARTELIA have following layers necessary for FRI evaluation: digital elevation model in resolution of 75m, shape files with information on different buildings, roads, water bodies, channels and a corresponding flood map with extracted minimal and maximal flood depths.

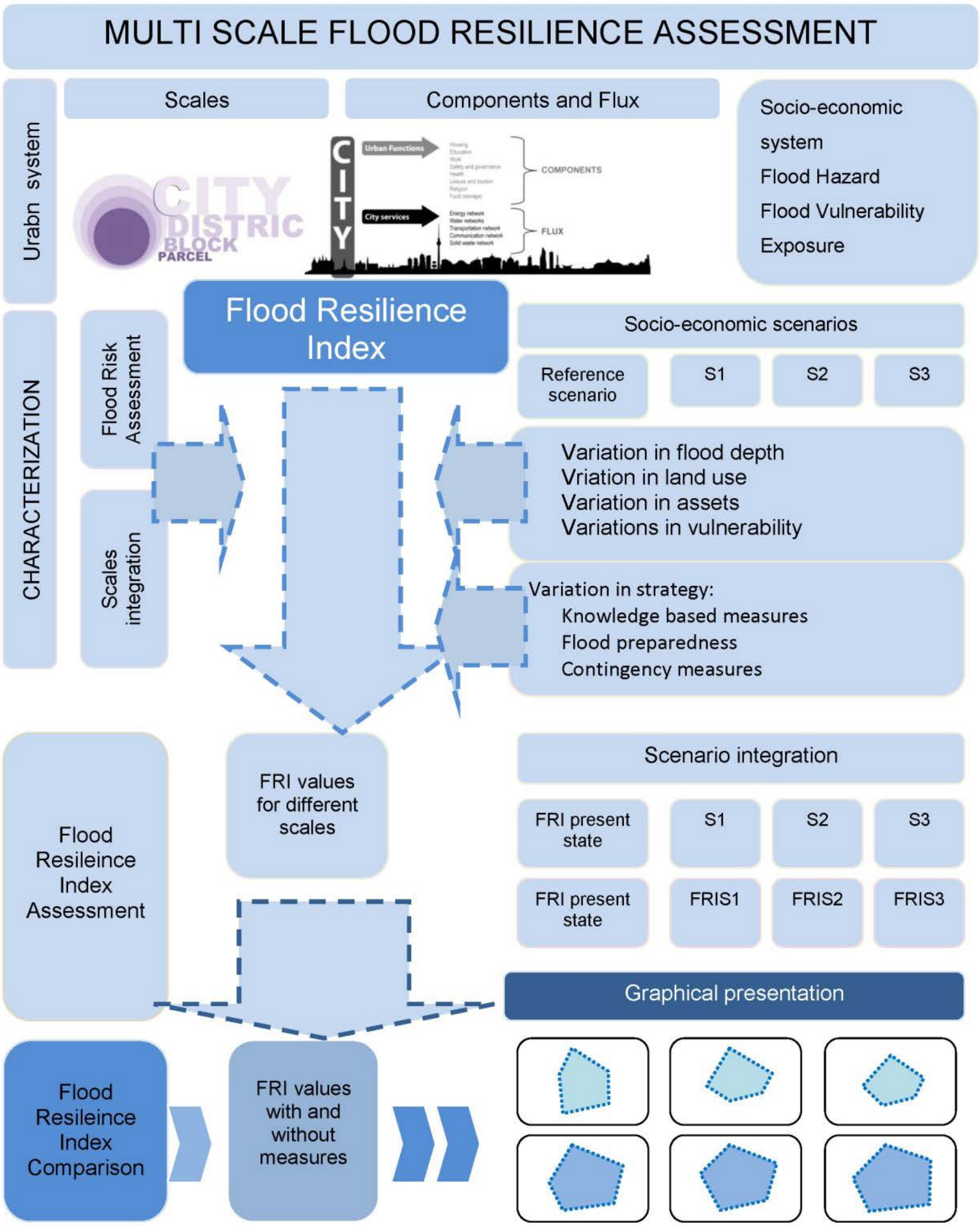
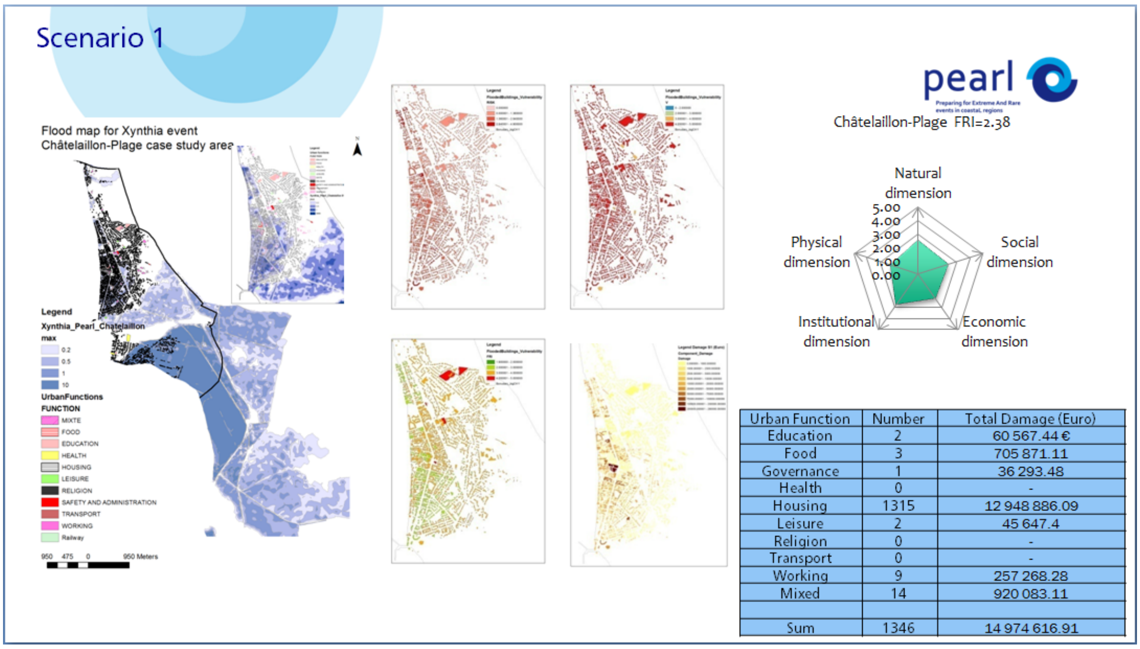


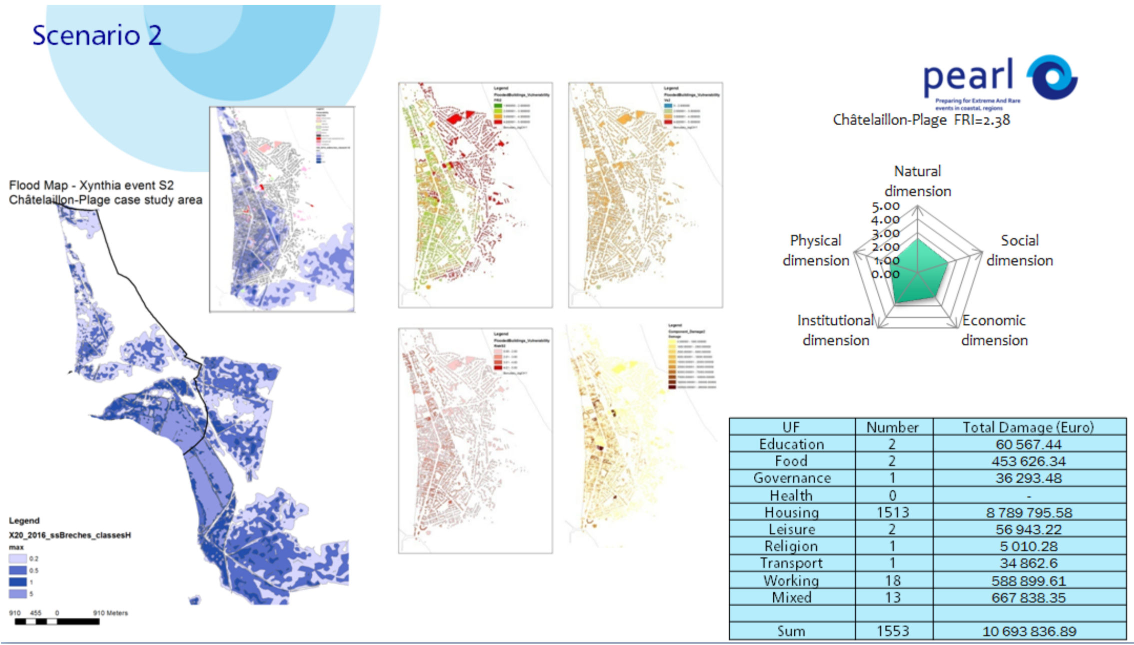
Figure 35: Applied framework for multi scale flood resilience assessment

The anlysis resulted in different maps that contain mapped Flood Resileince Index for each building. As mentioned before three scenarios are used.



Urban Function	Number	Total Damage (Euro)
Education	2	60 567.44 €
Food	3	705 871.11
Governance	1	36 293.48
Health	0	-
Housing	1315	12 948 886.09
Leisure	2	45 647.4
Religion	0	-
Transport	0	-
Working	9	257 268.28
Mixed	14	920 083.11
Sum	1346	14 974 616.91

Figure 36: Scenario 1 - flood map, vulnerability, risk, direct damage and Flood Resileince Index on micro and macro scale



UF	Number	Total Damage (Euro)
Education	2	60 567.44
Food	2	453 626.34
Governance	1	36 293.48
Health	0	-
Housing	1513	8 789 795.58
Leisure	2	56 943.22
Religion	1	5 010.28
Transport	1	34 862.6
Working	18	588 899.61
Mixed	13	667 838.35
Sum	1553	10 693 836.89

Figure 37: Scenario 2 - flood map, vulnerability, risk, direct damage and Flood Resileince Index on micro and macro scale

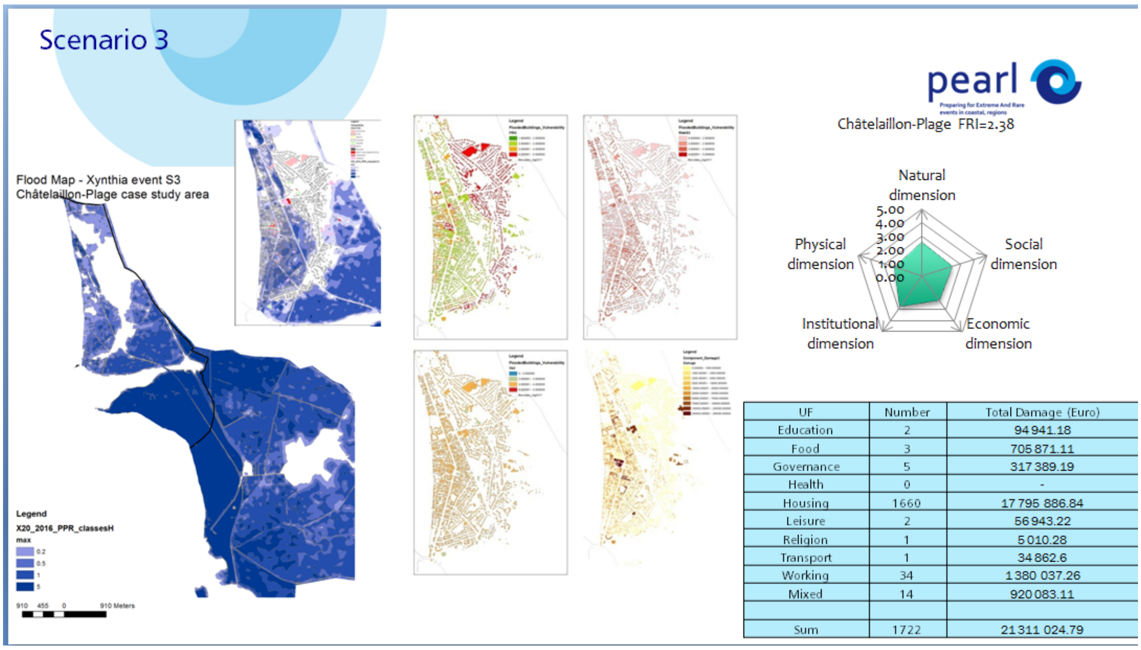


Figure 38: Scenario 2 - flood map, vulnerability, risk, direct damage and Flood Resileince Index on micro and macro scale

4.4.2 *Lessons learned from the case study work*

Research activities for Châtelaillon-Plage, French case study area focused on flood resilience, risk and vulnerability assessment. The case study team UNSA and ARTELIA defined frameworks for vulnerability, risk and flood resilience. In addition all results are available in the form of maps.

Lessons learned from this case study are mainly related to better communication among all actors. This can be done by mapping the communication roads. Creation should be done with caution since this area is very sensitive. The social component is very strong therefore constant collaboration with stakeholders remains the only way in increasing the risk perception and willingness to accept future flood risk management planning.

Case study work also took into account possibility for application of developed LAAA framework for stakeholder analysis. Here, we could not apply to whole framework like it was done within Rethymno case study (Greece). The reason is already mentioned in the text above. However, we partly performed the framework. Up to now we had several meeting with city officials and local NGO were we presented our analysis, discussed about possible measures and actions acceptable from their side and concerning adaptation to floods. Mapping the results was a big advantage during the meeting and in addition we got a green light to continue to cooperate on this matter.

4.5 Concluding remarks

The real long-term lesson drawn from Xynthia is a need for a complete revision of the coastal settlements, which during last two centuries had little in common with a sustainable development. Finally, Xynthia storm and its repercussions demonstrated the weakness of the awareness of the risks on vulnerable coastal territories and the depth of the collective lack of responsibility (Chauveau et al. 2011). The new project RECONECT H2020 should provide enough resources to focus on green and blue infrastructure in this area as a measure for adaptation to future floods.

5 Case Study – Genoa, Italy

5.1 A brief description of the case study area

The case study concerns the city of Genoa, and specifically the coastal area and the Bisagno river basin. The focus of the case study is on the Bisagno final reach (last 5km of the river), streaming into urban area.

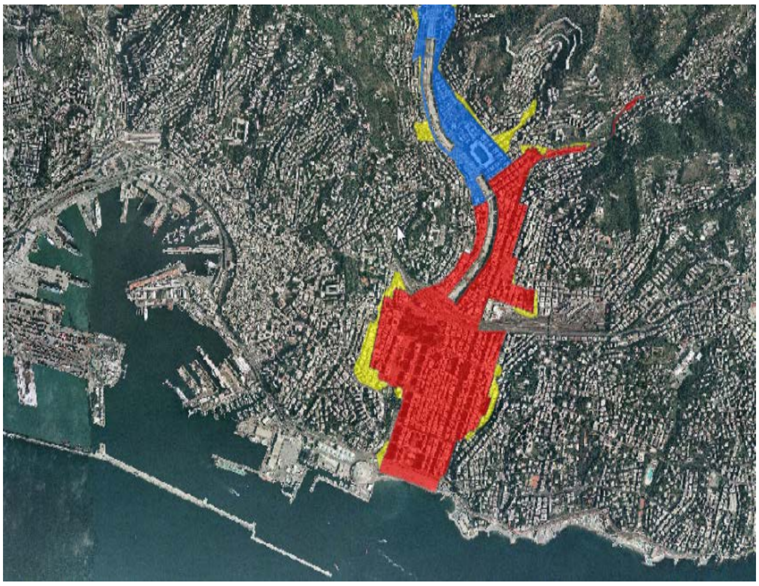


Figure 39: Flood prone areas for different return periods, T = 500 (yellow), T = 200 (blue), T = 50 (red)

Extreme events affecting the Bisagno river basin are heavy precipitation that generates flash floods and pluvial. In the study area, localized extreme precipitation is produced by large-scale flow interaction with regional topography. Cyclones relate with a low pressure area, also referred to as Genoa low, insisting on the Genoa gulf. The depression bears rain, often intense, on the Liguria coast. Recently Genoa was hit by two major flash floods in November 2011 and October 2014, both resulting in fatalities, displacement of people and high financial damage.

The city of Genoa needs for tools and methodologies able to deal with “residual risk”, meaning the risk that remains after structural hydraulic works will be completed. A “no risk” situation will never be possible in Genoa, and local stakeholders needs for detailed information on city vulnerability and risks to better plan interventions and deal with emergency situations. In such a view, the PEARL holistic approach has revealed very interesting and helpful, especially for taking into consideration social and economic aspects of the area.

5.2 Understanding the formation of vulnerability and risk in coastal regions (WP1)

5.2.1 Description of the activities performed in the case study area with the key outcomes

Risk and Root Cause Analysis (RRCA) was conducted for Genoa and the analysis drew on 17 semi-structured telephone interviews with key stakeholders to supplement a review of the vast existing literature on the floods and flood history in Genoa, including technical reports, planning documents, legal documents and scientific reports and articles as well as analysis of relevant media reports, which covered more than 150 articles published online between 2010 and 2015. The RRCA focused on the flooding events of 2011 and 2014 in Genoa. In particular, the analysis highlighted the governance issues that prevented structural mitigation projects planned as far back as the 1990s from being realised.

Vulnerability assessment (VA) in PEARL, for Genoa, comprises an approach for spatial vulnerability assessment, including the calculation of a compound index and also the integration with data from a survey on household level. A geo-referenced vulnerability assessment approach was developed. The purpose of the spatial vulnerability analysis is to display the results on maps, so a better understanding of the vulnerability structure can be achieved. The aggregation of numerous components into a single index allows to draw conclusions at one glance, because every spatial entity is assigned to one value. For the calculation of indicators information is required, starting with (1) geo spatial data and (2) spatially explicit statistical data on the respective scale.

5.2.2 Lessons learned from the case study work

The results of the vulnerability assessment can be integrated in ongoing or future spatial planning or management processes. The vulnerability assessment in PEARL includes a methodology which is flexible in terms of the data and as such it can be applied for every case study area with regard to the availability of data. The concept and outcome is furthermore explained in Deliverable 1.3. Local partner (GISIG) is exploring the possibility to test and apply, into research projects or activities, the methodology into another river basin in the Genoa area, with the aim to demostrate the reliability and the usefullness of results to local administration, and translate the methodology into a common governance tools for Liguria basins.

The RCCA revealed that the interplay between legal and financial issues generated a deadlock that prevented local authorities from effectively reducing risk. The availability of new integrated and detailed information on risk can play a crucial role both for resources allocation to increase resilience (e.g. insurance, securing area, evacuation and plan for prevention...) both to plan interventions during the extreme events, helping the authorities to cope with the so-called residual risk.

5.3 Understanding the formation of hazards under extreme events (WP2)

5.3.1 Description of the case study work

The WP2 work in the Genoa pilot was mainly addressed to implement models to study the behaviur of the basin and of the area under extreme hydro-meteorological events, such as the event of October 2014 when the Bisagno overflow the riverbank at the level of Borgo Incrociati causing also

one fatalties. A further simulation was carried out using rainfall data from the really extreme event of 24-25th October 2011, affecting the area of Cinque Terre, and translated on the Bisagno basin.

Implemented models were:

1) Hydrogeological model, for the entire area of the basin, by using the MIKE Drift module from DHI.
2) 1D hydraulic model, implemented for the last 5km of river, from the historical cemetery of Staglieno to the Mouth, including also the last reach streaming in culvert. The open source model HEC-RAS has been used.
3) 2D flood maps, generated through ArcGIS. Maps show water depth for each cell of the DEM (2m x 2m) for different time steps.

5.3.2 *Lessons learned from the case study work*

Modelling activities carried out in PEARL for the Genoa case study have been well structured and related results are reliable and compliant with real observations. Water depths maps generated for October 2014 event have been compared with the ones of the observed event, so allowing a good model calibration. A first attempt by local partner GISIG was to carry out an integrated simulation including both natural and artificial drainage network, but the lack of appropriate tools (e.g. MIKE Urban) and the low quality data of sewer network brought not to continue in this direction. Integrated simulation is however something worth to be done, since combined sewer concurrs as well to floods in Bisagno area.

Implemented model represented the situation (river sections, DEM) as it was in 2014. For being used now or in the future, the model should be updated since structural hydraulic works to Bisagno are running, with changes in the discharge capacity (e.g. reconstruction of the coverage, by-pass channels).

Modelling work carried out in the WP2, and the generation of flood hazard maps, was propedeutic to the risk assessment, carried out in WP3. Thanks to the networking activities with Fondazione CIMA and RISC KIT project, it has been possible to discuss about model implementation and tools, and compare results with one of the organization at local level expert in engineering and modeling activities in the area. It is also assumed that the models can be applied and replicated in different areas, even if some of them are not totally free and need for a SW licence.

Really interesting was also the application of the Cinque Terre rainfall event to the Bisagno basin, useful to study the behaviour of the basin in a really critical situation (more than 500mm/rain in 24h), that can anyway occur in a changing climate regime. The value of this approach has been to catch the attention of local authorities about potential impacts and damages in the area.

5.4 Holistic and multiple risk assessment (WP3)

5.4.1 *Description of the case study work*

In WP3 the elaboration of data from WP1 and WP2 has been carried out, to assess flood risks in pilot areas. Specifically, for Genoa risk maps have been generated by the combination of hazard maps (flood maps derived by the modelling activities) and vulnerabilty maps. Two different kinds of flood risk maps are available for Genoa. The first is a map derived by the combination of risk map vulnerability based on census and geo-spatial data. The second is a map based on vulnerability

enriched with survey (household interviews) data. If compared, the two risk maps are really different, and this signifies that citizens perception, experience and general life conditions can weight a lot on risk assessment.
Other work has been done by UNESCO-IHE to estimate the evolution of land cover up to 2030 in the pilot area, starting from Corine Land cover data.

5.4.2 Lessons learned from the case study work

Risk assessment carried out in WP3 generated interesting results for the Genoa pilot. At research level, no similar works were done till now, able to calculate the risk starting from a vulnerability with assigned valued different from 1. In fact in Italy it is conventionally to calculate the vulnerability (and consequently the risk) in an area by assigning V=1, with a high degree of approximation. In areas like Genova, where morphology and territorial characteristics change over time and space, it is really importan to have risk maps calculated a high level of detail.

Genoa Municipality is the coordinator, from now to the next three years, of the Climate Change Partnership in the framework of the Urban Agenda, and lessons learned from risk assessment in PEARL are expected to be transferred to them and made available for different purposes for building capacities and addressing research.

5.5 Stakeholder involvement for strengthening resilience of coastal regions (WP5)

5.5.1 Description of the case study work

As reported in Deliverable 5.1, also for the Genoa pilot, the analysis of stakeholders and the methodology to foster their involvement was carried out. A core PEARL stakeholders group has been created since the first project phases, also thanks to the networking with Fondazione CIMA, local RISC KIT partner, that strenghten the participation in the group by local authorities. The core group of Genoa stakeholders was hence composed by:

- Municipality of Genoa
- University of Genoa, in particular Environmental Engineer and Earth Science Departments
- IREN Group (Genoa multi-utility company)
- Fondazione CIMA (Civil Protection Research Centre)
- ARPAL (Regional Environmental Agency)

Different meetings have been carried out to enforce the link between PEARL and the stakeholders and to report them about activities and results. Great involvement of the stakeholders was done on the occasion of the household interviewes of November 2015, when Municipality of Genoa contributed to the training of the interviewers togethet with the partner University of Stuttgart. As well results from the household survey and vulnerability and risk assessment was presented.

Worth to be mentioned, at stakeholders involvement level, is the lecture on PEARL risk and vulnerability assessment carried out in November 2017 by the partner GISIG in the framework of the Applied Geomorpholgy course of the Master of Science in Geology at the University of Genoa. In this occasion, it has been explained the generation of flood risk maps, including socio-economic aspects, and it has been calculated for Genoa the Flood Resilience Index.

5.5.2 Lessons learned from the case study work

The main elements of success in the LAA so far is to have agreed, among involved stakeholders, about the inclusion of "societal and economic" aspects into the vulnerability and risk assessment. A challenge was also to connect administrations and research work. What the research creates is not, immediately, applicable to current governmental practices. Vulnerability and risk assessment, as well as Flood Resilience Index, instead, have revealed as tools that can be applied at city level to have a better knowledge in terms of climate change impacts and and flood residual risk management. Thanks to the dialogue undertaken with the Municipality of Genova, there are good chances that the PEARL results will be assessed and used in the framework of panels that are going to be organized within the Climate Adaptation Partnership of the Urban Agenda, coordinated by the Municipality of Genova. This 3 years initiative, having importance at EU level, is aimed at drafting and appliying an Orientation document on Climate Change Adaptation and Resilience in terms of regulations, funding and knowledge.

5.6 Measures and strategies for strengthening flood resilience in coastal regions (WP5)

5.6.1 Description of the case study work

For the Genoa case studie, in WP5 it has been calculated the Flood Resilience Index, by following two different approaches. The first one, focused on the 2014 event, used the methodology developed by the University of Nice, where indicators were divided into 5 categories (natural, sociale, economic, institutional, physical) and for each indicators it has been assigned a FRI value and a weight. The second approach, developed by the University of Athens, similar to the previous one but simpler, was calculated through an on-line tool, available for each pilot site, and offers a really good overview of strong and weak points in a city that can influence its resilience.

Finally, through the Web Learning Platform of PEARL, stakeholders are also able to look and manage features of the different maps developed in the project.

5.6.2 Lessons learned from the case study work

Calculation of flood resilience index has been revealed as useful to deal with residual flood risk and individuate, in such a way, non-structural interventions that can help in managing extreme situations and reduce risk and vulnerability of an area and its exposed elements. As well, the on-line availability of maps of pilot area is a good instrument for preliminary assessments and impact studies.

City of Genova is really interested in the use of the Flood Resilience Index. Local partner GISIG is investigating the possibility to propose it as instrument to study the city and the overall behaviour of the system in front of floods. This can be done in the framework of the project Anywhere, with the support of Fondazione CIMA and the Municipality of Genoa.

A living lab on the calculation of the FRI has been carried out within a lecture on PEARL in the Applied Geomorfology course of the Master of Science in Geology. Students have been asked, upon its perception, to assign value to each indicator of the five categories, draft a spider diagram and calculate the general FRI. A limit of the FRI is that is based on own feeling, an advantage is that it requires also territorial knowledge, so it is scientifically based.

The FRI can be applied in different context, since its potential of replicability. It is in fact investigated the possibility to test is in other areas/basins in Liguria, in the framework of research activities.

5.7 Concluding remarks

Regarding the activities carried out in PEARL for Genoa pilot, it is outlined that future activities will be mainly focused on exploiting the results and their possible inter links to improve the resilience of the city, the governance models and the emergency management. This will be done following the PEARL olistic approach, and pushing towards the inclusion of social and economic aspects into flood management and maps.

Important is, at this stage, the collaboration with the Municipality of Genoa, that is expected to grow up in the framework of expert stakeholders group of the Climate Change Adaptation partnership, as well the collaboration with the University of Genoa, when for the first time PEARL and its olistic approach to risk assessment have been teached.

6 Case Study – Marbella, Spain

6.1 A brief description of the case study area

Marbella is a city that belongs to the province of Malaga and it is part of the "Costa del Sol". It is located in the south of Spain, in the region called Andalucía. The city extends for 117 km^2 and (according to the Spanish Statistical Office in 2015) 138,679 habitants live there with a density of almost 1,200 hab/km^2.

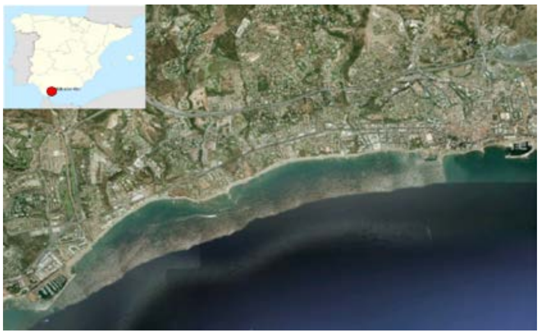


Figure 40. Marbella map and location.

The city is between a small mountain range and the sea. The case study is limited to the city centre where there is two main water streams, Represa channel and Huelo River. Marbella presents a typically Mediterranean topography with high slopes on the upper part of the basin and very flat areas close to the sea. As a Mediterranean city, it benefits with wet warm cool winter and ever drier hot summer, with a mean annual temperature of 18 °C.

The main challenges that have been identified in Marbella city are flash flood, storm surge and collapse of the sewer network due to the incapacity of the conduits. These events are characterized by high potential to create huge damages to people, assets and natural landscape.

The risk is even increased when flash flood and storm surge occur at the same time because, in this case, water runoff cannot be discharged into the sea. The main consequences are higher water depth and velocity values, so higher damages to assets and people. Climate change is expected to accentuate the risk. Some effects have been already identified, like the jellyfish bloom, which has been jeopardizing tourism in recent times.

Further information about the case study may be consulted in previous deliverables, D3.4 and D6.2.

6.2 Understanding the formation of hazards under extreme events (WP2)

6.2.1 Description of the case study work

In WP2 extreme events scenarios have been analysed thanks to a coupled 1D/2D model of Represa subcatchment that has been developed by AQUATEC. The software used for the creation of the model is InfoWorks ICM by Innovyze (2016). The outcome of this first elaboration consists of simulations of flood events corresponding to three return periods. The results have been exported from the software in form of triangular meshes in which to each triangle a water depth and velocity values is associated.

6.2.2 Lessons learned from the case study work

- The hydraulic model gives a very detailed idea of the network and the infrastructure. Moreover, once the model is developed several scenarios can be run in a quick and easy manner. Which seems to be a cost-demanding task at the beginning results in a very useful tool for the present and future scenarios. Through a comprehensive calibration, the model represents in a proper manner the reality in an urban flooded area.
- It will be useful to implement proposed adaptation measures and compare outcomes with previous state (without measures).
- On the other hand, the easiest way to explain the impacts of urban flooding to non-experts and even experts is through maps. When showing flood maps people recognize rapidly the critical areas of the study area.

6.3 Holistic and multiple risk assessment (WP3)

6.3.1 Description of the case study work

In WP3, a risks and damages assessment has been conducted. Risks assessment required a previous Hazard and Vulnerability analysis. The first was carried out through a hazard criteria (low, medium and high hazard levels were proposed) and based on the Martínez-Gomariz et al. (2016) work, where stability thresholds for pedestrians exposed to pluvial floods were defined. Vulnerability assessment was conducted based on statistical data for Marbella population, namely age, percentage of tourists and density per census districts. After defining three vulnerability levels a map was performed, in the same manner that a hazard map was developed. Both maps, hazard and vulnerability, allowed to perform a risk for pedestrian map based on a proposed risk matrix, which establishes a risk level based on hazard and vulnerability levels.

On the other hand, a direct damage to buildings assessment has been conducted, by employing tailored damage curves for Marbella and proposing a methodology to consider a water depth inside the building based on a sealing coefficient for buildings. Two previously-developed tools have been employed to conduct this damage assessment. Firstly a toolbox developed by UNESCO-IHE was utilized in order to calculate the mean water depth around any building of the case study, based on the flood maps previously obtained. As a second stage, another toolbox developed by the University of Exeter for the project CORFU was employed in order to calculate the damages based on the inside-the-buildings water depth and the damage curves. In between a methodology to transform the mean water depth outside the buildings to water depth inside the buildings was proposed. It is assumed that the water leaks into the building slowly and a sealing coefficient is proposed to be utilized as a calibration parameter. Damage maps have been created for the two different floors (ground floors and basements) and three return period events.

Indirect damages due to both business interruption and traffic disruption have been estimated too. In case of indirect damaged due to **business interruption** a new econometric model was developed. This new methodology is based on the current Input-Output methodology. First, a panel of data was created using the I/O methodology since there are not available specific data for the Marbella case study. I/O methodology was chosen because of the high level of accuracy that it provides. Then, using the results of the direct damages assessment per each type of land use and the calculated indirect damages data, and econometric model was created. The aim of this model is to make possible to apply the indirect damages assessment only using the input and output data of the Direct

Damages Assessment. But, as the model is based on an I/O table panel of data, the expected accuracy of the model is higher than in a traditional econometric model.

Results of the estimates suggest a clear and strong positive relationship between the direct and indirect damages, as it could be expected. Furthermore, indirect damages are higher when unemployment is lower (unemployment can be understood as an indicator of economic activity). Evidence also suggests that summer is the season with the lowest indirect damages, while spring is the season with the highest indirect damages. In addition, indirect damages seem to be relatively higher for agriculture and relatively lower for manufacturing, construction and retailing.

This new methodology has been tested successfully using as a baseline the direct damages for land uses of design storms for three return periods (1, 10, 100 years) without and with the implementation of adaptation measures.

Regarding indirect damages due to **traffic disruption**, a SUMO model has been employed, which computes the increase in distance, time and fuel consumption as a consequence of a flood. As a result of the traffic disruption an increase in the ground transport travel cost is expected (e.g. by car, by train or on bike). It is assumed that commuters use always the more efficient (optimal) itinerary, so that a disruption always causes an increase in costs. This increase in cost is caused by three vectors: an increase in pollution, caused by an increase of fuel consumption and an increase in time spent to reach the destination.

The map of the maximum flood depth in the catchment was adopted to represent flooding conditions in the traffic model. This was replicated for different traffic setting in the peak hours in the morning and evening and an off-peak scenario in the afternoon.

1. Morning flood

The morning flood occurs between 7:30 and 9:00 AM, when around 25 % of the daily traffic is happening. The normal morning traffic was already suffering congestion in the main roads and the closure of many streets due to flooding exacerbated significantly the already slow traffic. **Fehler! Verweisquelle konnte nicht gefunden werden.** illustrates the change in number of vehicles over simulations time. During the flood conditions, many vehicles were slowed down and remained circulating in the network for longer. Consequently, the number of vehicles is a good indicator showing how efficient the traffic supply is. The number of vehicles nearly doubled throughout the flooding conditions. Moreover, the number of vehicles remained considerably high long after the flooding has receded, causing some vehicles to be late for work. The repercussions of the event were felt for more than 2 hours after the network has become operational again.

During the flooding 3,095 vehicles were rerouted, meaning that they had to choose alternative routes to reach their original destinations. The additionally travelled distance by these vehicles was 2,837.7 km, hence each travelled 1 km on average to complete their journeys. Not only the vehicles that had to change their route suffered the flooding conditions, but also other vehicles experienced indirect impact during the event. Nearly 20 % of all vehicles in the 24h simulations suffered a delay longer than 5 min. The delayed traffic is not the only indicator for the impact of flooding on traffic. Some vehicles had to delay the beginning of their trips because of congestion on the roads where they were supposed to start their journeys.

2. Afternoon flood

If a flood occurs in the off-peak hours of the day, the impact on traffic is less significant. However, a tendency of increasing vehicles with time can be noticed which lead to the conclusion that a longer flood can potentially be dangerous even for traffic conditions that are not initially heavy. Comparing the percentage changes, the most significant is again the lost time in delayed traffic.

3. Evening traffic

Generally, the evening traffic accumulates more vehicles in the network, because they are all released at 6 PM, whereas in the morning traffic vehicles leave their homes according to the time needed to reach their work. If we compare it to the flooding in the morning, the following observations can be made:

- The increase in running vehicles is not as much as in the morning
- The transportation system takes longer to recover in the evening scenario. The traffic goes back to normal 3.5 hours after the flood (in the morning scenario it takes just over 2 hours)
- The evening scenario has more rerouted cars, but it has only half of the delayed vehicles in the morning traffic
- Overall the additional travelled time and distance are in a close range for both scenarios
- The additional CO2 emissions in the morning scenario are slightly more than the evening one.

The static flooding scenarios, applied to different times of the day, demonstrate the most important impact to be the loss in time due to the delayed traffic. The nature of the flooding in Marbella has very short temporal dimension, but nonetheless shows significant delays not only for the vehicles passing through a flooded area, but for the whole traffic system.

For further information, it is possible to consult the deliverable D6.2.

6.3.2 Lessons learned from the case study work

- Risks maps indicate rapid and easily where the most risky areas for pedestrians are. Which let to make decisions and explain easily to non-experts why those have to be made.
- Damage assessment allowed to have an overall view of the potential damage provoked to properties and assets by flood events characterized by a set of design storms with several return periods.
- About post-flood event analysis, in Marbella it has been found that post-flood effects usually last for days and affect at very local scale because convective storms occur locally. Typical damages to assets are accounted for cleaning, repainting and changing skirting boards and some furniture close to the floor reparation or substitution. Moreover, in the case of commercial activities, there is a higher economic loss because the affected businesses use to close during cleaning and restoration (business disruption).
- According to experts' advice water depths in basements can be considered as double of the water depth beside the building wall, because those act as small water storage tanks.
- Once the damage model is totally implemented, different scenarios can be treated in an easy manner and even replicated in other cities thanks to the knowledge acquired that will make it easier and faster.
- The indirect damage assessment due to traffic disruption aims to be easily replicable, so that it can be useful in different places and different times.

- The new methodology for indirect damage assessment due to business interruption has successfully been tested in Marbella case study and aims to be easily replicable and useful for doing simulations and predictions.

6.4 Flood forcasting and early warning systems for coastal regions (WP4)

6.4.1 Description of the case study work

Two main issues have been treated in this work: a) The use of GPUs (high performance graphic cards) to achieve faster simulations that allow the simulations of a 1D+2D hydraulic model in real time every time that new precipitation data is available; and b) The development of an EWS (Early Warning System) based on radar-nowcasting that allow increasing anticipation in the flood warning.

Regarding the first issue, a specific proposed configuration allowed to run the full model in real time in less than 5 minutes using the GPU compilation of Infoworks. This run time opens the possibility to run the model in real time (every time that new rainfall information is available: every 10 minutes in the case of the AEMET –Spanish Meteorological Agency– radar network, which covers the Marbella Case Study). For further information, it is possible to consult the deliverable D4.2.

On the other hand, the EWS uses radar precipitation estimates to calculate radar precipitation forecasting (the following 2h: Nowcasting). Additionally, Information of local sensors (rain gauges) has also been incorporated into the EWS and used to issue warnings on their values. Warning based on thresholds on sensor registered values are calculated and disseminated in the EWS to confirm the forecast warnings based on radar nowcasting.

Precipitation information of both rain gauges and radar (observed and forecasted) is used to feed a hydraulic model to issue warning over specific elements of the sewer network in real time. For further information, it is possible to consult the deliverable D4.5.

6.4.2 Lessons learned from the case study work

- EWS combining precipitation estimates, forecasts and model simulations provide valuable information to manage flood events.
- EWS can be affordable as non-structural measures to increase resilience.
- In theory there are two early warning systems, named WiCast and Cowama, for flooding forecasting and bathing water, which still need calibration and precision improvements.

6.5 Stakeholder involvement for strengthening resilience of coastal regions (WP5)

6.5.1 Description of the case study work

The current governance in Marbella aims to integrate flood risk management and urban planning in order to stop fighting against water and adapt to live with it. To get this objective it is necessary to create networks of stakeholders, engineers, professionals and decision makers who can cooperate, share interests and ideas, generate knowledge and results that allow to adapt the city of Marbella to the new climatic challenges.

Stakeholders analysis have been conducted in the context of a past meeting that took place in order to ensure the maximum participation of the local stakeholders and to facilitate the participation of entities from other municipalities. These stakeholders' analysis led to several findings.

About exposure and impact on assets and population, Marbella's most significant critical issues are related with natural water courses that were urbanized. In particular, main critical events in Marbella are flash floods, which therefore are characterized by hourly time scale. The lack of inlets cause an underuse of the underground channelized steams and sewers networks, which would be able to accept more water in case of heavy rainfall events. Other types of structures able to fight floods like detention tanks are not present in the city.

About post-flood event analysis, in Marbella it has been found that post-flood effects usually last for days and affect at very local scale because convective storms occur locally. Typical damages to assets are accounted for cleaning, repainting and changing skirting boards and some furniture close to the floor reparation or substitution. These damages are usually repaired directly by the owners since insurance companies do not pay for them. Furthermore, in the case of commercial activities, there is a higher economic loss because the affected businesses use to close during cleaning and restoration.

The stakeholders' analysis, begun during that past meeting, involves also preparedness and early warning systems in case of urban flooding. In theory there are two early warning systems, named WiCast and Cowama, for flooding forecasting and bathing water, which still need calibration and precision improvements. Moreover, Aemet (national meteorological agency) provides a national system useful for early warning system.

The analysis about decision-making processes and procedures in case of flood event detected civil protection and local police as authorities in charge to inform population. Warnings are transmitted by local media, although the situation is further exacerbated because of tourists who are not aware of the major flood risk in the city.

6.5.2 Lessons learned from the case study work

- The political instability between stakeholders stopped the progress of the Learning and Action Alliance.
- Visual outcomes such as maps and the web based platform became the most understandable outcome for stakeholders. It will worth for us to make it public.
- A part of the emergencies involved stakeholders, there was a lack of general knowledge about Urban Drainage.
- The majority of the Spanish cities in the Mediterranean coast are in the same situation, but almost all are not aware.
- Overall, people were unaware about the previous systems, which are known just by the responsible entities. There is not enough flood risk awareness among people and information about what to do in case of flood events in critical streets is often lacking.

6.6 Measures and strategies for strengthening flood resilience in coastal regions (WP5)

6.6.1 Description of the case study work

Forty groups of structural measures have been proposed within the study area, which were classified into 5 levels of prioritization according to their impact over the operation of the sewer system (P00, P01, P02, P03 and P04). Among all the measures the main ones are related to repair bad conduits connections, increase of conduits hydraulic capacity, elimination of discharges, construction of new conduits and transformations from combined to separate sewers in certain places. The total estimated budget for them is 15,188,001.23 €.

A detailed cost benefit analysis will be carried out in order to make a proper selection. Results from this analysis will provide insights on the economic efficiency of the adaptation measures against the business as usual scenario, since the economic value of the potential impacts will be analysed jointly with the costs of implementing and maintaining the adaptation measures. Within the scope of this analysis, benefits will be defined as the reduction in the expected annual damages (EAD) that will presumably be achieved by implementing the considered adaptation measures. Costs will be analysed by taking into consideration the initial costs of setting up or constructing the respective measure – the capital costs (CAPEX) – and any costs that are required to operate and maintain the adaptation measure – the operational and maintenance costs (OPEX).These measures have been implemented in the hydrodynamic model, thereby obtaining post-measures flood maps. According to future rainfall projections (WP2) no significant variations are expected, therefore same design storm were utilised as inputs for the model. Therefore, only selected measures differentiate current status from the future one, since land uses are expected to remain in the current state as Marbella City Council stated. This measures implementation let to compare risk and damage assessment between current and future state.

The risks maps when comparing 100 years return period flood in current and future state indicates clearly how risks for pedestrians drops significantly, especially in Nabeul Avenue which is the most risky area currently. The damage assessment comparison denotes a high drop of the Expected Annual Damage (EAD) from 1,0066,939.68 € to 97,767.24 € (91% of reduction), which means an adequate functioning of the proposed measures.

6.6.2 Lessons learned from the case study work

- In the recent period, the damage has been increasing exponentially, therefore urgent measures have to be taken as soon as possible in order to avoid losses and to save economical resources which have been spent to recover previous conditions so far.
- A current and post-measures state comparison is essential in order to assess how they improve risks for pedestrians and reduce damages. After this comparison a more reliable selection of measures can be conducted.

6.7 Concluding remarks

Briefly, the present research activity allowed to have an overall view of the potential risk for pedestrians and damage provoked to properties and assets by flood events characterized by a set

of design storms with several return periods. A risk and damage assessment has been conducted, focusing on pedestrians and buildings respectively.

The obtained result were necessary for the correct flood management in Marbella city due to old and recent flooding problems. The main consequences of typical heavy rainfall events in Marbella are that flooding can happen in a very short time and significant discharges are produced in few hours or minutes. Furthermore, in the recent period, the damage has been increasing exponentially, therefore urgent measures have to be taken as soon as possible in order to avoid losses and to save economical resources which have been spent to recover previous conditions so far. Besides the hazard increase, Marbella has been also experiencing a raise of vulnerability because of the increasing urban population.

Furthermore, Marbella conditions are further exacerbated because the economic activity of the city relies mainly on tourism, which is heavily affected and damaged by the extreme events that happen with a more and more high frequency in Marbella. Hazard and vulnerability increases imply that risk has been growing as well. Therefore, in order to manage the flooding risk, more tools have to be available for decision makers.

Thus, it is clear that this difficult situation needs measures to be solved and the risk analysis can be considered as a first important step towards the definition of a management strategy that includes efficient measures capable of reducing risk and extreme events frequency or, at least, their consequences on people.

Forty groups of structural measures have been proposed, together with the non-structured measure of Early Warning System (EWM) developed, within the study area, which were classified into 5 levels of prioritization according to their impact over the operation of the sewer system. Among all the measures the main ones are related to repair bad conduits connections, increase of conduits hydraulic capacity, elimination of discharges, construction of new conduits and transformations from combined to separate sewers in certain places. The risks assessment when comparing 100 years return period flood in current and future state (with measures) indicates clearly how risks for pedestrians drops significantly, especially in Nabeul Avenue which is one of the most risky area currently. The damage assessment comparison denotes a high drop of the Expected Annual Damage (EAD) from 1,0066,939.68 € to 97,767.24 € (91% of reduction), which means an adequate functioning of the proposed measures.

In this context, our research focuses on the need of new efficient and accurate tools. Risk and damage analysis represents a new way of thinking about flooding management because municipalities, companies, organizations and people are now able to have an overall view of the risks that threat their lives, properties and assets.

7 Case Study – Crete, Greece

7.1 A brief description of the case study area

Rethymno, the area under study, is sited at the Region of Crete in Greece and its population stands at 32,468 inhabitants according to Census 2011(Hellenic Statistical Authority, 2011) with a density 140.12 population/km^2. As the 3rd most populous urban area in the island of Crete, commercial, administrative, cultural and tourist activities are being developed along the north coast where the city is located. The mean absolute altitude is 15 m and the length along the coastline of the area under study is 8 km (Makropoulos C. et al., 2015).

For the city of Rethymno (*Figure 21*), multiple stressors have always posed flood threats. The terrain and streams morphology convey volumes of storm water runoff from the upstream rural areas to the highly urbanized, flat downstream zones, pressurizing the drainage facilities and the flood defence infrastructures. The dominant strong northern and north-western winds highly affect the exposed coastal zone and result in the development of waves, which often overtop the harbour infrastructure and erode recreational beaches. Historic floods (1969–1999)(Archontakis D., 1971, 1991, 1993, 1999, 2006, 2013) led to adverse human, material, economic and environmental effects and eventually to the selection of prevention and mitigation measures, e.g., arrangement and diversion of streams and torrents, construction of circular storm water drainage collectors, internal-primary drainage network and flood control dams (Karavokiros G. et al., 2016). Nevertheless, both the urban and coastal areas are still subjected to flood problems (Makropoulos C. et al., 2015), e.g., extensive damages to windward breakwaters of the harbour (Tsoukala V. et al., 2016) and backwater effects at drainage network outfalls as experienced during recent flood events (2010–2015). As such, the need to manage flood risk through a more integrated approach which would also be coupled with stakeholder involvement was initially identified and eventually formed the primary goals for the specific case study.

The PEARL approach applied in Rethymno could be summarised as follows:

1. Identification of the area under study and its problems (i.e. gaining knowledge from the stakeholders, collecting data, conducting field research and literature review)
2. Understanding flood risk under different scenarios (e.g. hydro-meteorological, failure of infrastructure, urban growth etc.)
3. Assessing the level of city's resilience (for different flood events or for the identification of suitable measures for the case study's needs)
4. Equipping authorities with tools for decision making in order to enhance decision making processes towards flood resilience planning
5. Developing an actionable roadmap specifically developed for case study needs which will enhance flood risk management and will be commonly agreed with local stakeholders.

All the above steps, where accomplished while ensuring bidirectional communications and cooperation with local stakeholders through the Learning and Action Alliances (Gourgoura P.,Blätgen T., et al., 2015).

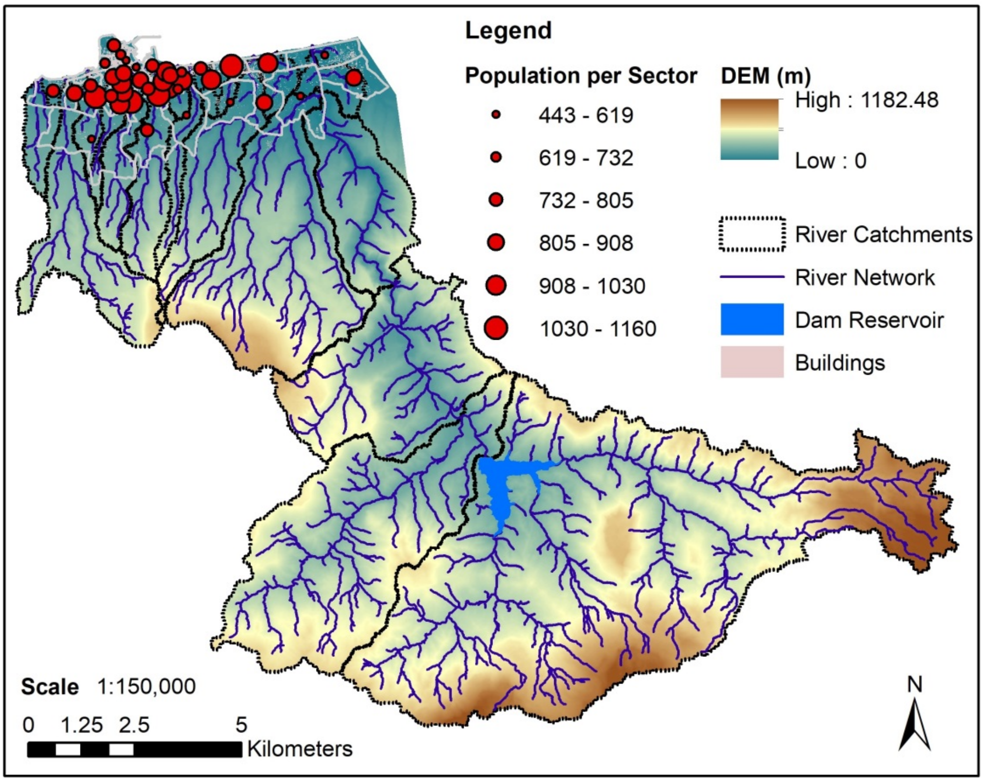


Figure 41: Rethymno case study

The challenges encountered in the beginning of PEARL project where related to hazard i.e. the simulation of multiple hazards and types of flood which required coupling of multiple models in different spatial and temporal scales. The missing data was one more difficulty faced. Such data were discharge measurements necessary for models' calibration, the absence of the sewerage and stormwater network in digital format in order to be included within the setup of hydraulic models and finally the plans of infrastructures (closed conduits) crossing the urban area and leading stormwater from river beds to the sea. The latter was handled by designing the route of closed parts of river beds based on the road network (studied from the high resolution ortho-photographs available in the case study), logical assumptions related to slopes and elevations of closed part of the network and available textual information in case study reports. One more challenge was the long computational time of simulations while utilising data of high resolution (e.g. Digital Surface Model of 0.8 m). The absence of a responsible authority and flood management plans, unclear jurisdictions among existing authorities, low preparedness and flood risk awareness of citizens, civil engineers, authorities, etc. where challenges faced within stakeholder engagement activities, as well as the comprehension of Roots and Causes of severe past flood events, specifically in terms of social aspects. All the above challenges were handled within PEARL and it became clear that providing tangible results and tools to the city of Rethymno was of primary importance.

7.2 Understanding the formation of vulnerability and risk in coastal regions (WP1)

7.2.1 Description of the activities performed in the case study area with the key outcomes

For the Rethymno case study, three methodologies, developed within WP1, were applied. These are: **Risk and Root Cause Assessment (RRCA**) and as part of the **Vulnerability Assessment** a **Household survey** and the spatial disparities in vulnerability patterns.

Root Cause Assessment: In Rethymno, findings from face-to-face interviews with individual experts and stakeholders were coupled with results from the stakeholders' workshops. For Rethymno, the interviewees included experts from water resources and civil protection agencies, the former mayor and regional authority, NGO representatives, port authority, hotel and restaurant owners and local households. The interview questions and Root Cause Analysis reports were structured around the Root Cause Analysis framework, and focussed as far as possible on understanding the causes of specific disaster events. The drafting of the Root Cause Analysis report was undertaken in close conjunction with the local partner NTUA, and the findings fed into, and corroborated against, the 1st stakeholders workshop undertaken in Rethymno.

Root Cause Analysis of annual flooding events in Rethymno, Crete, highlighted how flooding related to storm waves and flash flooding, was also linked to the challenges of maintaining existing risk mitigation infrastructure and moving to a more holistic risk governance approach, including greater public awareness-raising. The analysis highlighted how these challenges reflected a long-standing history of weak governance capacity at the local level, political organisation that precluded wide stakeholder engagement and institutional fragmentation of disaster risk management at higher levels of governance. As well as the interactions and feedbacks between these processes, the historic analysis also revealed the discontinuities and non-linear nature of such processes: an earlier period of infrastructure investment by the EU in risk mitigation measures was superseded by a more recent period characterised by the impacts of austerity. However, austerity measures are also rupturing pre-existing political relations, opening up new possibilities in the future for public engagement in disaster risk management in the town. A key product of the RRCA is the RRCA scheme, which distinguishes between drivers of hazard/exposure/vulnerability, as well as physical/socioeconomic/ governance aspects. Further sub-categories are historic/contemporary/future impacts.

As the method focussed on interviews with relevant experts rather than affected households and individuals, root causes and drivers related to perceptions, values and beliefs were not systematically explored and not included in the scheme. However, the analysis highlighted that often conflicts of perception formed part of the governance root cause category, while socio-economic and related demographic change influenced perceptions, values and beliefs. Root Cause Analysis was also conducted in conjunction with a household-level vulnerability assessment - for a discussion of the use of the two methods together see Deliverable 1.3 (Fraser A.; Sorg L. et.al., 2016).

Household survey: As previously stated, a household survey was conducted for Rethymno (for more details see report by Sorg L. (2016). The aim of the survey was to assess how individuals respond before/during/after a flood, and thereby gain an understanding of various risk management strategies. The survey covered questions on the availability of information (e.g. early warning, evacuation routes), social networks and support from local authorities, as well as individual preparedness. Findings illustrated the differences in conceptions held by different stakeholders:

household respondents in Rethymno, for example, wanted officials to take responsibility for better technical, protection measures, whereas the general consensus among officials in Rethymno was that there was a need to focus on awareness-raising and private activities that contribute to flood risk, including private violations of planning regulations. The results of the household survey were already presented to stakeholders, followed by discussions in the course of the 2nd stakeholder workshop in Rethymno (Gourgoura P. et al., 2016).

Spatial Vulnerability Assessment: The Case Study in Rethymno/Crete also employed the proposed vulnerability framework. This gives the opportunity to elaborate the flexibility of the framework showing besides Genoa a second implementation and hence the adaptation of the framework to the local necessities and data availabilities. The raw data for the calculation of indicators was extracted by several sources such as the Hellenic Statistical Authority (after signing confidentiality agreements), the Technical and Planning Department of Rethymno's Municipality and open access databases (e.g. http://geodata.gov.gr/). The base maps used for cartography and presentation of results were taken from Open Street Map, ESRI ArcGIS.

The geospatial data used for the analysis or the creation of maps and representation of results were:

- Boundary of river catchments (.shp)
- Boundary of last flooding event as produced during hazard assessment (.shp)
- Administrative boundaries of Rethymno case study (.shp)
- Boundaries of census' sectors (.shp)
- Boundaries of blocks (.shp)
- Boundaries of buildings (.shp)

The spatially explicit statistical data were consisted of three basic categories as collected during Census 2011 which are the below:

- Statistical data concerning individuals/citizens available at block scale
- Statistical data concerning households available at block scale
- Statistical data concerning buildings available at sector scale

The vulnerability assessment was conducted on the smallest possible scale i.e. block scale since the majority of data was available at that spatial scale. All calculations were performed either in MS Excel based on raw data or extracted after queries in ArcGIS while using/building SQL expressions and then imported in excel sheets. Finally, the results of calculations were linked to ArcGIS shapefiles for the creation of maps and their representation in space.

After the calculation of each indicator for the block scale, the three sub-indexes were estimated and finally the overall vulnerability index. In order to have the results immediately comprehendible for Rethymno's stakeholders, values of vulnerability were normalised (through min-max normalisation), therefore, the newly derived values ranged from 0 to 100 as depicted in the map of *Figure 42*.

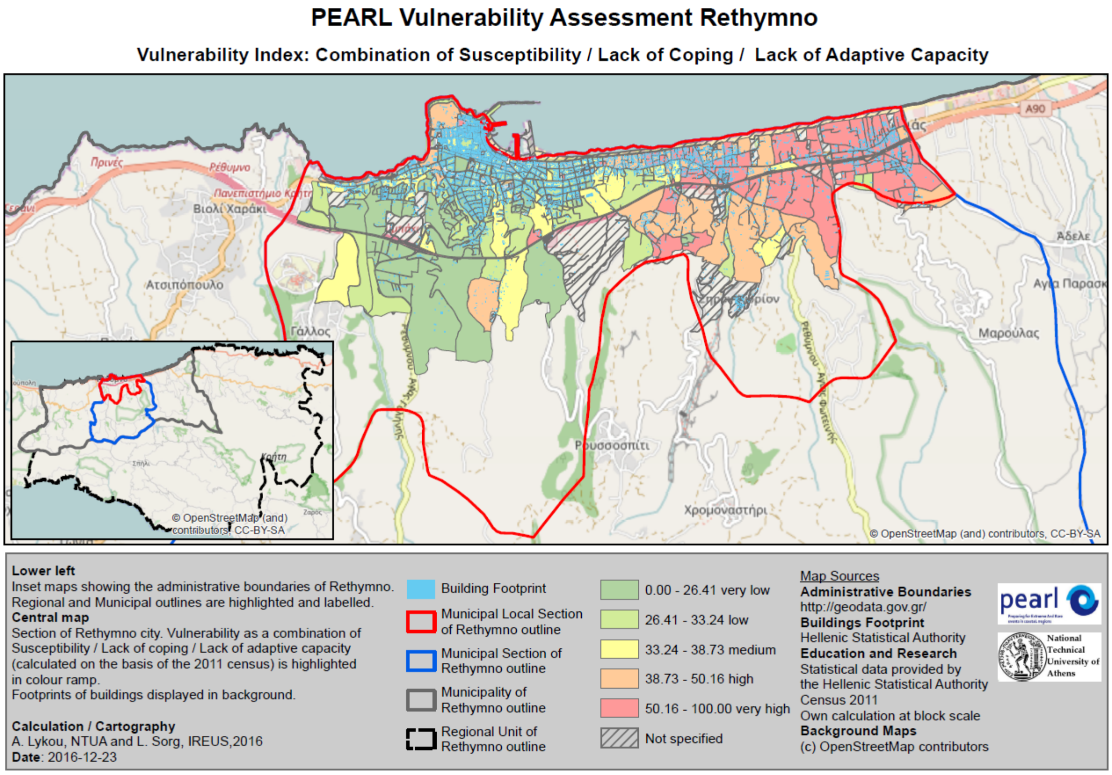


Figure 42: Vulnerability map of Rethymno case study (analysis was conducted at a block scale, values were normalised)

Additional information can be found in:

- Deliverable 1.2: Final PEARL framework and source book document
- Deliverable 1.3: Final Report describing the full RRCA methodology and its applicability
- Deliverable 3.4: Report on assessed risk and impacts in all EU case study areas including inputs into the platform developed in WP6
- Deliverable 6.2: Summary Report on EU and international case studies

7.2.2 Lessons learned from the case study work

The Rethymno case study was one of the main case studies for the development and application of the WP1 tools, therefore the holistic approach was strongly considered. All results were fed back into the stakeholder´s Learning and Action Alliances (WP5). Here, the results were discussed and the feedback was incorporated into the respective reports and deliverables. Since Rethymno was a forerunner case study the WP1 tools were successfully applied and transferability, as well as up-/downscaling options for other case studies were ensured (for tools and results see section above). Moreover, this engaged an effective interaction of tools and knowledge. For Rethymno, the good arrangement and co-operation between the involved research partners has to be highlighted in this regard.

7.3 Understanding the formation of hazards under extreme events (WP2)

NTUA is not officially participating in WP2. Even though part of the implemented work related to risk assessment and modelling could be described in WP2 section, it has been agreed with the consortium to claim reseach activities within WP3 where NTUA has budget as per DoW.

7.4 Holstic and multiple risk assessment (WP3)

7.4.1 Description of the case study work

Having as primary objective the hazard assessment for multiple stressors for the city of Rethymno, an integrated modelling framework has been developed which combines different models and methodologies utilised in the simulation of flood risk. The primary components of this framework are comprised of the followings (Figure 23):

1) Estimation of atmospheric variables and development of climate change scenarios
2) Estimation of Wave Characteristics (4-level downscaling approach)
3) Modelling of nearshore response to hurricane impacts and storms (e.g. storm surges, wave propagation, sediment transport, erosion, wave diffraction and refraction, etc.)
4) Catchment hydrological modelling (incl. hydraulic calculations of natural channels networks)
5) Urban flood modelling (incl. surface flow & stormwater network)
6) Comparing alternative solutions and suggesting interventions for damage repair & protection

Figure 43: The integrated modelling framework applied in Rethymno

While trying to understand downstream stressors from the coast, the components of this framework include a sequential process working on different spatial and temporal scales (*Figure 24*), starting from the level of climatic analysis at a regional level and ending with the simulation of wave overtopping at port facilities and wave run-up at the shore. Further information in terms of the classification of storm events can be found at Martzikos et. al. (2016, 2017). For the simulation of the hydrodynamic field and the sediment transport in shallow water regions, as well as the estimation of wave runup and overtopping, special efforts have been allocated by using Xbeach (developed by Deltares) and MIKE softwares (developed by DHI). Results on wave propagation, hydrodynamic and morphodynamic conditions from both models are availalbe in Afentoulis V. et al. (2017) and Kragiopoulou E. et al. (2016).

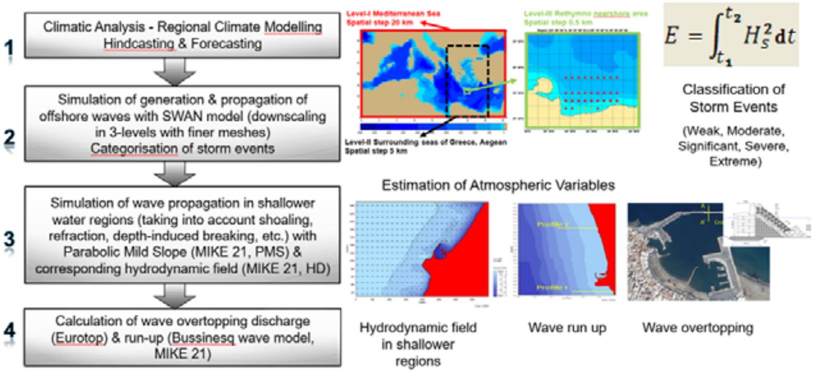


Figure 44: Schematic of integrated modelling framework for the comprehension of coastal stressors (adopted from (Tsoukala V. et al. (2016))

Moving to the inland area and the comprehension of the upstream pressures, the research activities were initiated with the pre-processing of geospatial data which enabled the sub-catchments and river network delineation, the estimation of stream and sub-catchments characteristics such the concentration times, the estimation of hydrological parameters and finally the derivation of necessary input data for hydrologic and hydraulic calculations.

After performing research on several commercial or open access existing models for hydrologic and hydraulic simulations, the MIKE products by DHI were selected. Specifically, a combination of 1D-2D MIKE models (MIKE 11, MIKE 21FM and MIKE Urban) has been setup and coupled through MIKE Flood (*Figure 25*) for the simulation of flood events and their propagation in space and time. The total area under study is defined by all the river catchments that cross the urban area of Rethymno (145 km^2) as presented in *Figure 21*. This area has been taken into consideration for the hydrologic simulation and the calculation of the total volumes of water that drain through the city. Parts of the main river beds with open channel cross section at the upstream areas or all the way down to the sea (e.g. Gallianos River) have been set up in the 1D model MIKE 11. The parts of river with closed cross sections that cross the city have been simulated with MIKE URBAN in order to enable interactions between the subsurface drainage network and the surface runoff. MIKE 21FM is the 2D model used for the simulation of surface runoff by using its hydrodynamic component. All three models have been coupled with MIKE Flood enabling combined 1D-2D simulation of flood phenomena.

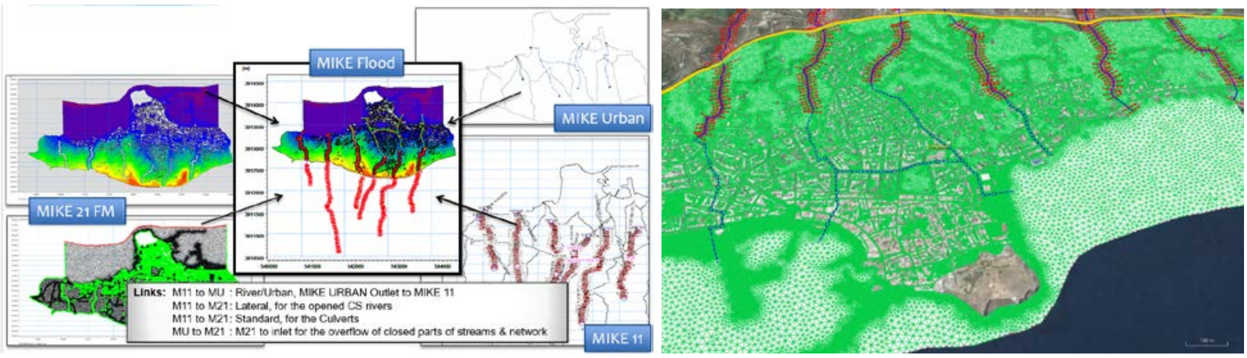


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Figure 45: (a) Schematic of integrated modelling framework for the simulation of urban floods, (b) Conceptual model of Area 1 as presented through the WebLP interface (mesh elements in green triangles with different size based on desired spatial resolution, parts of rivers with closed cross sections in dashed blue lines, cyan

rectangles are manholes of subsurface network through which interactions between surface runoff and flow in subsurface networks is enabled, blue continues lines represent the parts of physical channels/rivers with open cross sections and red lines stands for the cross sections derived from DEM)

Utilising the above models, different scenarios has been examined, the outcomes of which have been assessed. Those scenarios were:

- Precipitation scenarios:
  - Historic precipitation event of November 10th, 1999
  - Precipitation events of 10, 50, 100 and 1000 years return period in alignment with the EU Flood Directive
- Storm scenarios of North, Northeast and Northwest wind direction, of different wave height and duration
- Failure of infrastructure: Dam break scenario of Potamon Dam

For each scenario several outcomes were derived during normal run complete of models. Those are: maximum water depth (meter), time at maximum water depth (second), maximum current speed (meter/second), time at maximum current speed (second), duration above threshold (second), surface elevation (meter), still water depth (meter), total water depth (meter), U velocity component (meter/sec), V velocity component (meter/sec), P flux ($meter^3$/sec/m), Q flux ($meter^3$/sec/m), CFL number (HD) (undefined). Of special interest for the coastal simuation were results such as the significant wave heigh (m), currenct velocities in both x and y directions (m/s), sediment load in both directions (m^3/s/m), flactuation of surface water level and changed in bathymatry due to sedient transport. The abovementioned components vary in space and/or in time too.

Having produced maximum water depth and velocities values in domain, hazard classification was conducated in three intensity levels i.e. Low, Medium and High. Classes of water depth and velocites were drafted based on local conditions and citizens risk perception. Following the procedure described in Vojinovic et al. (2016) under the traditional approach to flood risk assessment, the combined risk assessment was fulfilled by multiplying the map of vulnerability (refer to section 7.2.1) with hazard maps. Areas received scores of risk lower than 0.25 were considered of low risk, whereas areas with scores higher than 0.45 were considered as high risk zones. A typical flood risk map for the 1999 precipitation event is presented in *Figure 46*.

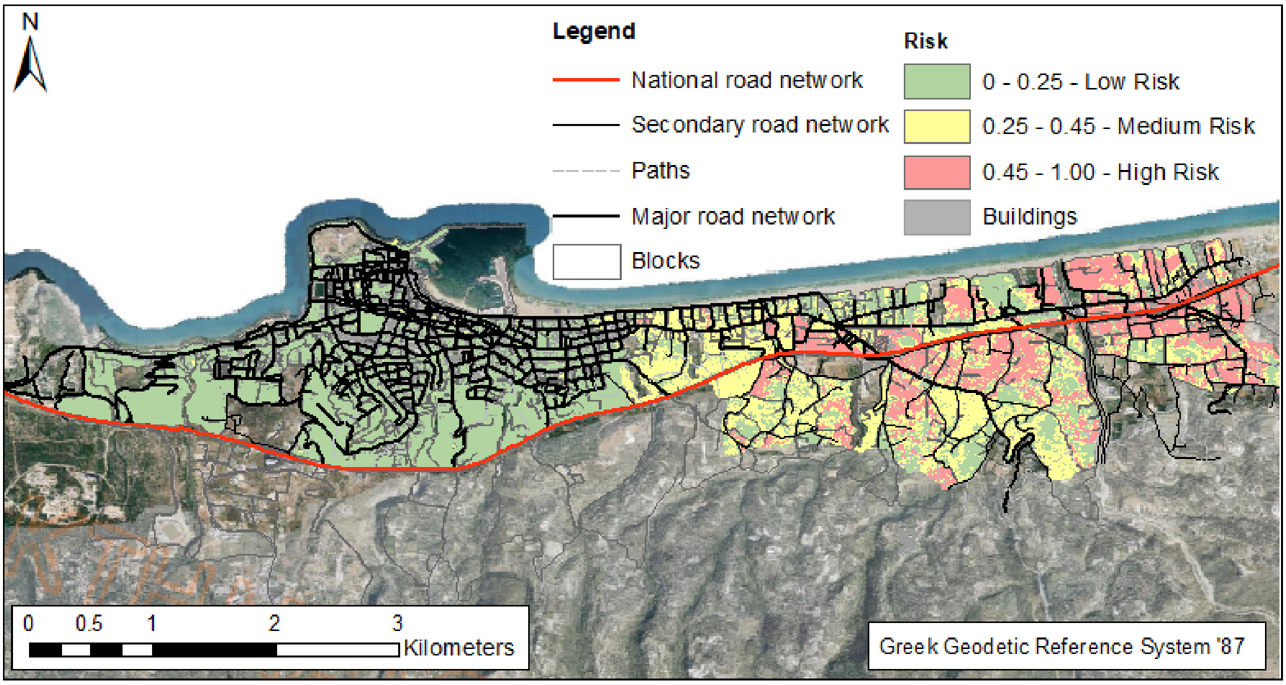

Figure 46: Flood risk map of 1999 historical precipitation event

7.4.2 Lessons learned from the case study work

After assessing the flood risk results for the inland part, areas of Rethymno which are under higher risk are the Arkadiou Street in the Old Town of Rethymno and the adjacent zones of Platanias River due the flat terrain. It is worth mentioning that after comparing the areas that receive higher flood water depth values with the areas which were highlighted by the LAA members (i.e. areas where Rethymno's is facing flood problems) (Gourgoura P.,Lykou A., et al., 2015), it was apparent that those areas fit and overlap. The latter indicates the validity of the hydrodynamic models and their proper setup despite the fact that no data were available for calibration purposes. In terms of the coastal simulations, the models' results indicate that the coastal system is exposed to significant erosion due to energetic waves and strong hydrodynamic currents. The main direction of the sediment drifts is towards North West offshore areas. Furthermore, intensive overtopping discharge and wave run-up are also revealed from the numerical simulation of the coastal processes. Agreement between the two models' results (XBeach and MIKE models), provides a more secure estimation of the physical processes (Afentoulis V. et al., 2017).

Within this case study, globally known and accepted software was utilised (commercial and open access) structured within a methodological procedure which can be applied at every case study and at any scale (depending on available data and scope of work). Hence, the modelling framework and methodology is fully transferable.

Apart from the hydrodynamic processes, the social rout causes were investigated as part of WP1 i.e. through the RRCA framework, the household survey and the social vulnerability assessment which was conducted on the basis of the available statistical data. The technical rout causes were taken into consideration by including available infrastructure in the models' set up, as well as by investing scenarios of infrastructure failure (e.g. the dam break scenario of Potamon dam). The natural root causes were included in the analysis under the form of different precipitation and storm

scenarios. The combination and incorporation of social, technical and natural aspects form the holistic approach followed in Rethymno case study.

Even though the modelling set-ups cannot be utilised by the local LAAs due to the highly sophisticated and unfamiliar to them software, in collaboration with them, knowledge was produced valuable for the design of their future infrastructure and the repair of the damages in the windward breakwater of Rethymno's port. While utilising available models, different repairing solutions were assessed along with their estimated cost. Additionally, all the results produced are available to the authorities through the developed Web Learning and Planning Platform of WP5. That serves for the flood risk awareness of authorities themselves, which became apartment during the LAA workshops, but also enables the utilisation of the maps for raising the awareness of citizens.

Last and of primary importance was the fact that the analysis and work produced within PEARL provided justification on why Rethymno city should be included in the areas of the island of Crete to which the EU Flood Directive is being implemented even though Rethymno was not characterised as an area of potential significant flood risk during the preliminary flood risk assessment. Hence, no work has been conducted in Rethymno as part of the EU Flood Directive implementation. Nevertheless, the results of PEARL have been asked to be communicated officially to the responsible regional and national authorities, so that Rethymno will be included in the potentially high risk zones i.e. Rethymno's authorities will be eligible in the future to apply for funding related to the implementation of new flood risk management measures.

Detailed information related the methodological framework and modelling work can be found in Deliverable 3.4 and 6.2 of PEARL.

7.5 Flood forcasting and early warning systems for coastal regions (WP4)

7.5.1 Description of the case study work

For the case study of Rethymno various tecniques (suggested in WP4) were tested for achieving faster simulations since a higlhy sophisticed and complex model chain was set up demanding great deal of computation power. Rethymno flood models employ a 3-way coupling of 1D and 2D simulations engines (DHI's MIKE models), enabling analysis of urban, coastal and riverine flooding under different precipitation scenarios (past recorded events or produced under different return periods) (Deliverable 4.2).

Followng the general guidance described in Deliverable 4.2 and DHI's suggestions, the following speed-up techniques were tested and evaluated with Rethymno urban coastal flood model. Those are the following:

1) Selection of model domain, computational grid type and elements size
2) Modification of modelling approach
3) Maximising computational power

Components 1 and 2 of the above list aim to minimise computational loads whereas the last one mainly targets to increase computation speed by maximising and utilising computational power.

Furthermore, within the WP4 work, the crowdsourcing application named after PEARL Detective was tested in Rethymno and several flood reports were collected and integrated in the PEARL WebLP of WP5.

7.5.2 Lessons learned from the case study work

While applying the first and second speed up technique, the set up of operational and functional models which ensured normal run complete of simulations was possible. The use of MPI method instead of OpenMP gave a speed up factor amost equal to 1.42. The total overall gain while comparing the performance of the two computers along with GPU computing resulted in the greater speed up factor of around 6. Comparing the computation time of the two apparoches i.e. applying rain on grid on the domaim or distributing runoff to a fictive network, it was evidenced that the simulations lasted around 7.9 times more when 2D rain was used. Further details on all three speed up approaches and key lessons extracted during geometry set up, the computational times achieved and the compariosn of results are being provided in the Deliveralble 4.2 (PEARL Consortium: Lead Author: DHI, 2017).

Even though the research activities and approaches descibed in the previous section (7.5.1) were performed by using only MIKE models, neverthelss it is argued that the same work can be performmed with any other model which provides and supports similar capabilities i.e. combination of 1D and 2D component and creation of mesh zones of different resolutions. The methods related to the maximisation of computational power may also be applied with the use of other software products to any case study, as long as compatibility and software requirements are known. It is highlighted, that each hydrodynamic model has different capabilities for the maximisation of computational speed with some models supporting the utilisation of multiple processing cores, others enabling GPU computing or even both.

In terms of the PEARL Detective, it is a user-friendly app which can be used by anyone who has an android phone and at any case study since it is freely available in Google Play[1]. Its utilisation enables the collection of data (text, images and location) related to floods from the field, information which cannot be obtained otherwise.

7.6 Stakeholder involvement for strengthening resilience of coastal regions (WP5)

7.6.1 Description of the case study work

A primary objective of WP5 was the identification of key stakeholders involved in decision making procedure regarding flood risk management in Rethymno and the establishment of a local Learning and Action Alliance (LAA). Moreover, this participatory procedure has resulted in the creation of a Roadmap i.e. a strategic risk management plan for the area under study, which has been designed with the local society's consensus and aims to increase city's flood resilience. The local LAA as a methodology of involvement of stakeholders and locals, is being evolved along three axis (based on Van Herk S. et al. (2011) and Ashley R.M. and Blanksby J.R. (2009) and Ashley R. M. et al. (2012)): establishing facts, creating common images and setting shared ambitions. Towards that direction, the work fulfilled within PEARL included a stakeholders' analysis, organisation of several technical meetings with key services and authorities involved in flood risk management and most importantly the implementation of participatory workshops where all interested parties and decision makers were represented and engaged through different activities.

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[1] PearlDetective app available at:
https://play.google.com/store/apps/details?id=com.hydrologic.pearldetective&hl=el

Based on the theory and the methodology of the PEARL LAAs (fully described in Milestone 14 (BlätgenT. et al., 2014) and Deliverable 5.1 documents (Sorg L. et al., 2016) three rounds of interactive workshops were foreseen for the whole project duration. Aims of those workshops were initially to launch the concept of the LAA to stakeholders, then to promote the establishment and eventually to secure the functioning of the initiative. The participatory workshops were designed in an interactive format so as to combine methods and results from all PEARL WPs (e.g. the root cause analysis, the household survey and the vulnerability assessment of WP1, the modelling framework, the hazard and risk assessment of WP3, etc.). Moreover through those events the PEARL tools were lively demonstrated and tested by the stakeholders' themselves after they have participated in the beta testing period and provided suggestions during tool's development. Such tools were the Web Learning and Planning Platform (WP5), the PEARL Detective Application (WP4), the PEARL ABM SAS (WP5), the Flood Resilience Index methodology and tool (WP5) and the PEARL Knowledge Base (WP5). The interactive procedure followed aimed and resulted in high involvement of local authorities and civil society in the PEARL's work and progress, which produced a bidirectional exchange of knowledge and a bottom up approach of the Roadmap design.

7.6.2 Lessons learned from the case study work

The LAA method for stakeholder engagement is considered applicable and transferable, but with necessary adaptations to local societies. Different local socio-economic conditions, levels of governance and multi-stakeholder approaches define the actual format of the method and the potential results in each case study area.

Concerning the LAA method implementation in Rethymno, it can be argued that it receives a pretty positive evaluation, whereas the LAA members are rather hesitating. Despite the increased interest expressed by all participants and authorities' representatives, several doubts and concerns were raised at the same time. Indeed there is a general sense that a LAA in Rethymno would be an asset in terms of flood management for the city, and all participants agreed to give a chance to an innovative approach, but on the other hand many of them rely on a pessimistic view that not many things can be done. The fact that no "leaders" were identified among the participants, who were/will be willing to actually run the LAA turns the success of the initiative doubtful (Gourgoura P. et al., 2015).

Although positive results and comments followed the workshops, a clear evaluation of the LAA itself is not feasible yet since the LAA is not yet self-running, and potential members of it have not taken any action yet. During the 2nd workshop specific actions were decided e.g. clean up of as stream in order to raise citizen's awareness, but so far nothing has been fulfilled. The final workshop and the presentation/demonstration of the almost completed PEARL tools supported and promoted the LAA initiative once more, as it provided the LAA members with the tools to work on specific scenarios and accordingly act or/and collaborate and in general equipped them with tools supporting decision making processes.

It is crucial to highlight that regardless the progress of Rethymno's LAA function, key points that define the direction of the future action have already been identified and commonly agreed by the participating groups and have been taken into consideration in the development of Rethymno's Roadmap. Those were the following:

- **The necessity of a LAA** that could provide significant support to the current authorities and municipality's work towards flood management and disaster risk reduction

- **The poor monitoring** of **several civil protection services** and **communicational/hierarchical gaps**
- The fact that **most of policies** applied are **of post–disaster management** and do not promote preparedness activities, awareness raising and risk mitigation
- **The need for awareness raising actions instead of structural measures.** Major flood problems derive from citizens' ignorance and private activities which intervene the flood risk evolution. It was commonly agreed that activities sensitizing citizens and building of a more responsible civil behaviour are of primary importance and should be first implemented.

In terms of institutional and governance practice in Rethymno and in Greece in general, even though there are several policies described within legal, international and national documents, they haven't actually assisted in the improvement of flood risk management at a local level due their spatial scale of implementation, the lack of multi-stakeholder approach and the fact that they are giving emphasis on post disaster management and reconstruction measures, instead of risks prevention and mitigation. At a local level, a crucial issue with bad impact in flood management process, is the lack of effective communication among authorities, bad monitoring of the different services and departments, overlapping of responsibilities and barriers derived by the several levels of hierarchy. The advanced bureaucracy in combination with the financial crisis the last 7-8 years, resulted to lack of sufficient funding and understaffed environmental public services, which in turn leaded to a downgraded flood risk governance performance (Mavrogenis S., 2016).

Despite the obstacles that were/are being encountered, a remarkable achievement has been accomplished within the LAA activities and workshops. Specifically, during the last LAA meeting (29th of September 2017), the PEARL partners were requested to communicate PEARL results (especially the ones related to modelling work i.e. hazard and risk) to the responsible for the implementation of the EU Flood Directive, regional and national authorities. The reason for communicating such a technical report is, that despite the fact that Rethymno area is not considered as an area of potential significant flood risk (based on the preliminary assessment results), the authorities having proved that Rethymno's facing flood problems, they will be eligible to apply and raise national and EU funds for the implementation and construction of new measures that the city needs.

7.7 Measures and strategies for strengthening flood resilience in coastal regions (WP5)

7.7.1 Description of the case study work

Equipping authorities with tools for decision making in order to enhance decision making processes towards flood resilience planning was one of primary objectives set within the PEARL and the current case study work from the very beginning. For that purpose and within the content of WP5, several tools, autonomous but also integrated, have been developed to serve the aforementioned purpose and assist measure selection. Those tools have been tested thoroughly in the case study of Rethymno and are the following:

1) The Flood Resilience Framework (FRI) and the PEARL online FRI tool (see Deliverable 5.2)
2) The PEARL Knowledge Base (KB) (refer to Deliverable 5.3)
3) The PEARL institutional ABM Simulating Authorities' decision making for the Selection of resilience strategies (the PEARL ABM SAS) (refer to Deliverable 5.4)
4) The PEARL Toolbox (refer to Deliverable 5.4)
5) The PEARL Web Learning and Planning Platform (refer to Deliverable 5.5)

The FRI methodology (described in Del 5.2) serves to a qualitative assessment of resilience of an urban system whereas the online FRI tool[2] "transforms" the slightly modified FRI methodology to a usable tool which enables stakeholders to assess the resilience per dimension (Natural, Social, Economic, Institutional, and Physical) of their city. After the end-users have rated the different indicators of the framework and the resilience index values have been estimated, they are able to identify the dimension which would require implementation of new measures in order to enhance its resilience. Further, all measures available in the PEARL KB have been linked to each indicator, hence, the users are able to navigate through the measures which would increase the value of each indicator and eventually the overall resilience of the dimensions and the urban system. FRI assessment results of Rethymno, as conducted by the LAA members, as well as the measures identified by them are available in Deliverable 5.2 and Karavokiros G. et al. (2016).

The PEARL KB[3] is an intelligent web-based application developed to assist end-users to navigate from their observed problem to a selection (screening) of possible options/interventions worth considering (through modelling or other work) while providing a repository of measures and application of measures around the world accessible and searched by different ways (graphical selections, texts, tables, pivot tables, etc.). Apart from contributing in the PEARL KB development, the stakeholders of Rethymno have been trained to use it, have provided material in terms of measures in order to be uploaded and interacted with it in order to identify measures suitable for the case study (Karavokiros G. et al., 2016).

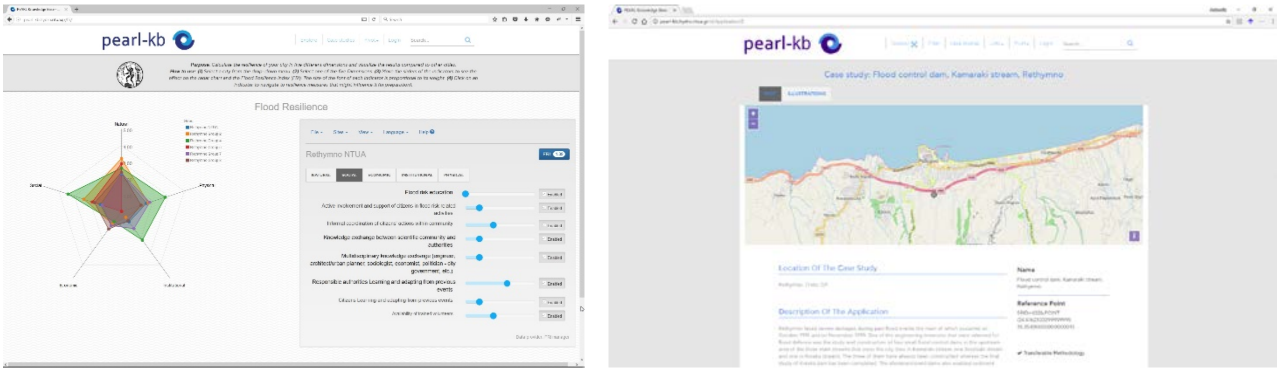

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Figure 47: Resilience assessment results of Rethymno's stakeholders (b) Flood control dam implemented in Rethymno and available through the PEARL KB's interface

What supplements the use of the PEARL KB is the PEARL ABM SAS and the PEARL Toolbox[4] developed under task 5.4. For identifying the most appropriate flood resilience measures and strategies, the PEARL Toolbox supports a methodology, which is divided in the following discrete stages: (a) the selection of resilince measure through the KB, (b) the use of optimisation and multi-criteria decision analysis algorithms to define specific attributes of the selected resilience strategies that offer a minimised cost and a maximised protection from extreme events and finally (c) the use of the PEARL ABM SAS[5] (Figure 48) which enables users to simulate the authorities' decision

[2] PEARL online FRI tool available at: http://pearl-kb.hydro.ntua.gr/fri/

[3] The PEARL Knowledge Base available at: http://pearl-kb.hydro.ntua.gr

[4] The PEARL Toolbox available at: http://pearl-kb.hydro.ntua.gr/tb/

[5] The PEARL ABMS SAS: http://83.212.168.149:8095/abmtool/

making process for the selection of resilience strategies and assess the performance of the case study area under different socio-economic and flood events scenarios. The latter provides a useful and a tangible way for authorities to examine and explore all decisive factors which affect the actual implementation of measure, after their selection has been made. Such factors are related to the available funding and how the funds are being allocated in time, the level of authorities' collaboration, etc.

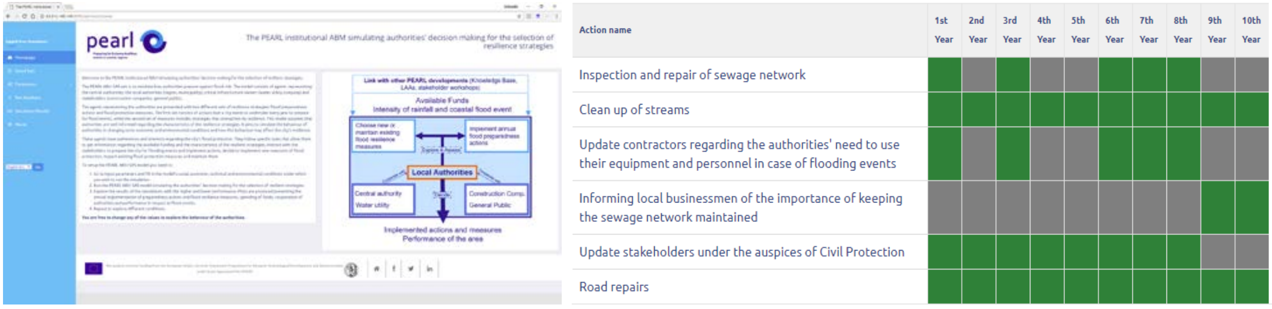

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Figure 48: PEARL ABM SAS (a) home page and (b) example of selected flood preparation actions produced from conducted simulation

The PEARL WebLP[6] provides a space where the LAA members may have full access to case study modelling results, but at the same time serves as a common space where all tools and application on measures selection can be accessed (through the same GUI under the "Generic plugin section"). Therefore, the authorities after having reviewed the areas which are at greater flood risk from the produced maps are able to identify measures and further assess those (Deliverable 5.5).

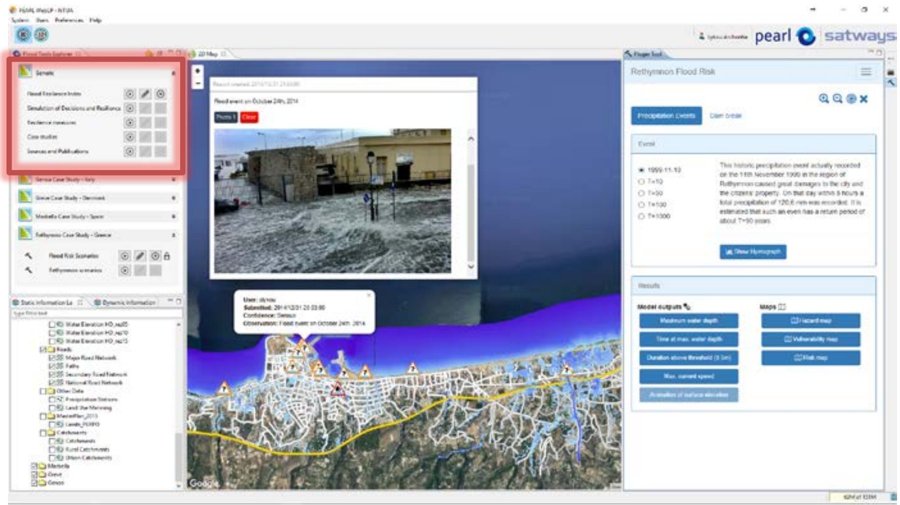

Figure 49: The PEARL WebLP

The combined use of the aforementioned developed tools with the conducted modeling work and the overall research activities performed parallel to stakeholders' engagement and guidance, revealed the measures which are necessary for Rethymno and drafted city's roadmap (Deliverable 5.6).

[6] The PEARL WebLP available for downloading: http://satways.static.otenet.gr:8083/pearl-weblp/

7.7.2 Lessons learned from the case study work

The overall suggested measures which have been suggested jointly by the members of Rethymno's LAA and the PEARL team were classified under the following axes:

1) Actions aiming to enhance decision making processes and flood risk governance
2) Actions strengthening information and raising flood risk awareness
3) Actions assisting in city's flood preparation and protection

All the suggested measures are thoroughly described in the roadmap document (Deliverable 5.6), as well as possible restrictions or suggestions in measures implementation as discussed thoroughly with the stakeholders during the LAA workshop (held on September 29th, 2017).

Prior to the roadmap drafting in the last LAA, demonstration and training activities were conducted related to the developed PEARL tools. All tools received highly acceptance by stakeholders and delivered the necessary information (links, instructions, etc.) to start using them. PEARL products attracted authorities' interest and detailed discussion were initiated focused on "officially" usability of the tools and their possible incorporation within authorities work and equipment. Since the PEARL KB and FRI tool have been covered in the first two LAA workshop, emphasis has been given to the PEARL ABM SAS and the WebLP in the last meeting of PEARL.

All tools which have been developed under WP5 are generic and applicable to any case study around the world despite local conditions. As a matter of fact, in order to cover all those needs the WP5 tools' functionalities have been developed in such way so that the tools themselves can be tailored to meet every stakeholder and case study needs.

7.8 Concluding remarks

The work fulfilled in Rethymno as part of the PEARL project can be argued that is fully comprehensive and tried to meet the holistic goals set as much as possible (as presented in Figure 30). In fact considerable efforts were required during the 4 year project's duration, since no data were available for the case study at the beginning of the project. To support the abovementioned argument an overview of the conducted research activities is following:

- **Identification** of the **area under study** (problem, measures & flood management procedures):
    - Literature review, field visits, collection of experts' knowledge
- Assessing formation of **vulnerabilities** primarily related to **social root causes**:
    - Application of the RRCA framework
    - Conduction of household survey and analysis of results
    - Spatial vulnerability assessment based on statistical data of people, households and building
- Understanding **formation of hazards**, physical procedures and **natural root causes**:
    - Modelling framework simulating the hydrologic and hydrodynamic processes from the origins of the river basins to the sea
- Flood **Hazard and Risk Assessment**
- **Examining measures & solutions** (technical root causes)
- Applying **techniques for faster simulations**
- **Developing and applying tools** for decision support and policy development for strengthening resilience of coastal regions:

- The PEARL online FRI tool
- The PEARL Detective app
- The PEARL KB
- The PEARL Toolbox
- The PEARL ABM SAS
- The PEARL WebLP

- **Engaging stakeholders – LAAs** :
  - 3 Workshops and several technical meetings
  - Numerous activities organised

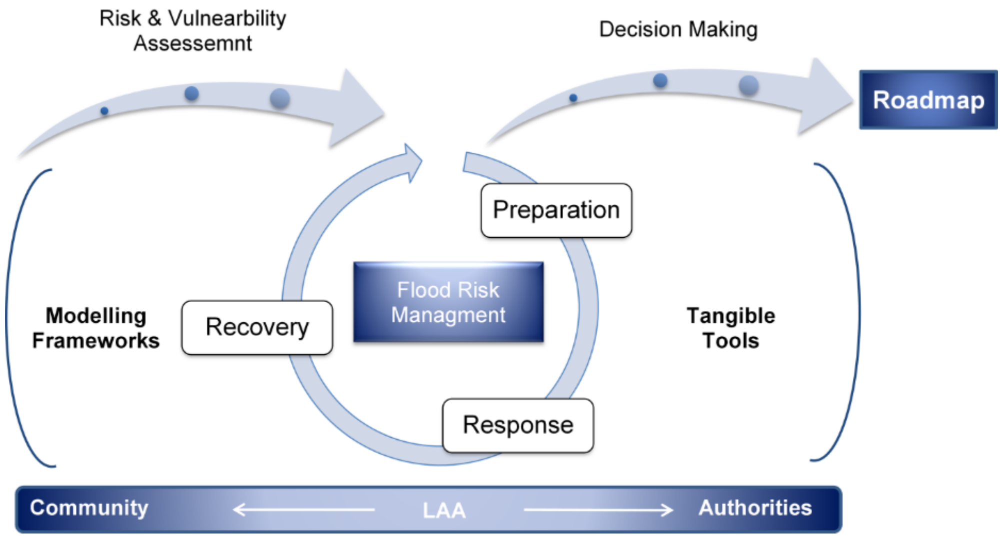

Figure 50: PEARL approach as applied in Rethymno

The last and major unifying action of the PEARL work and outcomes was the development of the actionable roadmap for the Rethymno case, a roadmap the city really needs which utilises most of the PEARL products and developed to assist flood management and decision making processes. The suggested actions were jointly derived with the stakeholders, hence, forming the best circumstances for their actual implementation while intriguing authorities interest the most.

Despite what the authorities of Rethymno will adopt and incorporate in their daily work eventually, the PEARL has left valuable knowledge and tools which couldn't have been obtained otherwise. But most importantly managed to provide sufficient justification on why Rethymno should be considered as a potential significant high risk area within the EU Flood Directive work, hence, gave the chance to Rethymno's authorities to be eligible and able to apply for future funding which will enable them to implement new measures and actually increase city's flood resilience.

For Rethymno, the good arrangement and co-operation between the involved research partners and Rethymno's stakeholders has to be highlighted in this regard.

8 Case Study – Taiwan

8.1 A brief description of the case study area

Taiwan, located at the central west of Pacific Ocean, has coastline of 1600 km and 23 million populations. The location is within one of the typhoon-prone area in the world. There are 3.5 typhoons approaching Taiwan in an annual average and the number of typhoons per year is increasing to 5.5 in the recent decade. Typhoons bring strong wind, extreme waves, high water level (storm surge) and heavy rain. These phenomena increase risks for the coastal area. In addition to extreme precipitation during typhoons, the river characteristics and topography of Taiwan are important factors that lead to flooding. The rivers in Taiwan are short and have steep slopes that exceed 1/100 in upstream reaches and 1/200~1/500 in downstream reaches. Concentrated rainfall in short and steep river basins generates rapid flow increases and flow peaks.

Tainan coast is the study area in PEARL project. The coastline of Tainan City is around 63.7 km. Located at south-western of Taiwan, Tainan City is bordered by the Taiwan Strait to the west (Figure 126). It is the oldest city with more than 80% of the population lives near the coast. In 2016, Tainan City had a population of 1.9 million in its 37 districts. The total area of Tainan is 2200 km2, with an average population density of 860 residents/km2. However, the population density in the Tainan urban area is 4500 residents/km2. There are six rivers that run through Tainan: the Bajhang River, Jishui River, Jiangjun River, Tsengwen River, Yanshui River and Erren River (from north to south). Midwestern Tainan is an alluvial plain of the Yanshui River and Tsengwen River, with a few hills and mountains distributed in the east. The only river that runs through the urban area of Tainan is the Yanshui River, with a length of 41.3 km and a watershed area of 340 km2. The selection of Tainan City as the study area is not only because of its significant urban development but also because rainfall is the dominant factor that influences flooding.

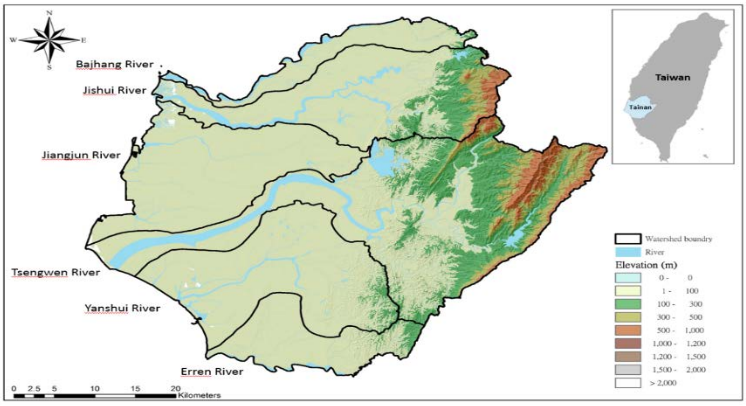

Figure 51: Location, river distribution and topography of Tainan City, Taiwan

8.2 Understanding the formation of hazards under extreme events (WP2)

8.2.1 Description of the case study work

In this work, the less frequent events (return periods of more than hundred years) are seen as extreme events and can be applied as reference for risk assessments. Extremely ocean wave usually happened during typhoons for Tainan coast. In this study, long-term historical typhoon wave

data were simulated because the length of field measurements on waves were not long enough. Parameters for more than 100 typhoons from 1980 to 2013 (totally 33 years) were collected. The data include typhoon central pressure, wind speed (field), moving speed and the path. Typhoon wind fields that generated by atmospheric numberical model were provided by Central Weather Bureau. The typhoon induced wave heights were then simulated by using MIKE21 SW module. It was found that Person Type III distribution is the best fitting model for typhoon generated wave heights. The various return periods on significant wave height were estimated and listed in Table 2.

A storm surge is usually characterized as an abnormal rise in water level generated by a storm, over and above the predicted astronomical tide. In this study, the High Water of Ordinary Spring Tide (HWOST) is used as the base tide height. The maximum storm surges derived from 105 typhoons from 1980 to 2013 are obtained by numerical simulation. The heights of storm surge at the Tainan coast, that were estimated for return periods of 5, 10, 25, 50, 100, 200 and 500 years, were also shown in Table 12.

Table 12 : Results of wave heights, storm surges and rainfalls for various return periods for Tainan City, Taiwan

	Duration (h)	**Return Period (Years)**						
		5	**10**	**25**	**50**	**100**	**200**	**500**
Significant wave height (m)		7.84	9.10	10.69	11.87	13.02	14.64	18.54
Storm surge (m)		1.50	1.57	1.67	1.74	1.80	1.87	1.96
Rainfall (mm)	6	179	207	240	262	283	302	326
	12	237	273	314	343	370	396	428
	24	289	347	419	473	526	579	650
	48	329	395	479	541	602	664	745

Table 33 lists the results of distributions of each factor at four stations. The results can be substituted into equation (8.2.1.1) to obtain CEVD of each station. The copula probability density function of Longdong station was illustrated in Figure 5. A further application to typhoon return period is also proposed using the results in *Table 13*. In contract to traditional frequency analysis method, which condisers wave height and tide level distribution are independent, the results of CEVD are more reliable.

Table 13: Stations and best-fit results

Station	Data duration	Best-fit tide level distribution	Best-fit wave height distribution	Best-fit copula function
Hualien	2004-2014	GEV	GEV	Frank copula
Longdong	2000-2014	GPD	LN3	Clayton copula
Hsinchu	2001-2014	GEV	GPD	Frank copula
Erluanbi	2001-2014	GPD	GEV	Clayton copula

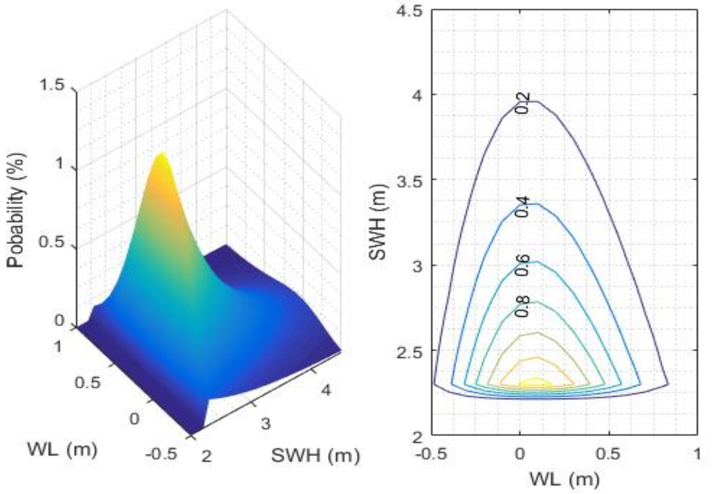

Figure 52: Joint probability density function (Clayton Copula) for tide level (WL) and wave height (SWH) at Longdong station (left) and three-dimensional plot with colours (right)

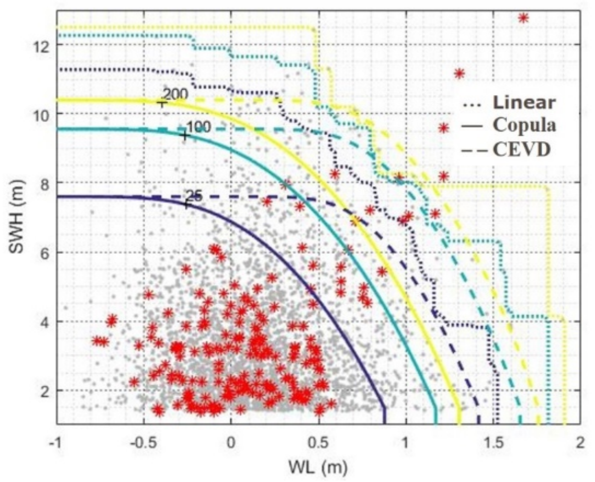

Figure 53: Typhoo return period at Longdong station. Red asterisks are measured data, grey dots are data generated by Monte Carlo simulation. Dotted line represents traditional linear method, solid line are Copulas and dashed lines are CEVD. Purple, green and yellwo colours represent return periods of 25 yrs, 100 yrs and 200 yrs

8.3 Holstic Holstic and multiple risk assessment (WP3)

Flood Inundation Map (FIM) is designed to represent the possible flood conditions under various rainfall scenarios. The information of potential flooded areas is necessary to assess the risk. Two

types of rainfall scenarios were assumed for the development of FIM for Tainan city: one is the topography-based cumulative rainfall (CR) and the other is the periodic rainfall (PR).

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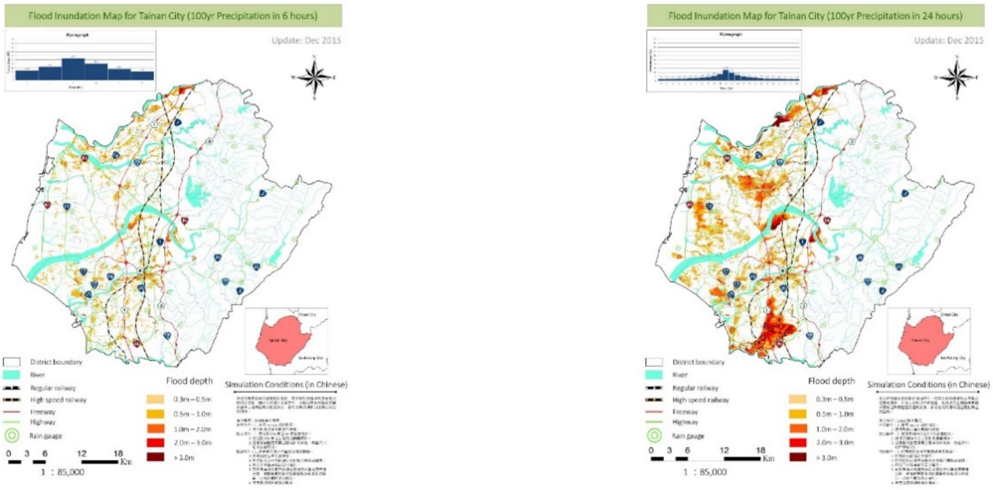

Figure 54: Productions of flood inundation map for Tainan City under conditions: 100-yrs rainfall for 6 h (left) and 100-yrs rainfall for 24 h (right)

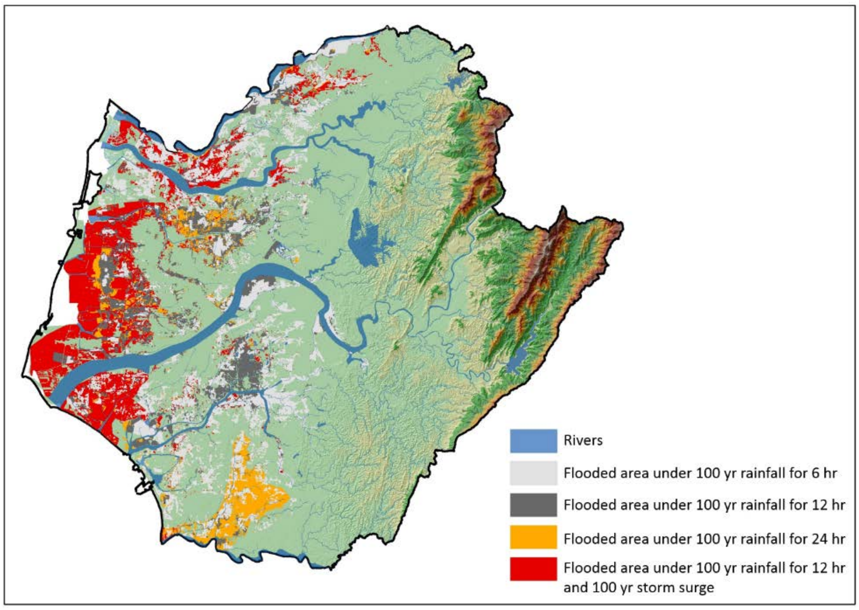

Figure 55: Overlap of the flooded area under various scenarios

Analysis for vulnerability assessment

This study adopted the indicators of coastal vulnerability that were established by United National Environment Programme (UNEP, 2005). These coastal vulnerability index (CVI) is a function of five indicators (Eq. 10). These indicators are population density in coastal area (PD), probability of natural disaster incidents (ND), forest cover (FC), geographic exposure (GE), and human development index (HDI).

$CVI = f[(\mathrm{PD}) + (\mathrm{ND}) + (1 - \mathrm{FC}) + (\mathrm{GE}) - (\mathrm{HDI})]$	*Eq. 2*

The indicators are standardised by Eq. 11 before being substituted into Eq. 10

$$\text{index} = (X - X_{min})/(X_{max} - X_{min})$$	*Eq. 3*

Table 14: Evaluated factors for vulnerability analysis

Evaluated factor	**Vulnerability evaluation parameter**
Physical Factor	1. population density 2. fundamental protection facilities
Environmental Factor	1. coastal morphology 2. mean wave height (m) 3. mean tidal range (m) 4. coastal erosion 5. coastal geology sensitive area 6. rate of land subsidence (cm/yr)
Social-Economical	1. Human Development Index 2. Fundamental facilities：harbor, aquaculture, lifelines areas

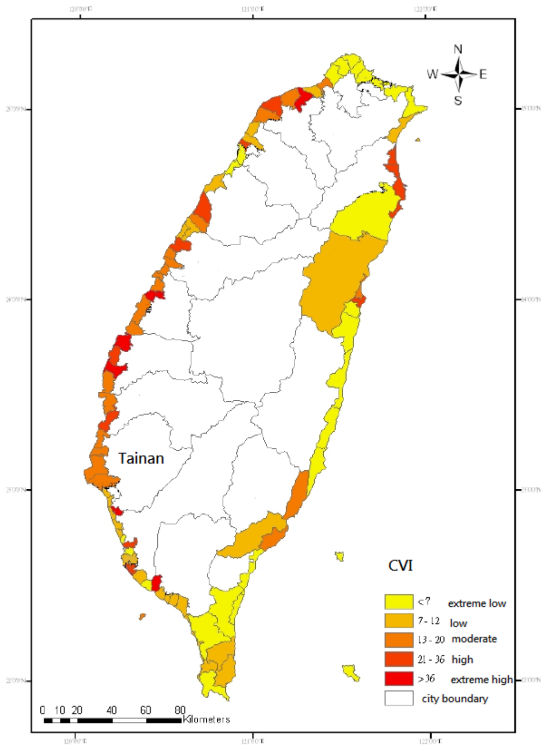

Figure 56: Coastal vulnerability map

Risk assessment

Based on the coastal vulnerability map that obtained from previous section (Figure 9), the risk map of Taiwan coastline was established and shown in Figure 11 (scenario of 1.4 m sea-level rising). Similar to vulnerability map, the western coast has higher risk than the eastern one. Southwestern coastline of Taiwan has the highest risks which might be caused by sea-level rising and Tainan City was classified with moderate risk. From the risk map of sea level rising, we can know that higher attention and protection are needed for area with higher risks, i.e. southwestern coastline of Taiwan.

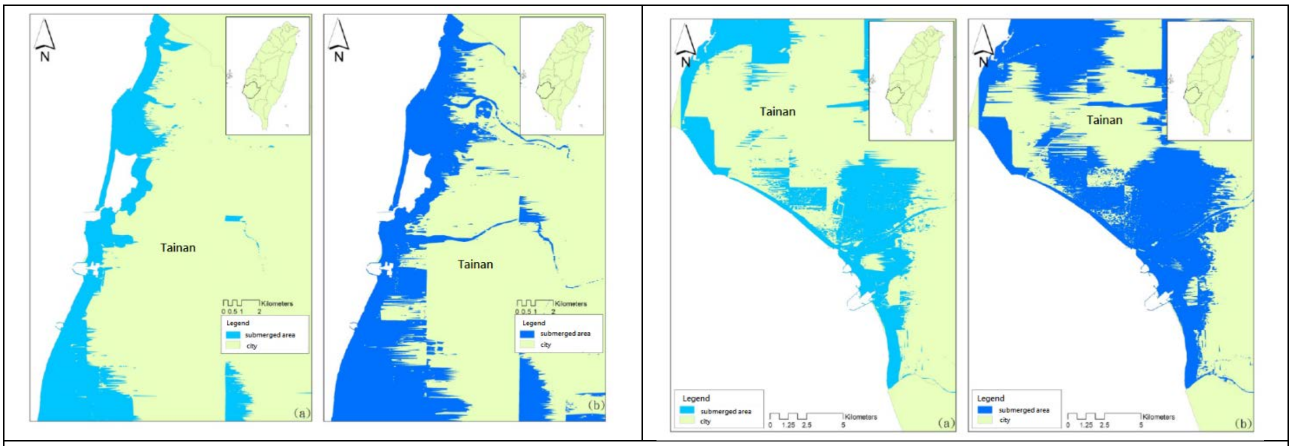

Figure 57: Maps of submerged areas due to sea-level rising: a) rise 0,5m, b) rise 1,4m, northern Tainan (left), southern Tainan (right)

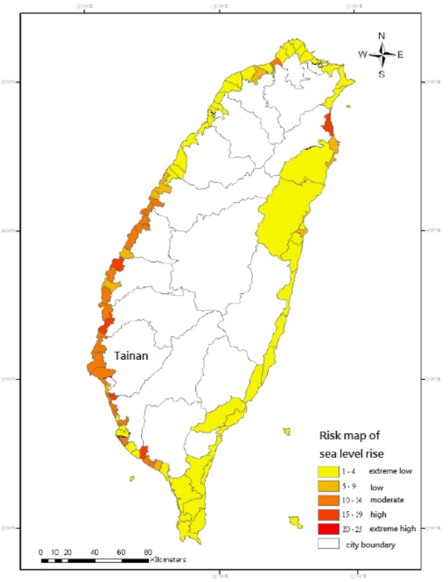

Figure 58: Risk map of sea level rise of 1,4 m

8.4 Concluding remarks

Taiwan is located at western Pacific Ocean. Due to the typhoon impact, coastal flooding is one of the main hazards in Taiwan. Typhoons bring heavy rains in a short time as well as extreme wave heights and storm surges from the seaside. When one of the threats occurs individually but extremely or more then two threats occur in coincidence, flood occurs especially in the coastal area. Water

Resources Agency (WRA) of Taiwan (which is the responsible authority of water problem in Taiwan) investigated that the flood induced loss every year in Taiwan is much higher than earthquake or tsunami generated.

Due to different types of threats as well as different geographic and social conditions, the strategies of the coastal flood mitigation are not fully the same with European countries have. Therefore NTOU/NCKU shares the cases and experiences we had in Taiwan with PEARL partners and learn European experiences by PEARL platform.

In Taiwan, the research focus for coastal flooding is on the development and improvement on the technologies for flood potential simulation and the warning system. According to frequent flooding, numerous field data and records were corrected which is a very good area for model calibration. However, we learn from European cases, much focus on social-economic issues, including public engagement, education and risk assessment which will be the direction for Taiwanese cases.

9 Case Study – St. Lucia, The Caribbean

9.1 A brief description of the case study area

The case study area is located in Castries City, the capital of Saint Lucia in the eastern Caribbean region (Figure 59). The case area mainly covers around half a square kilometre of the city centre (Figure 60).

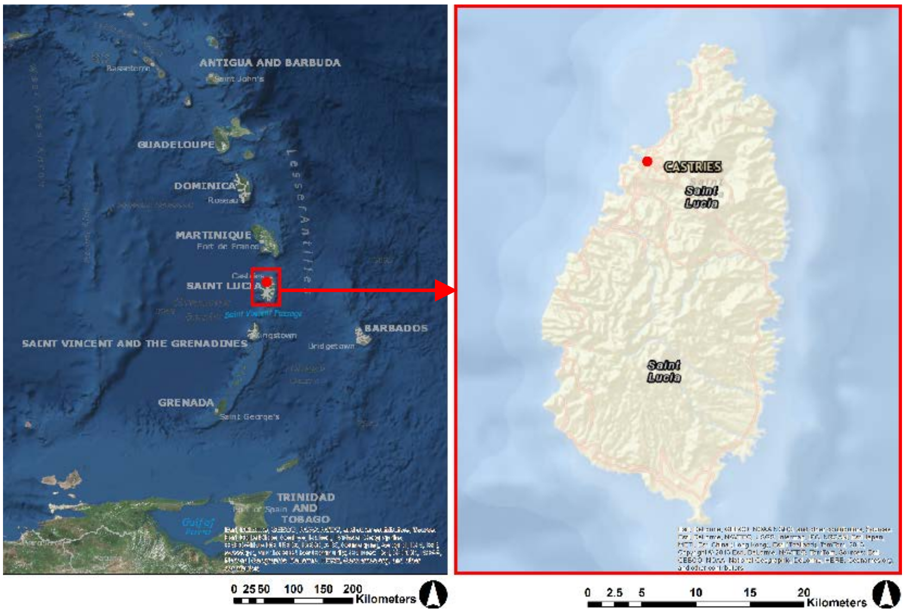

Figure 59 Location of the Castries case study area in Saint Lucia in the Caribbean.

Figure 60 Castries city centre (red outline) in Saint Lucia.

The major flood hazards to the area are:

- Pluvial and fluvial flooding (from intense rainfall)

- Coastal flooding (during storms/hurricanes)

The area is at risk from pluvial flooding, especially during short duration high intensity rainfall, as well as fluvial flooding from the river located south of the city (Rene et al., 2015). Coastal flooding is apparently rare but may occur during storm events given its coastal location in a hurricane-prone region.

In the PEARL project, Saint Lucia was used as a case area under Work Package 4 covering “Flood forecasting and early warning systems for coastal regions”. More specifically, a new online coastal flood warning system was developed for the area working under the following objectives:

- (O4.1) Improve the speed of state-of-the-art modelling tools for early warning, in order to achieve sufficient lead times for emergency actions.
- (O4.2) Develop new, and customise existing methods and concepts for fast flood simulations in areas with combined flood risks.

9.2 Flood forecasting and early warning systems for coastal regions (WP4)

A new online coastal flood forecasting system was developed for Castries, building on an earlier pluvial flood warning system by Rene et al. (2015). In the new system, additional components were implemented to allow forecasting of combined flood risks from pluvial and fluvial flooding due to extreme rainfall, as well as coastal flooding due to storm surges and extreme sea levels. Moreover, techniques for model speed-up were applied to the flood forecast model working behind the system to optimise it for real-time warning application.

9.2.1 Description of the key activities in the case study areas

The Saint Lucia Flood Warning System uses a flexible mesh 2D flood model to forecast coastal flooding in Castries. The model is driven by forecasted NWP (Numerical Weather Prediction) rainfall and sea water levels, and modelling results are routinely published on a website in real-time (www.stlucia.dhigroup.com) (Figure 61).

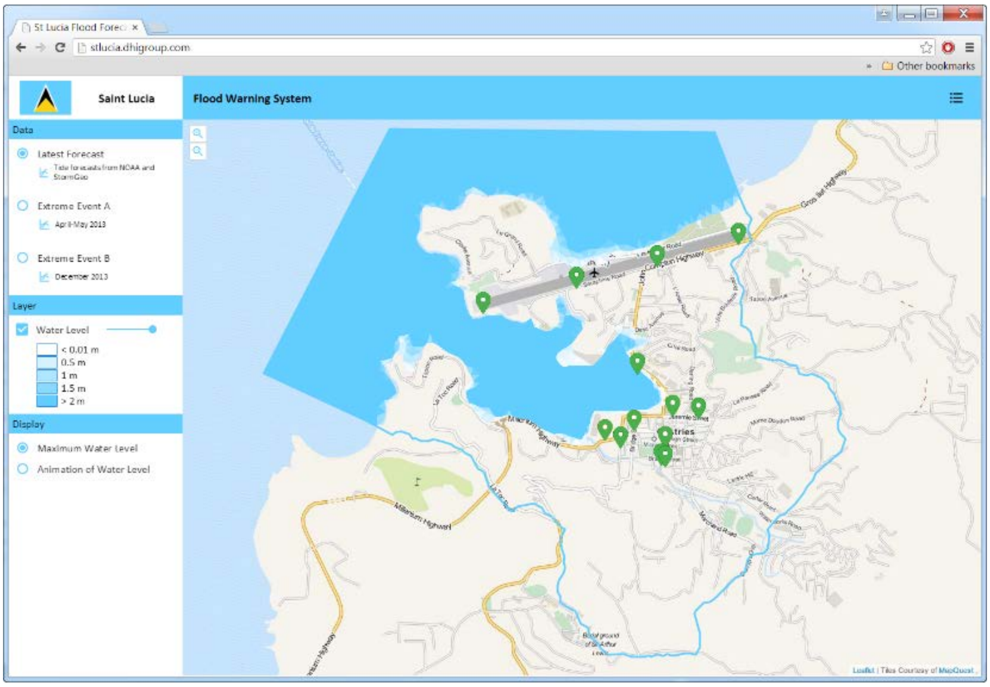

Figure 61 Homepage for the Saint Lucia Flood Warning System in Castries, Saint Lucia (www.stlucia.dhigroup.com) (Source: PEARL, 2016).

The new system was extended to also simulate coastal flooding in addition to pluvial flooding, involving expansion of the model domain to cover not only the city centre but also upstream sub-catchments and the land and sea areas around the port (Figure 62).

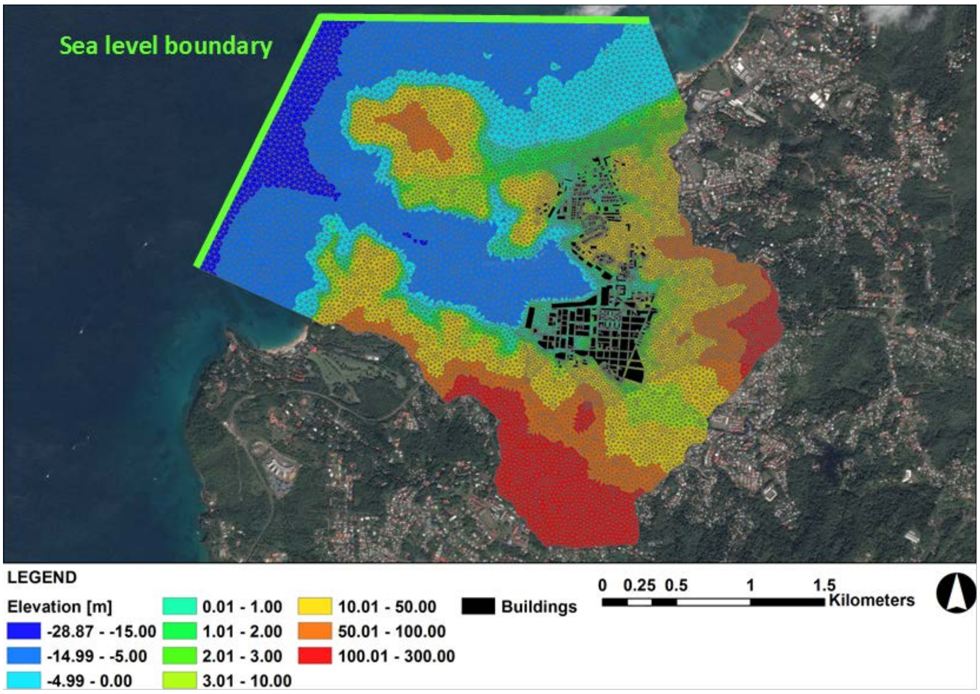

Figure 62 A plot showing the 2D coastal flood forecast model for Castries, Saint Lucia (Source: PEARL, 2016).

Use of a more efficient flexible mesh grid, instead of the previous rigid Cartesian grid, for the 2D flood model offset the increase in computational points with the expansion of the model domain. Moreover, a flood modelling technique was applied, wherein the presence of structures (i.e. buildings) was considered in the computational mesh in order to simulate the effect of these impervious structures to computed flows and water levels in the model domain.

The flood model, more particularly the computational grid, was optimised to ensure fast and accurate flood computations appropriate for real-time forecasting. The model speed-up techniques that were tested and implemented in the Saint Lucia case study were:

- Modification of computational grid type
- Optimisation of computational grid size
- Parallelisation of computations

More details on the Saint Lucia Flood Warning System may be found in the report D4.1 “Online Modelling Tools and Techniques for Early Warning Systems” (PEARL, 2016).

9.2.2 Lessons learned from the case study work

The Saint Lucia Flood Warning System demonstrates how such a system may be built despite data limitations in an area. System components were streamlined according to basic forecasting needs and data availability. For example, a 2D model was used for flood simulation, instead of the ideal coupled 1D/2D flood model for an urban coastal area due to lack of data on the sewer system. Data available for model verification were also limited, comprising of images for two flood events in Castries published online (Rene et al., 2013; Rene et al., 2015). Nevertheless, various approximation

techniques for model setup and performance evaluation could still be applied, and the case study indicated that the current streamlined model could still give a good indication of the location and magnitude of expected flooding for a real-time flood forecasting system (PEARL, 2016).

9.3 Concluding remarks

In contrast to Greve, the Saint Lucia case was most suited as a testing ground for assessing the scalability and adaptability of methods that had been developed in other case areas (i.e. Greve) for a place with different flood risk and data availability conditions, such as Saint Lucia. Thus, the case study work centred on trying to build the same type of flood forecasting system that had been developed for Greve in Castries.

A flood hazard model considering extreme rainfall and sea levels, occurring individually and concurrently, was developed in the Saint Lucia case study using a 2D flexible mesh flood modelling approach.

Compared to the system in Greve, the Saint Lucia system is more simplified and lacks several components such as a sea level forecast model, or a feature for recording system reliability statistics. Nevertheless, the case application shows how it is still possible to build an informative coastal flood forecasting system in an area not rich in data. It demonstrates that the level of detail and complexity of a coastal flood forecasting system may be adjusted according to data availability, while maintaining usefulness and relevance.

10 Case Study – St. Maarten, The Caribbean

10.1 A brief description of the case study area

Sint Maarten is a constituent country of the Kingdom of the Netherlands as of 10/10/10. It encompasses the southern third of the Caribbean island of Saint Martin, while the northern two-thirds of the island constitute the French overseas collectivity of Saint-Martin. Its capital is Philipsburg. Its population is 40917 on 34 km^2. [7] Sint Maarten is located at the northern end of the Leeward Islands at 18.4^{0}N and 63.4^{0}W with a coastline of 364 km, seeFigure 63. The island is of volcanic origin with low and hilly terrains. Elevation ranges from near sea level along Caribbean Sea to 386 m above mean sea level of Mt Flagstaff at the northern hilly part along the borderline. Arable land accounts 10% of the land use in the island.[8]

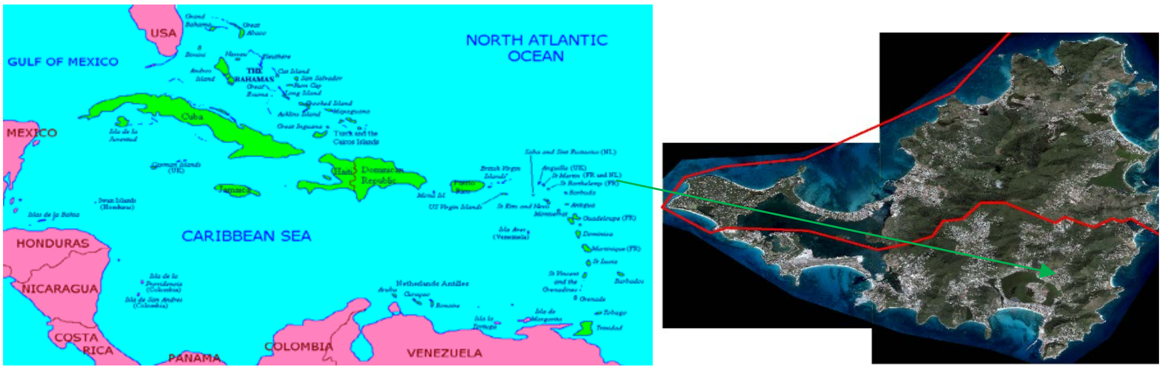

Figure 63 Location of St Maarten

Being located in the North Atlantic Ocean, Sint Maarten has been subject to hurricanes for many years. The Atlantic Tropical Cyclone Season runs from June 1st up to November 30th. Almost every year at least one tropical cyclone occurs within a range of 100 miles and on the average once every 4-5 years hurricane conditions are experienced in the island. The most recent hurricanes to cause considerable damage to the island were the hurricanes Omar (2008), José (1999), Lenny (1999), Georges (1998), Luis (1995), Marilyn (1995), Hugo (1989), Donna (1960) and Dog (1950). Within the time spam of PEARL, Sint Maarten was hit by hurricane Irma, causing extensive damage to the island. Hurricane Irma and its impacts is subject of an additional report and its impacts and assessment are addressed in deliverable 3.5.

Sint marten has been used as a test case study area within work package 3 for holistic risk assessment. From previous studies conducted by IHE, there were hydrodynamic models that enables the assessment of hazards. For risk assessment the institutional ABM model (strategic planning) was developed and tested in Sin marten. Also the ABM for traffic simulation was initially

[7] Hurricanes and Tropical Storms in the Netherlands Antilles and Aruba –report from Meteorological Department Curacao - http://www.meteo.cw/Data_www/Climate/documents/HurricanesandTropicalStorms.pdf (Accessed Nov 1, 2014)

[8] CIA World Fact Book - https://www.cia.gov/library/publications/the-world-factbook/geos/sk.html (Accessed Nov 1, 2014)

tested with this data set. Another tool applied and developed for St. Maarten was the ABM for testing evacuation rules to help minimize risk by reducing the exposure of people while an extreme event is unfolding. Deliverable 6.2 contains a description of the conducted research activities.

10.2 Understanding the formation of vulnerability and risk in coastal regions (WP1)

- *Description of the activities performed in the case study area with the key outcomes*

- The Risk Root Cause Analysis for St Maarten followed the methodological approach laid out in PEARL Deliverable 1.1. The research is based on individual, expert interviews with stakeholders, where the aim was to capture as diverse a set of views about disaster causation. 22 interviews were conducted between July and November 2015, the majority face-to-face interviews but also telephone interviews with those whom it was not possible to meet during fieldwork on the island.
- The Root Cause Analysis highlights many of the inter-connections across the physical, socio-economic and governance domains and pathways that give rise to risk. This has been reported in deliverable 1.3. The information from the Root Cause Analysis has been used as an input in the description of the Agent-Based Modelling work in a format that highlighted the actors, actor-relationships and underlying institutions conforming the current flood 'system'.

- *Lessons learned from the case study work*

- The Root Cause Analysis has been used as an input in the description of the Agent-Based Modelling work in a format that highlighted the actors, actor-relationships and underlying institutions conforming the current flood 'system'.
- Root Cause Analysis, as based on purely qualitative methods cannot specify quantitative thresholds for decision-making, such as the magnitude or extent of a flood that might trigger changes in policy measures. In conjunction, however, the methods can join the drivers and impacts of flood risk.
- The assumption of conscious and rational decision-making in the ABMs is not reflected in qualitative analysis for the Root Cause Assessments. This demonstrates the importance of retaining the two methods as independent parts of the whole, alongside their integration through model formulation.
- In conjunction, the outcome of the interviews also provides a timeline of policy measures and the underlying motivation for relevant policies, as reported in interviews.
- The broad frame for Root Cause Analysis leads to the question of where ABMs should bound the system and what agents or institutions exert the most influence. The Root Cause Analysis did not weight actors or causes. What this form of RCA can do is clarify and support the assumptions made in this respect.
- A limitation of the study lies in the sectors and stakeholders who were unrepresented in the study sample – for St Maarten this was representatives of the tourist and hotel trade, critical infrastructure facilities, donors, property developers as well as community leaders and affected residents.

10.3 Understanding the formation of hazards under extreme events (WP2)

▪ *Description of the case study work*

St Maarten is prone to flood hazards from two different sources or drivers. 1. Coastal flooding due to the passing of hurricanes and tropical storms and 2. Inland flooding due to heavy precipitation and the morphological characteristics of the island, some catchment have steep slopes and short streams draining to the sea. The coastal system was modelled to investigate the surge impact of three hurricanes that made an impact on Sint Maarten in the past. For the inland flooding hydrological and hydraulic models were used to support the identification of hazards from inland floods (i.e. pluvial and flash floods). The hazard assessment was done using MIKE software suite of tools, due to the previous participation of IHE delft in similar studies in the past. The tools being developed in WP2 in the framework of PEARL were not directly tested in St Maarten. The hydraulic modelling was carried out by coupling the one-dimensional (1D) MIKE11 and the two-dimensional (2D) MIKE21 flow models. The two modelling packages were integrated into a single, dynamically coupled modelling system through MIKE FLOOD.[9] The coupled 1D-2D simulations were carried out for five return periods. For these simulations, the 1h duration precipitation depths were considered.

▪ *Lessons learned from the case study work*

- While widespread flooding occurs in several parts of the island, the coupled hydrodynamic model results indicate that the most vulnerable area, with the most serious flooding, is the Cul De Sac catchment area.
- Residential areas in this catchment are predominantly situated on low-lying areas, with little consideration for stormwater drainage and as such are subject to flash flooding from surrounding hills, or extreme rainfall events such as direct thunderstorms.
- The drainage channels are inadequate to convey excess rainfall-runoff due to the limited capacity, obstructions and the morphological rising of the streambed and as such are not able to convey anything larger than 5 or 10 year rainfall event. Since the large contributing areas are steep, with some vegetation coverage, any rainfall is likely to cause erosion and landslides. The streets are usually narrow and as such represent a limiting factor for further enlargement of stormwater channels.
- During the heavy rainfall events, especially those caused by hurricanes, the large-scale flooding can cause a widespread damage to the residential and commercial areas and even loss of human lives. The information related to hazard assessment has been used to test some of the models being develop in the framework of PEARL for flood risk assessment.

10.4 Holistic and multiple risk assessment (WP3)

▪ *Description of the case study work*

Within work package 3, several models were developed to facilitate the application of the holistic risk assessment framework. In the case of St Marten, three ABM models were developed and tested.

[9] http://www.dhisoftware.com/Products/WaterResources/MIKEFLOOD.aspx

The first one focuses on the interaction of floods, humans and their built environment as drivers of hazard, vulnerability and exposure. The drivers are the institutions which in model terms are expressed in terms of institutional statements. The ABM in this study addresses long-term institutions related to prevention and mitigation and recovery phases of the disaster management cycle. The second ABM focuses on the short-term, operational and management related to the preparation and response phases of the disaster risk management cycle. These are connected to flood early warning and evacuation processes. The third ABM model connects flood events with traffic simulation, the generation of traffic jumps, loss of productivity and increase of atmospheric emissions. A brief description of each model is presented here below:

- Coupled Flood-Agent-Institution Modelling (CLAIM) framework

CLAIM is a modelling framework that integrates actors, institutions and hydrologic and hydrodynamic processes. The framework conceptualizes the complex interaction of floods, humans and their environment as drivers of flood hazard, vulnerability and exposure. The human subsystem which includes actors and institutions is modelled using agent-based model (ABM). The ABM is coupled with a flood model dynamically to understand how humans and their environment co-evolve, and to experiment different institutions and implementations to capture an emergent behaviour, if any.

The coupled human-flood system of St. Maarten flood risk management dynamics is modelled using the CLAIM framework. The aim is to build a model to understand the implications of different policies, and to understand how agents' responses to these policies influence the overall flood risk. The ABM is structured using the MAIA meta-model and developed using the Repast Simphony development environment and flood modelling is carried out using MIKE FLOOD hydrodynamic software. In the social structure, two agent types are identified to be important: household agents and government agent. Household agents are characterized by location and elevation, and they have houses. The government agent is characterized by budget and level of enforcement. Both agent types make decisions about FRM measures implementation. In the institutional structure, three formal institutions, i.e., Flood Zoning Policy (under the draft National Development Plan), Beach Policy and Building Ordinance, and one policy implementation, i.e., implementing structural measures were considered. The physical components defined in the physical structure are houses, drainage channels, hazard triggering factors (i.e., rainfall and storm surge) and flood. In the operational structure of the ABM, agents' actions and interactions are defined. For example, considering urban development, household agents build new houses. Before building, they may decide where to build it and if they would follow the institutions. To reduce flood risk, the government agent may decide to introduce the flood zoning policy. In the flood model developed, design rainfalls of 5yr, 10yr, 20yr, 50yr and 100yr recurrence interval were used. The assumption is that any rainfall magnitude below the 5yr recurrence interval does not result in flood. Impact of the floods is assed based on the number of flooded houses.

-Agent Based Model for evacuation strategies

A novel Agent Based Model was implemented to serve a platform for testing different evacuation strategies under extreme hydro-meteorological events in coastal areas, the model was set up and validated using the case study of St. Maarten in the Dutch part of the island. Two general concepts were used during the implementation of the ABM evacuation model, Firstly the implemented ABM

was built in such manner that it has the ability to represent the daily behavioural pattern of a complex environment such as it is a coastal urban city: interactions between agents (humans) and the agents with the environment (the city). And secondly the ABM includes a module where human cognition is represented in order to be able represent the complex decision making process of humans during evacuation of cities during flood events.

The process of implementing the ABM is summarized as a 5 step process as follows:

1. Agent's Description: Two type of agents were applied in the model. Individuals and organizations (Figure 64).
2. Agent's Classification: Sub classification of different type of agents based on subjective and objective parameters of individuals according with the characteristics of the inhabitants of the case study.
3. Environment Characterization: Physical representation of the space where agents interact, i.e Buildings, roads, water, etc. As well a list of the possible agents' interactions are defined at this level.
4. Model Parametrization: Consist a set rules known as WWW, WHO (each agent) does WHAT (specific action) and WHEN (time)
5. Cognitive Module: Using this module of the ABM is possible to give the agents the like behaviour when the flood is perceived or acknowledge (see Table 1for possible agents actions).

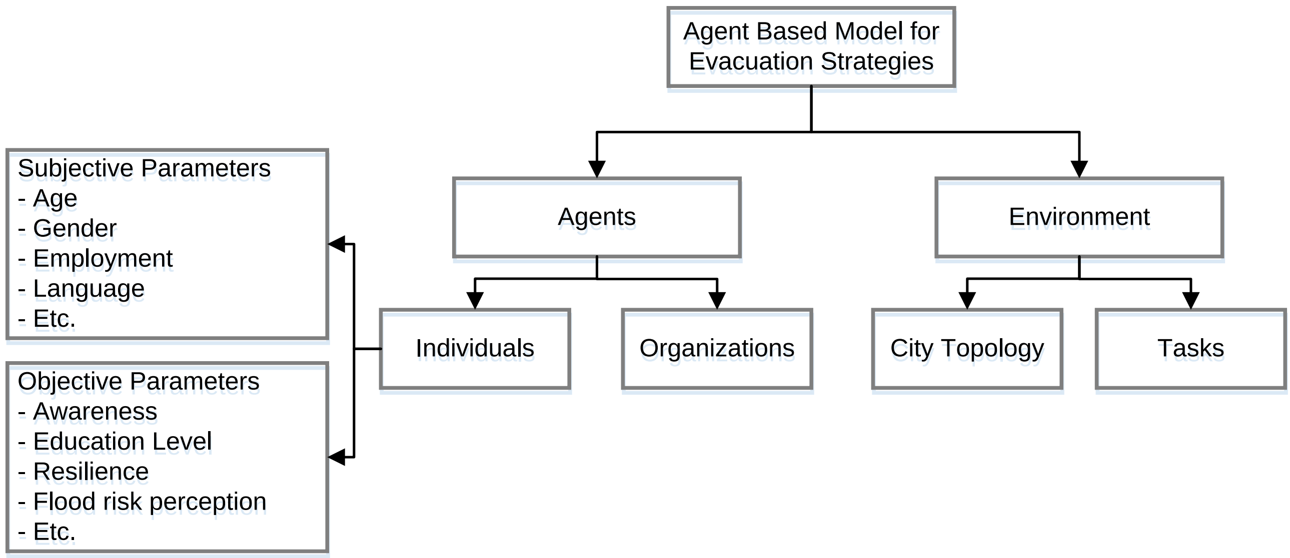

Figure 64 Agents and Environment Description and Characterization

Table 15 Individual Agents Classification Actions

Action	Observation
Evacuation	Planned and Organized, Follow instructions.

Fight	Prepare in situ
Flight	Random Evacuation (not follow orders)
Sideration[10]	Inability to respond
Search Relatives	Wife, children, parents, etc.
Return home or work place	Feel safe in these places and stay there.
Assist Others	The agent becomes an organization actor.
Antisocial Behaviour	Panic, looting, etc.

The implementation of this ABM was done in Repast Symphony as a Java base, free and open source modelling system for creating, running, displaying and collecting data from Agent Based Simulations. The version used was Repast Symphony 2.3.1 running under Windows 7 Professional, 64-bit operating System on a laptop with an Intel Core i7 processor and CPU @ 2.4GHz with 16 GB of RAM memory. For the case study of St. Maarten (Dutch side), a total of 6046 agents were used to represent the population of the island. The model was set up to run for an entire week from Monday to Monday and as a start of the simulation it was selected 04:00 hours considering that rush hour is estimated to be around 9 am. At the beginning of the simulation every agent select a destination and start its movement towards it, which is chosen based on the individual's classification (Table 15) and according to the day and the time of the day for each agent, going from home to work, leisure, school and so on, to represent as accurate as possible the real movement of the inhabitants and tourist of the island. For the flood hazard representation a hurricane was introduced in the ABM to test the evacuation capabilities of the agents, this flood model came from a 2D MIKE by DHI hydrodynamic simulation.

Furthermore, to explore and evaluate the effects of the warning information in terms of content and dissemination strategies, 4 different scenarios were set up in the ABM: 1. A baseline scenario, were agents evacuate randomly based on previous knowledge (or non) of where to evacuate. 2. A clear message to where to evacuate is sent to the whole population on the island (scenario 1). 3. A stage evacuation message, this is the evacuation message is send gradually according with the expected arrival time of the hazard (scenario 2) and finally a targeted message to only those that are within the area expected to be hit by the hazard (Scenario 3).

A more complete description of the implementation of the ABM was presented in, Medina et al 2016.

- Traffic Model

The impact of extreme hydro-meteorological events on transportation is twofold – coming from rainfall events and flooding of the road network. First, the extreme weather conditions lead to reduced maximum speed limits (Keay and Simmonds, 2005). The decrease of speed limit will be driven by the intensity and the duration of the rainfall event and it will reduce road capacity before the flood has even occurred. Thus the flood impacts will start evolving in a transportation system, which already has reduced capacity due to heavy rainfall intensities

The SUMO software (Behrisch et al., 2011) has been used to create a basic model, so that the proposed methodology can be tested. The initial setup of the model uses the traffic network of the

[10] The sideration term within this research is defined as the inability to respond from the psychological perspective

whole island of St Maarten, which is rather large for conventional microsimulation network (total area 87 km2 and nearly 80 000 inhabitants). For example, when 30 cm of flood depth was used as a criterion for street closure, 268 streets in the whole network were identified to be closed and the traffic through them should be rerouted. From a traffic modelling point of view, the road network was going to suffer from 268 accidents, whose temporal characteristics depended on the propagation of the flood. In SUMO terms, each of these accidents had to be represented independently and this posed a problem when multiple scenarios were going to be modelled and discussed. Therefore, to simplify the problem, the test simulations focused on the cul de sac area. The following setting was used to setup the sumo model:

- Simulated 5000 vehicles for 3 hours (10 800 seconds)
- A vehicle is inserted each second for the first 5000 seconds of the simulation
- Once the vehicle reaches its destination, it disappears from the network
- The street closures are from 300-5000 s simulation time

The results can be summarized as follows:

In terms of travel time

- 720 hours of additional travel time (78% increase from the normal scenario)
- 1951 vehicles have increase in travel time (57 % of the overall vehicles)
- 444 vehicles experienced delays mode than 30 min

In terms of travel distance

- 1369 vehicles rerouted (41 %)

In terms of vehicles being indirectly affected

- (%vehicles with longer travel time) – (% vehicles travelled longer distance) =

  57%-41%=16% indirectly affected by slower traffic

▪ *Lessons learned from the case study work*

- Coupled Flood-Agent-Institution Modelling (CLAIM) framework

The modelling approach conceived by the CLAIM framework helps us to understand the importance of institutions in flood risk management. It also helps to test different policy options by taking into account agents' behaviors to different constraint levels of a given policy. In the coupled ABM-flood model built for Sint Maarten, results of the modelling exercise show that the Building Ordinance is a very important institution affecting flood impacts. Since many houses are elevated (floor height elevation of 20cm according to the Building Ordinance), flood impacts are lower. Lowering the initial number of elevated houses or lowering the threshold of agents' complying rate with the Building Ordinance show that more houses are flooded. In addition, that institution is effective as it affects all the houses (buildings) on the island. On the other hand, the effect of Flood Zoning Policy is minimal as it only affects new houses building in some specific zones (i.e., the flood zones).

There were some challenges experienced while building the CLAIM model for Sint Maarten. Both the ABM and the flood model requires lots of data, and its availability was a big issue. Even though agent and institutional data was collected through the Risk and Root Cause Analysis of the Work Package 1, most data were qualitative and not readily available to be used in the ABM. Hence, the researcher had to make assumptions to parametrize the policies in to quantitative values. Assumptions had to also be made for data which are not available. For example, all agents are assumed to have residential houses as there was no available data on the building functions on the island. One main issue regarding assumptions is that since Sint Maarten is one of the non-European case studies and the researcher could not get a chance to visit the study area, making assumptions was difficult. Another challenge is related to the coupling of the ABM and the flood model. The first issue is that to test different policy alternatives, the coupled model should be run thousands of times. The ABM alone may have very short computation time but the flood model takes longer time. Therefore, the total experimentation may take very long time (in months) even with the use of high performance computing machines. The second issue is that manipulating the input files of the hydrodynamic model from the Repast Simphony development environment was a big challenge.

In general, the framework and modelling exercise in Sint Maarten helped to investigate the policies that matter in reducing flood risk on the island. Previous flood risk management studies on the island by UNESCO-IHE used to focus only on modelling the effect of different structural measures. With the application of the CLAIM framework, the current modelling experimentation also includes the behavior of actors to policies that help to reduce flood risk. The CLAIM framework can also be applied in any other area provided that there is data availability. An important aspect regarding modelling is that CLAIM can be applied using any ABM and flood modelling environments/software.

-Agent Based Model for evacuation strategies

The modelling approach used in PEARL for evacuation strategies explores and demonstrate the feasibility of using ABM to test large scale city evacuations under an extreme flood threat such as a hurricane and also to test different evacuation strategies and has the potential of becoming a powerful tool for operational risk management purposes such as:

1. Determination of evacuation patterns, identification of critical infrastructure. Such tool can also be used to identify the need to improve existing emergency locations (i.e. number of beds, food storage, roads capacity, etc).

2. This type of ABM has also huge potential to test different communication strategies before and during the flooding event is unfolding, to test the effects of warning lead time, the effects of formal and informal communication in the overall performance of an evacuation, etc.

3. As part of the main conclusions that can be drawn from this part of the project is that during large city evacuation not only the message content matters but the way the message is deliver, accepted and understood by individuals and the community plays a major role in the effectiveness of the evacuation itself, It can also be concluded that in the era of social media there is a clear need to better understand the effects that social networks have on evacuation processes and how them can be used to achieve better evacuations results instead of creating new problems to an already complex problem. A more in deep research in this field is seen at this point as a further step to be address by future research projects.

4. It is not surprising that having a more informed community on how to react to a certain flood threat, will lead to a major number of people reaching safe area, however based on the results of this case study it can be concluded that there is not a better evacuation strategy that can be generalized as the best strategy. This should be understood as that the implementation of a generic ABM for city evacuation seems to be an impossible task, and that such models need to be built case by case.

- Traffic Model

The impacts of adverse weather conditions on traffic have been studied in detail, but have never been previously integrated with flood events. This methodology combines the joint impacts of both adverse weather conditions and accumulated floods to road transportation.

The traffic model was limited by the reduced availability of transportation measurement data, therefore, modelling different vehicle classes and purposes of trips are reliant purely on assumptions. However, different vehicle classes can give valuable input, when traffic delays or cancellation of trips are monetized. This is currently represented by the activity based traffic demand model, which generates trips according to synthetic data about population and locations of big employers, schools and shops.

Traffic measurements are needed to verify and calibrate the parameters used in the SUMO model to ensure the modelling results can represent the traffic conditions properly. Cost assessment model of travel delays also needs to be adjusted to regional specifications of salaries in Sint Maarten. This information was not available for this study area, therefore it generated a limitation to the application of the method.

10.5 Flood forcasting and early warning systems for coastal regions (WP4)

- *Description of the case study work*

In the case study of St. Maarten a generic Web Based App was develop to be used as a new tool to be used for authorities and inhabitants of the island to guide them through the evacuation to specific shelter (or safe area) when a possible hazard is forecasted. The web app (EvacuApp ver B1.0) was built within ESRI technologies, the app uses the location provided by the GPS of user's cell phone to give the evacuation driving direction as the "best" possible shelter to evacuate based on the current location of the user. The current development of the web app takes into consideration for the evacuation advice the driving distance to all surroundings shelters and the status of such shelters as: Open or Closed based on the occupation of the shelter during the evacuation phase. Figure 65 shows some screen shots of the current development of the web-App.

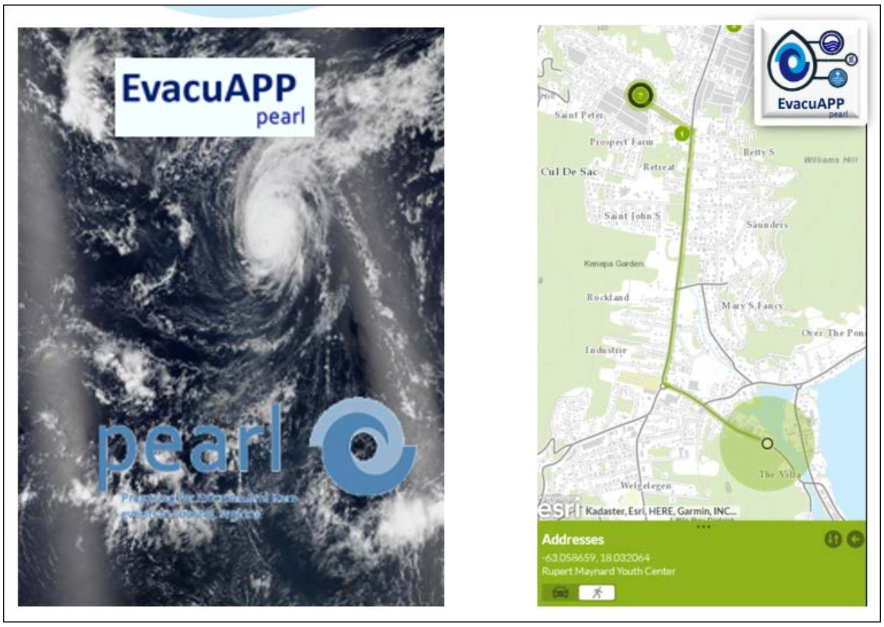

Figure 65 Graphical Interface and demonstration of the Web App for evacuation purposes

- *Lessons learned from the case study work*

The web app developed for this case study can be a powerful tool to be used for the authorities and the inhabitants of the island in order to have a more efficient and organized evacuation in case of a forecasted threat on the Island such a hurricanes that are common in this region. The potential of having a clear image of the status of each one of the shelters that are located in this island for residents, tourists and Evacuation managers can lead to a better location of resources, can lead to risk reduction as having the potential to reduce the exposition to the hazard, etc.

Due to time and budget restrains the app was not test on real case on the island, it was only tested using an emulator, using the ABM for evacuation purposes described in section 10.4.1. It will be of great usefulness to perform some survey of user's acceptability and/or use it in a simulacrum on site to evaluate the real potential of such a tool in the overall performance of an evacuation.

To improve the potential use of such type of technologies it is proposed that new developments or improvements of this tool evaluates the connection to real time traffic services provided by different companies (i.e. Google, Bing maps, ESRI, etc). This services carries an associated economic value and the cost/benefit of such service needs to be evaluated deeper.

10.6 Stakeholder involvement for strengthening resilience of coastal regions (WP5)

- *Description of the case study work*

King's College London carried out the Risk Root Cause Analysis for St Maarten. The findings from St Maarten have been used to structure and inform Work Package 1 inputs to the development of root cause analysis-informed agent-based models (ABM) in Work Package 3.

Although there was no formal stakeholder process convened through PEARL on St Maarten, the research findings can be validated by stakeholders, and then disseminated informally among stakeholders through ongoing contacts held by KCL and UNESCO-IHE as PEARL partners.

The work of WP1 has been used to identify key stakeholders as well as key behaviours (rules and norms) for the ABMs and contributed to a stronger understanding of institutions and institutional dynamics in the MAIA model which underpins the institutional ABM work.

Based on the secundary information collected for St Maarten, a research focuses on the institutional dimension of flood risk management (FRM) was conducted by TU Deflt and IHE. The main research question was formulated as “what is the effect of interdependencies and connectivity between institutions on FRM, for the case of St Maarten”. This work was describe in deliverable 6.2.

- *Lessons learned from the case study work*

The complementarity of the agent-based modelling work to the RRCA approach is that it provides a futures-oriented perspective and simulation of multiple scenarios, where

The Root Cause Analysis and Vulnerability Assessments are mostly oriented to a historic and contemporary perspective for a particular set of conditions, the methods are not clearly designed to provide direct inputs to ABM models as set of rules of behaviour or thresholds in the behaviour of institutions. However these methodologies can complement each other as the RRCA provides a futures-oriented perspective and simulation of multiple scenarios and also help with the identification of stakeholders and their connection or interdependencies. Information that is useful for the definition of the ABM structure.

10.7 Measures and strategies for strengthening flood resilience in coastal regions (WP5)

- *Description of the case study work*

Hydrodynamic models and optimisation techniques were applied to find the best sustainable strategies to reduce flood risk in a residential catchment. The strategies considered combine centralised and decentralised green infrastructure. A detailed description of methods and results were presented in Deliverable 6.2, Section 10.2.4.

- *Lessons learned from the case study work*

- Next remarks summarise the evaluation of method’s application and its outcomes:
    - The method applied is a useful tool to identify efficient strategies and to compare among different measures. Current work includes the addition of grey measures for comparison. It is expected that this method will be helpful in decision making processes for drainage measures selection.
    - Since the 1D-1D hydrodynamic model used has been develop from an existing 2D model, the outputs remain theoretical and approximate. Some fieldwork could have been useful to obtain more realistic results.
    - The measures evaluated have been chosen without collaboration with local stakeholders. The work carried out includes the development of a measures selection

tool, the idea of this tool is that local stakeholders answer several questions about measures suitability and local preferences. The tool has not been yet applied in St. Maarten case study, its application could help the definition of more adequate measures before the modelling evaluation. As a result, the final output could be better accepted as a possible solution.

  - After the selection tool and optimisation framework are applied, final results represented through Pareto fronts should be discussed with key stakeholders to agree on which the best implementable strategies are.

- Both products, the measures selection tool and optimisation framework, have been applied in several cases showing its transferability.

10.8 Concluding remarks

-One issue for this case study was the inability to travel to the case site due to EU regulations, which would have allowed the research team to have a more in depth knowledge, particularly for the implementation of the ABMs, in regard with the data collection for the implementation, validation and calibration of the models.

- All the models developed and/or implemented in this case study have shown its potentiality to advance the flood risk assessment towards a holistic approach and its potential to extrapolate some the lessons learned to European case studies. In particular those concerning the methods, the data availability and the limitations it posed to their application in other areas.

11 Case Study - Thailand

11.1 A brief description of the case study area

The case study area comprises the historic city of Ayutthaya, which lies in an island on the Chao Phraya River in Thailand. The city is located approximately 70km north of Bangkok, in the Chao Phraya River valley. The location is shown inFigure 66.

The island is at risk of flooding, in 2011 much of the island was inundated following heavy monsoon rainfall over a period of 3-4 months. During this event the entire island was inundated, and the water depth exceeded two metres in some locations.

The historic city of Ayutthaya has been designated as UNESCO World Heritage site, covering approximately one third of the island. Understanding the flood risk to the city and its cultural heritage is a challenge since their value cannot be easily evaluated in monetary terms.

Figure 66 Location of Ayutthaya Island and the area designated as UNESCO as a World Heritage Site (WHS).

Ayutthaya Island is susceptible to fluvial and pluvial flooding. The root causes of flooding were identified as the terrain topography in the Chao Phraya River basin, extreme hydro-meteorological conditions, and the lack of proper risk mitigation policies

Some of the studies performed within PEARL have also been applied in Sukhumvit. This study area is located at the eastern side of Bangkok and is part of the central business and commercial districts. Bangkok's central business district has suffered some fluvial flooding events in recent years, in particular in 2011. However, pluvial flooding is more common in the area.

11.2 Understanding the formation of vulnerability and risk in coastal regions (WP1)

Description of the case study work

Stakeholders' participation and analysis

Local stakeholders know much about flooding events in the area and the capacities required to cope with a disaster. Thus, public involvement is critical in the flood risk assessment process, as well as in the development of a disaster risk mitigation plan. Consequently, a range of activities were organised in Ayutthaya to learn from local knowledge and to contribute to building capacity among stakeholders.

The stakeholders included in this process were organisations at different levels in the governmental hierarchy, ranging from local government, through national government and international organisations (see Deliverable 6.2). These stakeholders were invited to meetings and they were involved at different stages of the flood risk assessment process (e.g. data collection, evaluation of mitigation measures, vulnerability analysis and evaluation of mitigation measures).

A socio-organigram of these organisations and their relations was built (shown in Figure 67). This diagram presents the organisations, where they are in the governmental hierarchy, the nature of their collaboration and communication flows, as well as their responsibilities related to flood risk management. This diagram is an important output which helps to understand which the institutional actors are, as well as their responsibilities and interconnections among them.

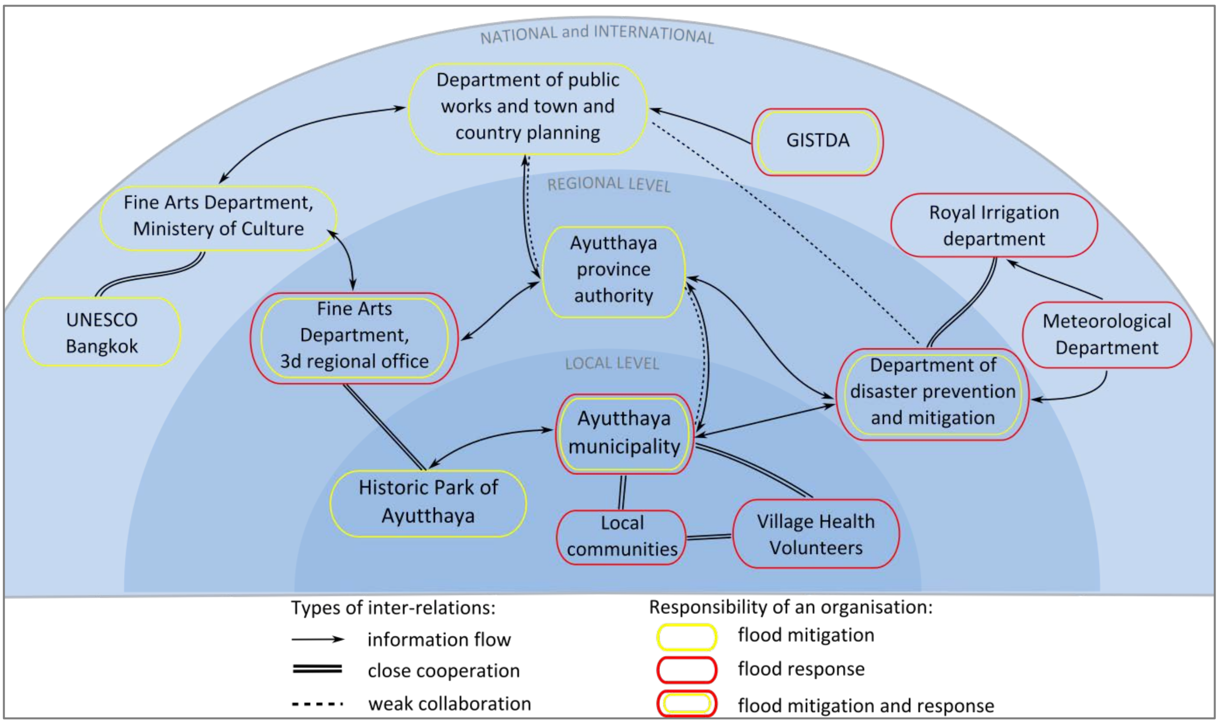

Figure 67 The organi-sociogram showing the stakeholders involved in flood risk mitigation and response in Ayutthaya.

<u>Vulnerability assessment</u>

A multidimensional approach was applied to assess the vulnerability of the island and its communities to flooding in the existing situation. Four dimensions are studied to develop the vulnerability analysis: physical, social, economic and cultural.

For the physical vulnerability assessment, four types of buildings were differentiated: residential buildings, cultural properties, critical infrastructure and roads. Critical facilities were identified during

a group mapping exercise with community representatives. People pointed out the importance of structures such as hospitals and schools.

Regarding the social dimension, it was chosen to work at the community level to assess social vulnerability. It was determined that Ayutthaya consists of 33 communities, for which indicators to assess social vulnerability were developed. These indicators can measure qualities of the community of interest and their relationship with vulnerability. To ascertain the values for each indicator, a questionnaire was developed with 42 multiple choice questions. The questionnaire was presented during Focus Group Discussions (FGDs) with approximately 180 representatives from 30 communities.

The analysis of the economic dimension of vulnerability is aimed to understand the capacity of the local economy to cope with or adapt to a disaster. This dimension was assessed by analysing the response of businesses to flooding during the event and afterwards, in the recovery period. Seven business sectors were identified (non-tourist accommodation, non-tourist goods and foods, non-tourist transportation, tourist accommodation, tourist food and drink, tourist services and tourist transportation). Twenty semi-structured interviews were completed with representatives of business owners in order to evaluate a set of parameters for economic vulnerability.

The cultural dimension of vulnerability was differentiated from other dimensions to capture the effect of flooding on cultural values, such as historical, spiritual or aesthetic values. The level of cultural vulnerability was assessed by considering the significance and sensitivity of the cultural assets in areas exposed to flooding. This significance was assessed by consultation with the responsible government department and local community. The sensitivity assessment was completed through expert opinion.

The data collected on each dimension of vulnerability were analysed and mapped in a GIS environment. Figure 68 shows vulnerability results for the four dimensions and the combined result. The combined vulnerability map was created by weighting the scores for each dimension. These weights were intended to be defined at the final consultation workshop. However, this workshop had very low attendance because of the political upheaval at that moment. Therefore, it was decided to give equal weight to each of the four vulnerability dimensions.

Lessons learned from the case study work

Stakeholders' analysis activities had useful outcomes regarding the understanding of local actors and their inter-relations. Through the mapping of organisations, their responsibilities and how they collaborate and communicate, it is possible to build realistic disaster risk mitigations plans. Moreover, stakeholders' consultation activities led to a better assessment of local vulnerabilities, for instance helping to identify critical infrastructure in the area. Besides, activities involving local communities helped to evaluate social vulnerability indicators, while door to door interviews to local business representatives facilitated the evaluation of economic vulnerability. The methodologies here applied show how the involvement of local actors can lead to a better understanding of the problem. Furthermore, these methods are transferable to be applied in other areas.

A weak point of methods involving stakeholders is related with the risk of low level of participation in organised activities. Although, in this case there was a good acceptance of the organised activities (with attendances of 100 people to some of the workshops), external factors determined the low attendance to the final consultation workshop. Due to this issue, the method to calculate the combined vulnerability was changed.

The holistic approach was considered through two main characteristics of the applied method. First, through the participation of different stakeholders, ranging from local communities to national and regional level institutions. This wide participation approach advanced the existing knowledge by allowing a much better understanding of the local problem. Secondly, through the multidimensional approach to assess vulnerability. This method allowed to consider separately the cultural dimension, which is a main aspect in this case.

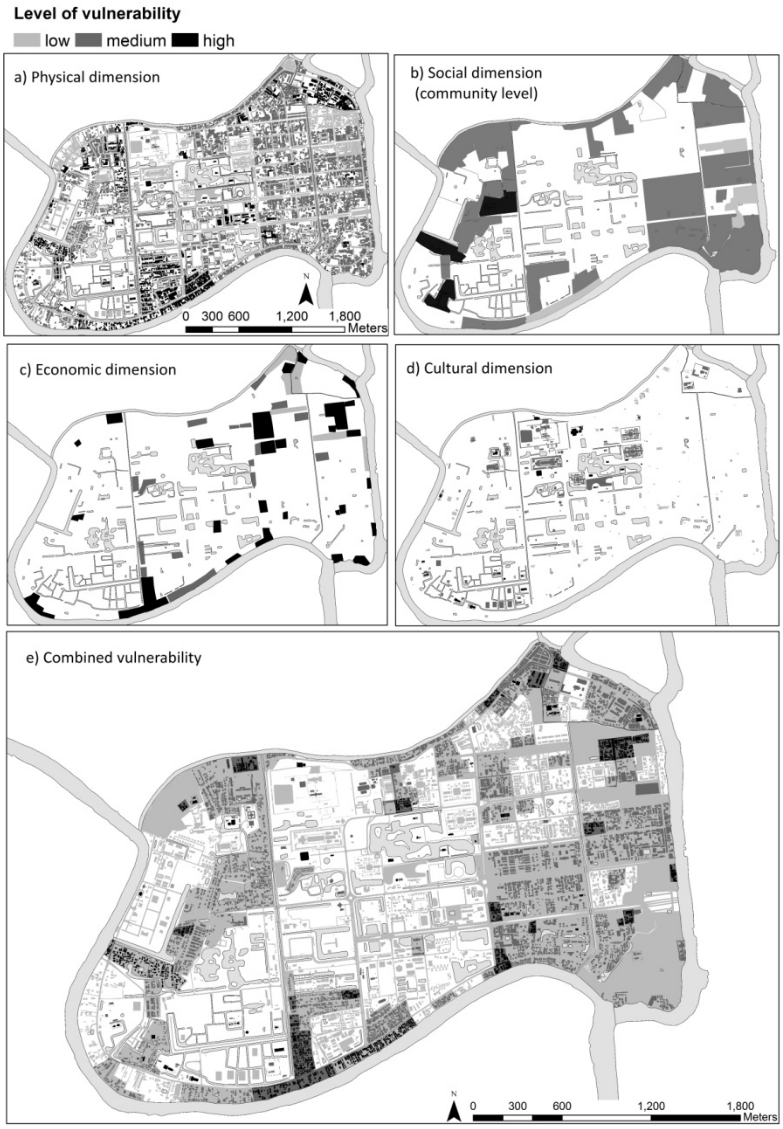

Figure 68 Vulnerability maps

11.3 Understanding the formation of hazards under extreme events (WP2)

Description of the case study work

The hazard component was determined from a simulation of the 2011 flood event. A coupled 1D-2D numerical model using the DHI MIKE FLOOD software was developed to investigate the propagation of excess floodwater from the 1D river model to the 2D floodplain model for the study area.

Time-series of rainfall from five weather stations recorded by the Thai Meteorological Department (TMD) were used as a boundary condition. The computed discharge, the regulated discharges and the tidal levels at different stations were also used as the boundary conditions. The 1D model was calibrated with observed data of discharge and water level in the event of the year 2011.

A coupled 1D-2D model of Ayutthaya was developed to investigate the propagation of excess floodwater from the 1D channels: Chao Phraya Rivers, Pasak, Lopburi, and Maung Canal, into the 2D urban area. The validation of the 2D component of the model was carried out using flood depths in the Ayutthaya area. Manning's roughness values were adjusted so as to match simulated and observed flood extents and depths on the island.

Hazard is defined based on the depth of inundation alone. Floodwater velocities in the site are known as low (less than 1 m/s) and can be neglected. In this research, threshold depths of < 0.5m, 0.5-1.5m, and >1.5m were used to define the flood hazard as low, medium and high respectively.

Lessons learned from the case study work

The coupling of 1D and 2D models allows the simulation of water depths in the floodplain area of the island. This type of models helps the replication of flood events by simulating water depths and velocities in front of different rainfall events. As a result, the impacts of different events can be estimated.

Real data for water level and discharge from the 2011 event allowed the calibration of both models, improving the results obtained. Due to local characteristics, the hazard is defined considering only water depths, this results in a very simple description of hazard levels which is easily understood by decision makers.

Holstic and multiple risk assessment (WP3)

Description of the case study work

<u>Risk analysis</u>

Methodologies for flood risk assessment have traditionally been based on quantitative methods and the knowledge of experts, excluding the views of the community. However, qualitative approaches are useful to address flood impacts that cannot be expressed in monetary terms. To achieve this, participatory activities that facilitate the involvement of various stakeholders have been frequently applied in recent years.

The approach used in the study combines both quantitative and qualitative data and methods. The four dimensions of vulnerability, as well as the hazards estimation, have been assessed using quantitative data (see Deliverable 6.2). To perform the qualitative assessment of risk, an estimation of the hazard and vulnerability was conducted using local and expert knowledge to identify vulnerable assets, and questionnaires and workshops to gain knowledge on the expected hazards and the vulnerability of communities.

Vulnerability and hazard maps are combined to produce a flood risk map. From the quantitative analysis case, a flood risk map for an extreme flood event like the 2011 flood event is presented in Figure 11-4. This map represents the risk under the current state of flood protection.

A group mapping exercise was used to assess the perception of risk by local communities, the risk map obtained is presented in Figure 69. Even though participants were encouraged to discuss and to colour the area of the Historic City of Ayutthaya, none of the groups did it. Participants were more interested in the areas of their own communities and did not show much interest in the World Heritage Site. Some participants expressed that it is the responsibility of appropriate experts to judge the risk for the World Heritage Site.

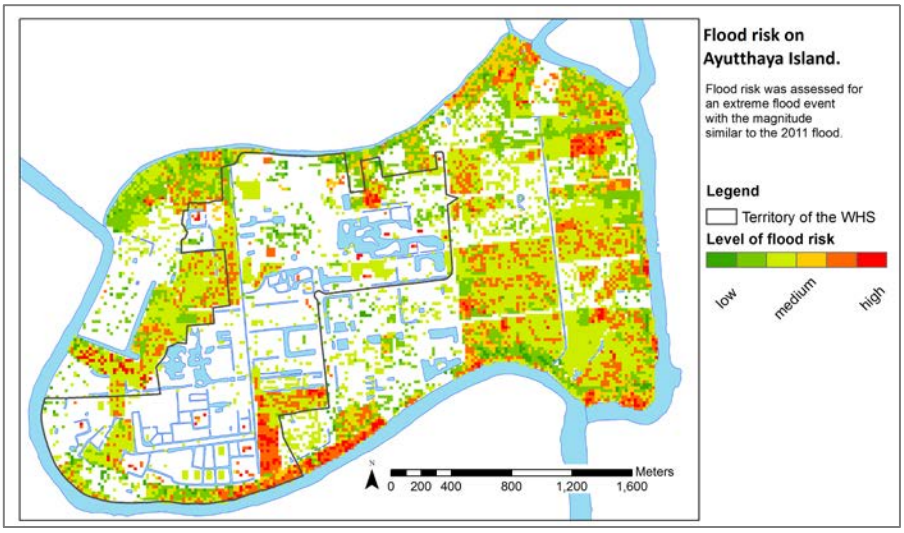

Figure 69 Flood risk map of Ayutthaya Island with the current state of flood protection.

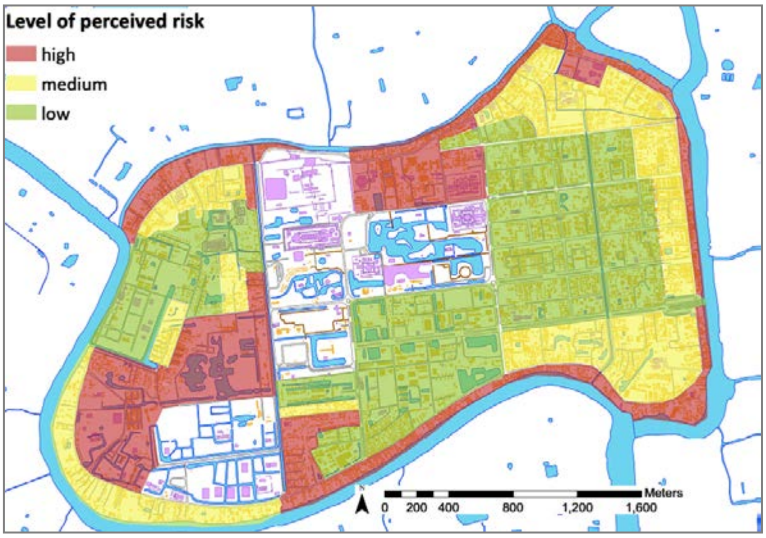

Figure 70 Risk perception map based on group mapping exercises.

<u>Risk communication</u>

Regarding risk communication, relevant flood risk related information includes flood magnitude parameters and vulnerability levels. The means and techniques identified for risk communication were maps, graphics, tables, and charts. The effectiveness of these means and techniques was

assessed during workshops and by questionnaires. The main objective was to understand the ability of local residents and stakeholders to receive and share information through maps and other means.

Workshop activities demonstrated that local residents and stakeholders are able to share flood risk related information. The preferred means of communication by residents was orally. Participants could easily describe flood levels during past events. Most of them could read written materials and respond to questions in written form. However, they preferred to receive illustrated information rather than written descriptions. Finally, it was noticed that residents had difficulties in interpreting information from maps and identifying locations. In contrast, local institutions and key stakeholders preferred maps and statistical data presented through charts and graphs, as communication means.

Figure 71 presents the results of a query in which a questionnaire regarding the preferred sources of flood related information was answered at the community workshop. Results show that the preferred source of information is television or radio. Other three sources are also relevant among residents, these are information given by local government, newspapers and community committee. Particularly, residents rely on local government information (Municipality) to make a decision about evacuation. The majority of the respondents were elderly people; therefore internet was not considered as a popular information channel.

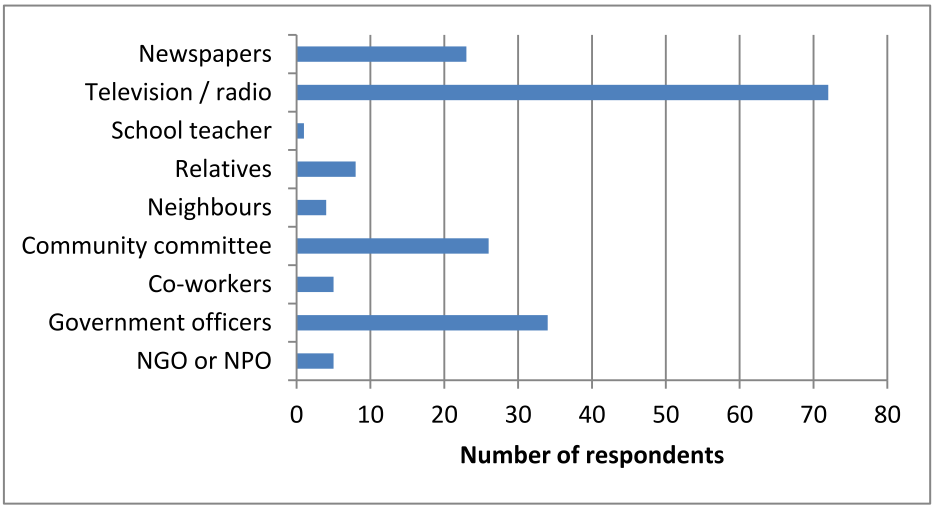

Figure 71 Preference of information sources in the context of risk communication among Ayutthaya residents

<u>Modelling pathogens to estimate the impacts of flooding in public health</u>

This analysis has been applied in Sukhumvit. Pluvial flooding is common in the area, resulting in the contact with contaminated water by children, pedestrians and cyclists.

Using a 1D/2D hydrodynamic model of the area, the rainfall event of 11 October 2014 was simulated to estimate pathogens exposure hazards. The calculated water depths from this model show that the maximum flood water depth in the area reached 0,36m. Water quality samples of flooding water and dry weather water were taken on three different days at different locations, in order to know the variation of E.coli concentrations in time and space. This data was included into the model.

The values E. Coli concentration, the water depths and the duration of the flooding event were used to generate a waterborne infection map. Results show that most of the flooded areas present a very high hazard for waterborne infections due to the long duration of the flood event (more than 60

minutes) and the high concentration of E.coli. Moreover, the simulated rainfall event occurred during lunch time, when many people from the business and commercial areas are out for lunch. This generates a significant public health risk since more pedestrians are exposed to this hazard. More detail results were described in deliverable 3.2.

Analysing Cascading Effects of Flood Events and Assessing their Impacts on Critical Infrastructure

This analysis has been applied in Sukhumvit. The present work uses 1D-2D models for estimation of hazards through the identification of flood-prone areas. Flood hazards are quantified on the basis of floodwater depths since changes in water velocities are negligible due to the flat local topography.

The data for the analysis of cascading effects comes from two different sources: interviews and utility records. Interviews with residents and utility operators had the objective of assessing the potential for cascading effects. Another objective was to define interdependencies between different infrastructures and their services. Two interview surveys were undertaken for this purpose, one targeted residents and business owners, while the other one targeted critical infrastructure operators.

The detailed methodology is presented in Hilly et al. (2018). Results show that the roads in Sukhumvit area are prone to flooding and consequently they can cascade in many other infrastructure and services. Therefore, the potential losses can be substantial. This has been established through the feedback of residents and businesses in the area. They expressed as main concerns the delays to schools, work place and business appointments. Furthermore, the cost of delay to restore water and electricity services can be substantial, but the inconvenience for population from absence of water supply is even greater.

Lessons learned from the case study work

In terms of the two flood risk assessment approaches applied in Ayutthaya, the traditional (or technical) and the risk perception (social) approach, these approaches differ in many ways. The social perspective on risk assessment focuses on the root causes of flood risk related to human mental processes and the human scale. The traditional approach provides the possibility of testing potential flood risk reduction measures. Consequently, flood risk managers can identify areas of the highest risk based on the map derived with the traditional approach. However, both the legitimacy of flood risk reduction plan and risk behaviour of residents rely heavily on the level of perceived risk. Both approaches reveal valuable insights into the phenomena and as such they both should be used in the process of flood risk management. Finally, the traditional approach provides detailed information, depicting which buildings are under higher threat, whereas risk assessed by local communities tend to assess risk on a large scale. This raises interesting questions over the best way to communicate flood risk.

Regarding risk communication, the activities performed had two main outcomes. First, it is very useful to learn that local stakeholders can share valuable data about past flood events. Moreover, the knowledge about which are the preferred communication methods of the different stakeholders can facilitate future information exchanges. These findings are useful to plan future meetings, workshops and data collection activities. Secondly, the analysis of preferred sources of information resulted in useful inputs to perform information campaigns and to deliver important messages related to early warning systems for example. These activities can be much more efficient if the preferred and most effective communication channels are known. Future work should focus on the analysis of

preferred sources of information by young people, since this study was performed mainly with elderly people.

Both studies performed in Sukhumvit area are beneficial to understand secondary impacts of flooding events. These impacts, despite of being secondary effects of flood events, can cause tremendous damages, as well as inconveniences and health related risk for people. The understanding of these issues helps to plan actions to mitigate these impacts in the future. Either through campaigns to inform people about the risks of being in contact with flood water, or through emergency plans to avoid water and electricity shortages, many of these impacts can be reduced or even avoided. The pathogens impact and the cascading effects studies, as well as the rest of the methods in this section, are transferable to other case study areas.

Stakeholder involvement for strengthening resilience of coastal regions (WP5)

Description of the case study work

In this work, we focused on the identification of key co-benefits that can be obtained applying green measures to reduce pluvial flooding in Ayutthaya. The stakeholders' perceptions analysis was taken as a central aspect to select flood risk reduction strategies. The participatory planning was applied through a simple and short questionnaire. The considered co-benefits were divided into three categories: environmental, social and economic. The questionnaire was answered by 42 stakeholders from diverse backgrounds, such as public authorities, international agencies, private sector representatives, citizens, and visitors to Ayutthaya. Details about the methodology applied and results obtained can be consulted in Alves et al. (2018b).

Results show that *biodiversity and ecology enhancement* and *water quality of the receiving bodies improvement* were identified as key environmental benefits. Regarding social benefits, *amenity and aesthetics enhancement* and *increment of green areas for recreation and health* were selected as the most important. Finally, the main economic benefits were identified as *rainwater harvesting* and *building energy consumption reduction.*

Another analysis performed focused on the answers given by different stakeholder's types. The objective was to understand how different actors perceive different necessities. The stakeholders were divided in three groups: general public, policy makers and scientific community. From this analysis, it was observed that different groups chose different benefits as the most important (see*Figure 72*). These results confirm that the common practice of making decisions only by the scientific community or policy makers, does not consider the preferences of residents or visitors who can have a different perspective. This analysis shows the importance of including different types of stakeholders in decisions making processes, and particularly residents and visitors, to consider local perceptions.

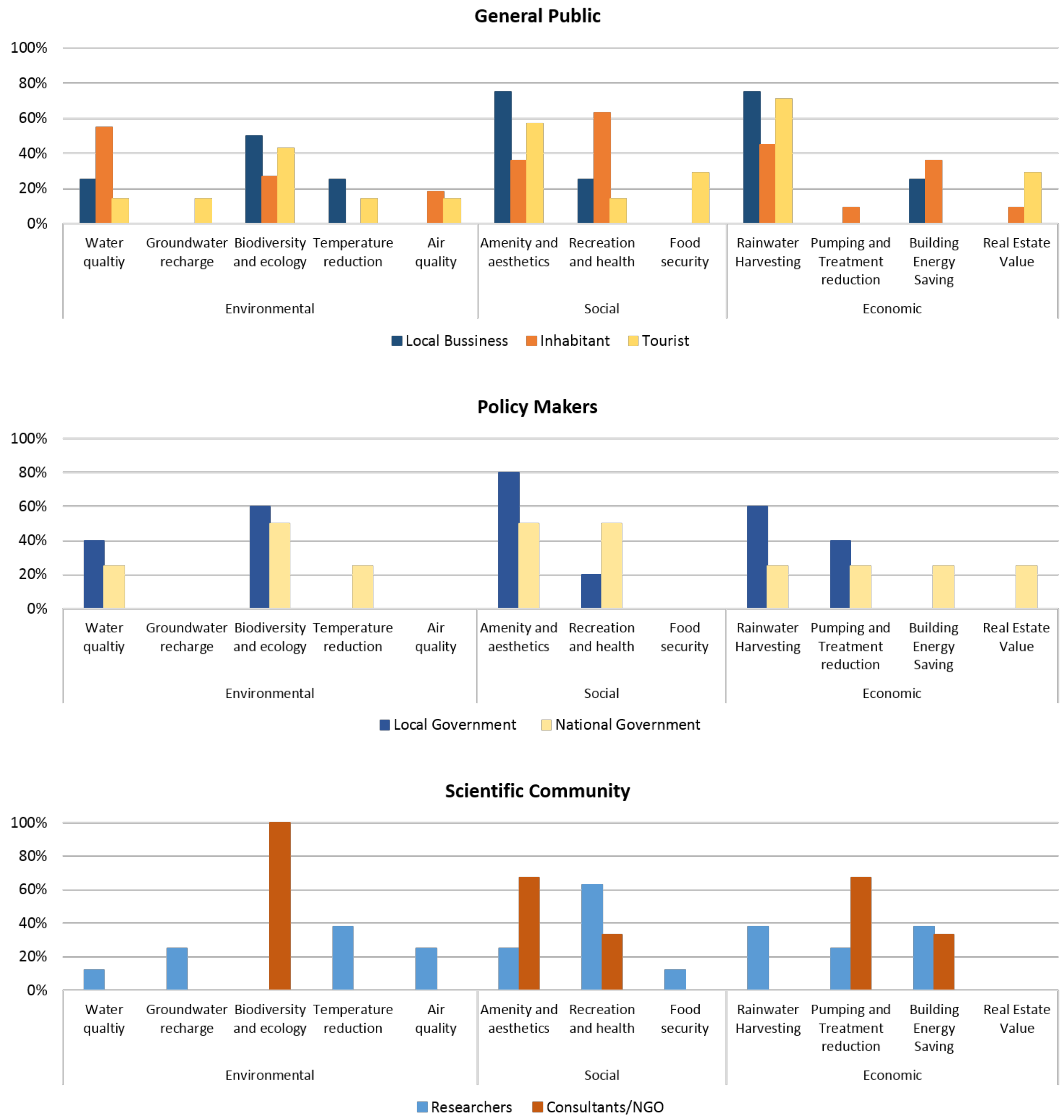

Figure 72 Selected most important benefits by different stakeholders' types: (a) general public; (b) policy makers; and (c) scientific community.

Lessons learned from the case study work

This work allowed to improve the knowledge about benefits preferences in the area, helping to plan better strategies for the area. The consideration of different stakeholders into the analysis permits a holistic approach which takes into account the points of view of different actors regarding the necessities for the area. The procedure applied in this case can be transferred to other cases. It is important to have as many answers to the questionnaire as possible, future applications should

consider this to increase the number of respondents. The broad range of different involucrate stakeholders in the case studied here is a positive remark.

The second part of the analysis presented in this section highlights the importance of bringing together different types of stakeholders in planning processes. Policy makers should consider the perspectives of scientific communities and general public related to the area, before making decisions about which strategy is the best for a neighbourhood. The variety of perceptions will enrich the final decision, establishing more suitable solutions for people living, working or visiting the area.

Measures and strategies for strengthening flood resilience in coastal regions (WP5)

Description of the case study work

Selection of green and grey infrastructure to reduce flood risk and increase co-benefits

A new method for selection of structural measures for flood risk reduction is applied in both case study areas, Ayutthaya and Sukhumvit. The method considers green and grey measures that can cope with different types of floods. The main objective behind the application of the method is to support decision-making processes. This method allows the selection of adequate measures in accordance to local conditions and preferences. The new methodology was through a tool which operates as a standalone application. Through this tool, stakeholders followed the process to obtain a ranking with applicable measures for each case. The process consists in the answer of questions and selection of preferences. A detailed description of this method is presented in Alves et al. (2018a). Table 16 answers and preferences chosen for both case study areas.

Table 16 : Answers and preferences chosen by stakeholders for both case study areas

Case Study:	Ayutthaya	Sukhumvit
Characteristics for screening:		
Flood type	Fluvial	Pluvial
Soil infiltration capacity	High	High
Groundwater depth	More than 1m	More than 1m
Bedrock depth	More than 1m	More than 1m
Draiange area slope	Lower than 5%	Lower than 5%
Coastline/riverbank space availability	Mainly urbanized	NA
Urban Configuration	Low urbanized	Highly urbanized
Realocation or re-build on pilars	Not possible	Not possible
Development stage of area under risk	Already developed	Already developed
Characteristics for ranking:		
Public space availability	More than 25%	Less than 25%
Roads with - availability of linear spaces	Availability	No availability
Average population density	Lowe than 100p/ha	Higher/similar than 100p/ha
Main land use	Residential/Touristic	Residential/Commercial
Type of sewer system	Combined	Combined

Volume reduction for WWTP/CCO issues	No	No
Co-benefits preferences weights:		
Water quality improvement	7	8
Environmental benefits	6	8
Liveability enhancement	7	9
Economic benefits	7	9
Socio-Cultural development	7	9
Goals weights:		
Flood reduction	3	3
Cost minimisation	2	2
Co-benefits improvement	1	3

From the answers given by stakeholders, it is observed that the main difference between both areas is population density. While Ayutthaya is a medium density area, Sukhumvit is a highly urbanised area with low public space availability. Also, the flood problem chosen for each site was different, while the main problem is Ayutthaya is identified as fluvial flooding, in Sukhumvit pluvial flooding is selected issue. In both cases flood risk reduction was selected as the main goal. However, more importance is given to the achievement of co-benefits in the case of Sukhumvit.

Results for Ayutthaya show that the elevation of existing dikes and generation of new polders are defined as the preferred grey measures. While open detention basins and floating constructions are selected as preferred green measures. Also, temporal measures are selected for this case, such as demountable barriers and dry flood proofing. In the case of Sukhumvit, several measures are listed as possible solutions. As preferred green measures the method chose rain gardens, green and blue roofs and rainwater harvesting, among many other. The grey measures chosen are close conduits and underground storages.

It is observed that decentralised options are preferred in the case of high population density, with higher preference of green measures which are oriented to achieve rainwater disconnection from the drainage system. These measures are also beneficial for the achievement of co-benefits, such as heat stress reduction and water reuse. It is also observed that both green and grey measures appear as preferred measures, suggesting that the combination of these two approaches can achieve efficient and sustainable solutions.

Green infrastructure for flood risk and enhancement of thermal comfort

This analysis has been applied in Sukhumvit. It addresses the effectiveness of green infrastructure (GI) measures on urban flooding reduction and enhancement of thermal comfort. This quantitative analysis is achieved by running a macro scale model for urban flooding and a micro scale model for human thermal comfort. To achieve this, the first step was to identify where the vulnerable areas to heat stress are located and which is the catchment area which influences flood events in the selected zone. With this data, it is possible to design appropriate multifunctional measures that would lead to the decrease of heat stress and the reduction of flooding at the same time. The second step was to evaluate the effectiveness of the four selected measures on the reduction of flood risk and heat stress in the area. The complete methodology is presented in Majidi (2017).

The results showed that the effectiveness of the measures for flood risk reduction is decreased when the rainfall return period is increased, highlighting the need to include other benefits as part of the analysis for selection and implementation of green infrastructure measures.

Additionally, green roof was the most efficient measure for this case study, while pervious pavement is the least effective measure. The microclimatic situation to evaluate efficiency in heat stress reduction has been done in two different urban configurations, one with low rise buildings and another one with high rise buildings. The most effective measure in both cases is rain gardens. One reason to explain this is that in the case of low rise buildings area more surfaces are exposed to sunlight, when trees are used as vegetation in rain gardens, the measure prevents sunlight reaching paved surfaces. An interesting finding is that in the case of high rise buildings, this measure can be more effective during night time. High-rise buildings absorb sun energy during the day and release it during the night, this effect can be partially controlled applying vegetated measures.

Lessons learned from the case study work

The first study performed in both areas, Ayutthaya and Sukhumvit, shows how flood risk reduction strategies can be selected based on local characteristics and preferences. Moreover, this method allows to consider which co-benefits are important for the area, taking into account the views of stakeholders to include their preferences into the selection process. Finally, it also shows the importance of considering both green and grey approaches, and how the combination of them can lead to an efficient strategy, which reduces flood risk but also is applicable in the case of space restrictions for instance. A final step of discussing results with stakeholders is missing. The discussion of results and the selection of one or few combinations of measures for further evaluation are valuable steps towards the definition of a flood risk mitigation strategy.

Regarding the thermal comfort study, the assessment showed that the effectiveness of green measures on thermal comfort enhancement depends on several factors. These factors are: characteristics of the implementation site, type of green measure, coverage and location of green measure, and time of the day. Moreover, this analysis can be seen as a further study after the preselection of green measures. Rain gardens and green roofs were two of the green measures chosen for Sukhumvit by the tool in the previous analysis. In this one it was showed that while green roofs are the most efficient measure for flood risk reduction, rain gardens is the best option to improve thermal comfort. Again, the most effective strategy is the combination of these two measures if both objectives want to be achieved.

Concluding remarks

The work performed in Thailand advanced the knowledge about the study case in several ways. First, a complete and wide stakeholders' analysis allows to understand which the relevant actors and communication canals among them are, as well as their roles. Moreover, the risk communication analysis established the best methods to communicate with local stakeholders. Both to learn from them about past events and risk perception, and to communicate with them in emergency situations for instance. Besides, the importance of taking into account different stakeholders during planning processes has been proven through the qualitative risk study and the co-benefits analysis.

Secondly, the comparison between quantitative and qualitative risk allowed to understand the importance of considering both points of view when studying risk. The technical approach enables to quantify vulnerability and hazards, as well as to assess different measures under different

scenarios. The social approach permits to understand root causes of flood risk. In summary, flood risk managers can identify the highest risk areas based on the traditional approach. However, the acceptability of the selected flood risk reduction plan depends greatly on the level of perceived risk, given by the social approach.

Thirdly, the analysis of pathogens exposure risk and cascading effects of flood events, demonstrated the importance of considering these secondary effects when studying risk. Despite of being secondary effects, the impacts can cause tremendous damages. Is through the understanding of these issues that mitigation plans for these impacts can be developed.

Finally, the work related to selection of green and grey infrastructure shows the relevance of considering co-benefits of flood reduction measures from the very beginning. When local necessities are taken into account, these co-benefits can add enormous value to green infrastructure. Moreover, the application of this concept is visualised through the analysis of green infrastructure for flood reduction and thermal comfort enhancement. Which demonstrated how these two issues can be solved with one green measures strategy.

12 Cross-linking of the finidings from the PEARL case study areas

12.1 Overview

The holistic approach and the corresponding tools and methods developed within the PEARL project are applied to a number of case study areas in Europe and internationally. European case study areas have different baselines and cover a wide range of geograpahical/topographical, risk and hazard as well as socio-economic conditions and each of the case studies experienced different hydro-meteorological extreme events in the past. Through the international case studies the project benefits from the international experience on extreme events. They extend the range of extreme events by e.g. cyclone, hurricanes and tsunamis.

The research activities in the respective case study areas revealed that holistic risk assessment can be the initial step in order to define comprehensive flood risk management and mitigation strategies. Holistic risk assessment helps to gain an insight in the formation of risks and hazards and the impacts of extreme events.

It became evident, that flood risk management and mitigation as well as risk governance have different level in the case study areas. In that sense, the German case study had an already an established set of methods and tools for flood risk management, with the stakeholder involvement process partly put in place, whereby in the Greek study area PEARL can be understood as an initiator of a systematic flood risk management practices in the area, putting it into the holistic context. The cases in Italy and France (Genoa and Les Boucholeurs) had a recent trigger i.e. a big coastal event (Ligurian floods 2011 and Xynthia resp.), which pointed out the weak points in the current risk management and called for actions. At the same time, in such cases the political sensitivity of the flooding issue could decisively shape or partly hamper more extensive implementation of the PEARL activities.

Also, a number of super-ordinate policies regarding institutional and governance practices do exist, but are not incorporated into the current flood risk management and mitigation frameworks and policies of the municipalities and authorities. In that sense, the PEARL LAA methodological framework represents a way forward to provide significant support to the municipality and authorities towards an enhanced flood management and disaster risk mitigation.

The outcomes of the application indicate different suitability and acceptance of the PEARL methods and tools deployed. They are here given in the following sections.

Due to rather heterogeneous local contexts, it is not feasible to perform a direct comparison among the case studies, but to analyse their achievements within PEARL taking into account their local contexts and the baselines. Still cross references can be drawn between the cases with a certain degree of similarity such as the St. Maarten and Greek case as both study areas are located on an island and share a number of similar attributes (touristic areas, multiple hazards, small communities).

12.2 Understanding the formation of vulnerability and risk in coastal regions

The formation of vulnerability and risk has been analysed in the 4 European (Germany, Italy, France and Greece) and 2 International case studies (St. Maarten and Thailand).

However, they have been implemented to different extents deriving the following outcomes and lessons learned in terms of their holistic nature, the upscaling and transferability potential, also opening the room for improvements.

An **extensive implementation towards the holistic approach** of the PEARL tools has been performed in the Rethymno case, even using the results from this analysis within the stakeholder´s Learning and Action Alliances (WP5). The outcomes have been assessed as very useful by the stakeholders and are intensively discussed within LAAs.

Also, a strong link between the formation of the vulnerability and risk and the stakeholder involvement has been achieved in the case studies in Thailand and St. Maarten. In Thailand, the activities involving local communities helped to evaluate social vulnerability indicators, while door to door interviews to local business representatives facilitated the evaluation of economic vulnerability.

A strong potential for **upscaling and transferability** of the outcomes have been assessed in the Genoa case study, where the results of the vulnerability assessment can be integrated in ongoing or future spatial planning or management processes. Furthermore, the PEARL local partner (GISIG, SME) is exploring the possibility to test and apply the methodology into another river basin in the Genoa area, with the aim to demostrate the reliability and the usefullness of results to local administration, and translate the methodology into a common governance tools for Liguria basins.

The German case study has tested the posibility to deply the RCCA study and develop a meta model with the data mainly coming from the available literature instead of perfoming a thorough door-to-door research. Still, the statements and facts available in the literature had to be cross-checked with the responsible institutions, requiring short intervews and communication. Such a study can be taken as a preliminary, which should be refined with focused interviews where required.

In the Italian case study, the RCCA revealed that the interplay between legal and financial issues generated a deadlock that prevented local authorities from effectively reducing risk and should be further refined with the up to date data as per availablity.

Potential for improvement has been identified in all case study areas and is mainly related to the data availability and quality (Germany), where the results could be improved if the other indicators had corresponding data available. Further, some statistical data retrieved were from a different year compared to the rest of the data.

Although assessed as a strength of the method, the involvement of stakeholders can have a two-fold impact. The attendance to the workshops can depend on the external factors, which can have an impact on the final outcomes.

The RCCA is strongly dependent on the data and information that is given as an input. In the St. Maarten case study some key sectors and stakeholders were unrepresented in the study sample such as tourist and hotel trade, critical infrastructure facilities, donors, property developers as well as community leaders and affected residents.

12.3 Understanding the formation of hazards under extreme events

The formation of hazards has been analysed in all European and International case studies (St. Maarten, Taiwan and Thailand). The cases had different starting points and the models availability ranging from the no existing models in Rethymno, to the Elbe Estuary or St. Martin cases where some initial modes were available and within PEARL were extended to analyse the multiple nature of the flood hazard in the area. In some cases the real data for water level could be used, improving the calibration (e.g. cases Ayutthaya (flood event 2011) or the Elbe Estuary (Xaver, 2013). Genoa (Ligurian floods, 2011)).

The key case study to analyse the **full extent of the PEARL modelling chain** was the Danish-Greve case study (DK). However, the timings of data collection procedures models development and full availability turned out to be a challenge for sequential application of the individual models.

Moreover, even a setup of individual models for single or multiple hazards requires considerable effort and enough time and resources have to be allocated for it. Moreover, the hazard assessment is the basis for the holistic risk assessment and management and as such should be performed at the required accuracy and level of detail. The timely availability of the required data and previous experience were the key factors to provide the calibrated model of the Elbe Estuary despite its high complexity. In the Genoa case, the networking activities with Fondazione CIMA and RISC KIT project, enabled cross checking the obtained result and opened a cross project discussion about model implementation and tools, which has been assessed as beneficial for both parties (PEARL and RISC KIT).

The developed maps have been further used to communicate with the stakeholders including non-experts within LAAs in the Spanish, Thai and Greek case. In the Ayutthaya case, the hazard is defined considering only water depths, this results in a very simple description of hazard levels which is easily understood by decision makers.

Potential for improvement is mainly seen in improved i.e. more realistic timing and planing of the development and apllication of the individual models in case they are to be deployed in a chain (both, parallel or subsequent order).

12.4 Holstic and multiple risk assessment

The holistic and multiple risk assessment has been one of the key tasks in PEARL and has reached different levels of implementation in the case study areas. It mainly depended on the main research and actual needs in the studied area and the available resources. It encompassed the quantitative and qualitative flood risk assessment as well as the agent- based modelling (Coupled Agent-Institution Modelling- CLAIM).

The results of the risk assessment in case studies exhibit rather heterogeneous level of detail (building vs. macro scale), type (direct vs indirect) and the corresponding methods and tools deployed.

The holistic aspect in the German case study has been brought by the analysis of the temporal evolution of the flood impacts and risk generated in the area of Wilhelmsburg. They are a valuable input and discussion point with the key stakeholders when discussing further urban development and flood risk management strategies in the area. Due to the high interest of the key stakeholders, this analysis will be used for refinement of the current meta model for the MAIA Framework and as an input to the agent-based model beyond the project lifetime.

The holistic aspects have been integrated into the Greek case study by developing the individual models such as root cause analysis (RRCA framework) or hydrodynamic models and using them for the stakeholder involvement, combining and incorporating social, technical and natural aspects.

In the Spanish case, the obtained damage and risk maps have been used for the communication with the stakeholders. The information contained both direct and indirect damages and though the communication process with the stakeholders qualitative risk assessment could be initiated.

Assessment of the indirect damages due to traffic interruption has been studied by combining the joint impacts of both adverse weather conditions and accumulated floods to road transportation, which can be considered as a novelty. The developed model deployed in the St. Maarten case, was limited by the reduced availability of transportation measurement data. Traffic measurements are needed to verify and calibrate the parameters used in the SUMO model to ensure the modelling results can represent the traffic conditions properly, which can potentially be a limiting factors for a wider application of the model.

Qualitative and quantitative risk assessment has been achieved in the case study in Thailand. Apart from their views and believes, the local stakeholders can share a valuable input about the past events and local characteristics, which can be useful for the improvement of the models used.

One of the main achievements towards the implementation of the holistic framework has been the enhancement and implementation of the Coupled Flood-Agent-Institution Modelling (CLAIM) framework. This model helps us to map and analyse the key actors/institutions in the flood risk management, enabling testing of different policy options by taking into account agents' behaviors to different constraint levels of a given policy.

This model has been applied in the St. Maarten case. For the German case, the meta model of a sub are (Wilhelmsburg in the city of Hamburg) has been developed and prepared for the input into the model. In both cases, the availability of data and information has been of issue. The model requires a large number of data of different types and sources, which currently limits its extensive applicability. Also, the agent based modeling alone may have very short computation time but the flood model can take longer. Therefore, the total experimentation may take very long time (in months) even with the use of high performance computing machines.

12.5 Flood forcasting and early warning systems for coastal regions

Improvement of the flood forecasting and early warning capabilities for coastal regions has been one of the major objectives of PEARL and has been performed in the selected case study areas based on the actual needs and availability of the resources (mainly data).

Enhancement of the forecasting capabilties can be considered as one of the major improvements of the existing methods and tools in the Elbe Estuary witin PEARL. This achievement is mainly due to the intensive collaboraiotn with the key institution/ stakeholder and the PEARL research team. This collaboration enabled an effective delivery of the tool that is needed by the practitioners and the affected public stakeholders, considering both, its technical capability and the usability.

A high level of transferrability has been assessed when implemented the developed technology. A variety of options is available for establishing a real-time forecasting system for an area. Each component of a typical system (i.e. Data Acquisition, Flood Forecasting, Decision Support, and Dissemination (report D4.1, PEARL)) may be customised according to forecasting needs,

stakeholder concerns, and data availability, and can thus be as streamlined or as sophisticated as appropriate.

Of high Importance is the result achieved in the St. Lucia region, which demonstrates how such a system may be built despite data scarcity in an area utilising various approximation techniques for model setup and performance evaluation. This opens the door to a number of small coastal communities in the area and worldwide.

The availability of the user friendly Apps, such as the PEARL Detective has been assesses as very usefull, based on the outcomes from the Greek case study work. Its utilisation enables the collection of data (text, images and location) related to floods from the field, information which cannot be obtained otherwise.

The same experience has been made in the St. Maarten case and evaluated as a powerful tool to be used for the authorities and the inhabitants of the island in order to have a more efficient and organized evacuation in case of a forecasted threat on the Island such a hurricanes that are common in this region.

To improve the potential use of such type of technologies it is proposed that new developments or improvements of this tool evaluates the connection to real time traffic services provided by different companies (i.e. Google, Bing maps, ESRI, etc). This services carries an associated economic value and the cost/benefit of such service needs to be evaluated deeper.

All developed tool will continue their operation beyond the project lifetime.

12.6 Stakeholder involvement for strengthening resilience of coastal regions

Due to different baselines and key research activities in different case study areas, the way and extent of the stakeholder involvement considerably vary across the case study areas. The political situation, the awareness and motivation of the key stakeholders turned out to be the most decisive factors for the setup and the agendas of the LAAs in the case study areas.

The political instability in the Spanish case study area, interrupted the established process as the strategic agendas and the priorities changed over time. Also, the political sensitivity of the flood issues in the French case study area affected by the Xynthia limited the stakeholder activities to individual meetings and fragmented communication with the parties involved. Still, in both cases a progress could be made considering the baseline. In the Spanish case study area, the low awareness of the flood problems by the key stakeholders and their major concerns have been assessed during the LAA meetings. Further, the communication with the participants has been mainly based on the flood maps that have been assessed as the key tool for the efficient communication. In the French study area, the method and the outcomes from the FRI tool have been the major incentive for the participants to take part in the meetings.

In both cases, the addressed areas are small coastal communities in the touristic areas. On the other hand, in the the Greek case study area, Rethymno with the comparable geographic features (size, location, type) the stakeholder involvement passed the way from no stakeholder involvement before PEARL to an established and active LAA that will exist beyond the project lifetime. Partly it can be linked to the fact that despite Rethymno area is not considered as an area of potential significant flood risk (based on the preliminary assessment results), the authorities having proved that Rethymno's facing flood problems, they will be eligible to apply and raise national and EU funds for the implementation and construction of new measures that the city needs. Also, the participants

assessed the LAA as an asset to the flood risk management, but the question of the formal/informal leaders has been raised and left open.

The rather specific situation in the Elbe Estuary case in comparison to the other case studies in PEARL mainly due to the high level of involvement and awareness of the key stakeholders in flood risk management, could be used as a chance to enahnce the existing LAAs concepts that are mainly developed to initiate the collaboraiton process. That was mainly done by tailoring the activities to the actual needs and interests of the key stakeholders. The collaborations and involvent activites that have been purshued within PEARL, will be maintained and further enhanced beyond PEARL.

Intensive stakeholder involvement can make a high impact on the policy in the Italian study area (specifically in the City of Genoa) where it is likely that the PEARL results will be assessed and used in the framework of panels that are going to be organized within the Climate Adaptation Partnership of the Urban Agenda, coordinated by the Municipality of Genova.

Based on the experiences made in the case study area in Thailand, policy makers should consider the perspectives of scientific communities and general public related to the area, before making decisions about which strategy is the best for a neighbourhood. The variety of perceptions will enrich the final decision, establishing more suitable solutions for people living, working or visiting the area.

12.7 Measures and strategies for strengthening flood resilience in coastal regions

Different tools and methods have been deployed in the case study areas, based on the availability of resources and actual research needs in the case study area. The valuable achievement is the active involvement of the key stakeholders in the development of measures protfolio or in the preparatory phase for flood risk management planning. In the Spanish case it was only partly possible, due to the political instability and changes in the priorities in the local agendas. In this case, the PEARL partners suggested and developed a

The French case study focused on the FRI method due to the interest of the key stakeholders in the area and the available expertise in the local PEARL team. During the PEARL lifetime, a more in-depth discussion on the specific measures could not be achieved, due to the high political sensitivity of the flood issue in the area, therefore, the high level FRI assessment and the consequent discussion with the stakeholders can be considered as a step forward in the rethinking of the current flood risk management towards more holistic approaches.

The FRI method has also been used as a basis for further development of the strategies in the Italian case study area, receiving the high acceptance by the local government, even beyond the PEARL study area. The applicaiton of the FRI method is liekly to be extended within the framework of the H2020 project Anywhere, with the support of Fondazione CIMA and the Municipality of Genoa.

The advantage of the FRI method is that the stakeholders are involved during the whole planning process. At the same time, it can be a drawback as the outcome of teh FRI is based on the individual perceptions and as such not always representative (as per findings from the Greek, German and Italian case study areas). More objective results can be achieved when a gorupf of stakeholders and experts from different disiplines deliver their FRI assessments.

A high level of the integration of the key stakeholders into the flood risk management planning has been achieved in the Greek case study area, where the measures have been suggested and discussed during the LAAs. This has been even enhanced by the demonstration and conduction of

the training activities for the PEARL tools with the stakeholders. All tools received highly acceptance by stakeholders and delivered the necessary information (links, instructions, etc.) to start using them.

All tools which have been developed under WP5 being FRI, Knowledge Base, WebLP are generic and applicable to any case study around the world despite local conditions. As a matter of fact, in order to cover all those needs the WP5 tools' functionalities have been developed in such way so that the tools themselves can be tailored to meet every stakeholder and case study needs.

A step towards to the assessment of the multiple and co- benefits has been achieved in the case study area in Thailand. It also shows the importance of considering both green and grey approaches, and how the combination of them can lead to an efficient strategy, which reduces flood risk but also is applicable in the case of space restrictions for instance. Also, the first results in the German case indicate the need for hybrid solutions (grey and green) calling for development comprehensive evaluation frameworks and approaches that go beyond PEARL.

13 Conclusions and recommendations for further work

Tools and methods developed within the PEARL project are applied to a number of case study areas all over the world. European case study areas cover a wide range of geograpahical/topographical, risk and hazard as well as socio-economic conditions and each of the case studies experienced different hydro-meteorological extreme events in the past. Through the involvement of the international case studies the project benefits from the international experience on extreme events. They extend the range of extreme events by e.g. cyclone, hurricanes and tsunamis.

The research activities in the respective case study areas revealed that holistic risk assessment can be the initial step in order to define comprehensive flood risk management and mitigation strategies. Holistic risk assessment helps to gain an insight in the formation of risks and hazards and the impacts of extreme events.

Methods such as RRCA or agent based institutional models have been assessed as ‘eye openers’ by a number of stakeholders either during the personal meetings or within the LAAs but at the same time they require considerable effort and involvement of a number of parties and as such are currently applicable only for selected cases.

The LAA method for stakeholder engagement is considered applicable and transferable, but with necessary adaptations to local societies. Different local socio-economic conditions, levels of governance and multi-stakeholder approaches define the actual format of the method and the potential results in each case study area.

During the project lifetime it became clear that the small communities need more effort to reach the local and national knowledge and financial sources in comparison to large cities, which also adds to their vulnerability. More comprehensive analysis and studies are needed to assess the requirements and the baselines in those communities and tailor the strategies, methods and tools to their needs and capabilities.

The concept of holistic flood risk governance is rather novel and the implementation of the holistic framework to its full extent requires resources and effort that are beyond PEARL. Although PEARL has improved the baselines in the study areas, continuous improvement and update of the existing models and setups and the stakeholder involvement is required to gradually implement the holistic aspects in the existing flood risk management practices.

In a number of case study areas, the issue of the co-benefits has been raised mainly when considering the application of grey, green or combined flood protection infrastructures and measures. This calls for more comprehensive approaches considering hydrological, economic, ecologic or social aspects when defining the flood risk manageemnt strategies ad should be researched within further researhc projects.

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Annex 2

Text (Arial 11)