# MANAGING FLOOD RISK IN COASTAL CITIES THROUGH AN INTEGRATED MODELLING FRAMEWORK SUPPORTING STAKEHOLDERS' INVOLVEMENT: THE CASE OF RETHYMNO, CRETE

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# MANAGING FLOOD RISK IN COASTAL CITIES THROUGH AN INTEGRATED MODELLING FRAMEWORK SUPPORTING STAKEHOLDERS' INVOLVEMENT: THE CASE OF RETHYMNO, CRETE

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## ABSTRACT

Coastal communities are increasingly at risk from coastal hazards such as floods. Extreme hydro-meteorological events related to sea level rise, storm surges, heavy precipitation, shoreline erosion are driven by climate variability and increase the exposure of people, livelihoods, environmental services, resources and infrastructure to hazard. Flood risk management, which aims to reduce the likelihood and/or the impacts of floods, is considered inevitable. Rethymno city in Crete is one of the case study areas that PEARL project, an EU funded research project – to be completed by 2017, will develop and apply a holistic risk reduction framework that will include multi-stressor risk assessment and risk cascading while strengthening risk governance by supporting the participation of key actors. The development of a multi-scale integrated modelling framework will enable the simulation of extreme event scenarios and multiple stressors covering the whole domain from the Mediterranean Sea all the way up to hydrological boundaries of Rethymo's river basins. The integrated modelling framework, briefly outlined in this paper, will include the estimation of atmospheric variables and the use of climate change scenarios, the estimation of wave characteristic based on a four level downscaling approach, the modelling of near shore response to hurricane impacts and storms e.g. storm surges, wave propagation, sediment transport, erosion, wave diffraction and refraction, as well as catchment hydrological and urban flood modelling. The socio-economic dimension of Rethymno's urban system as a risk evolution factor will be also investigated through the application of Agent Based Models and Cellular Automata techniques. The developed scenarios will take into account local conditions and flood problems as well as stakeholders' perspective, needs and ambitions. Stakeholders' involvement and their engagement with the integrated modelling framework and its outcomes will assist the development of an actionable roadmap for flood risk management for Rethymno.

*Keywords*: Extreme hydro-meteorological events, flood risk, active stakeholder participation, Rethymno

## 1. INTRODUCTION – RESEARCH AND WORK WITHIN PEARL

Coastal communities are increasingly at risk from several factors contributing to coastal floods. Extreme hydro-meteorological events are highly affected by climate variability which in combination with rapid urbanisation and poor governance acts as additional stress on coastal urban areas. Physical processes and phenomena such as sea level rise, storm surges, heavy precipitation, shoreline erosion stand for the occurrence of coastal flooding but additionally human activity adversely affect the evolution of flood risk. Understanding only the formation of physical hazards will not lead to efficient flood defence. Understanding the vulnerability of coastal regions is a core element by taking also into account governance and socio economic, cultural, historical and political diversity which have a strong influence on the actions taken to reduce risks, hazards, and subsequent disasters. Although technical measures do form and will form a major part of the solution now and in the future, the shift from flood defence to flood risk management seems inevitable and concepts like participation, dialogue, coordination, political will, transparency and volunteerism begin to have overriding importance in flood risk reduction.

PEARL (Preparing for Extreme And Rare events in coastaL regions) is a project aiming to develop adaptive risk management strategies for coastal communities against extreme hydro-meteorological events, minimising social, economic and environmental impacts and increasing the resilience of Coastal Regions in Europe. Having as objectives to develop a holistic risk governance framework, to increase the understanding of dominant root causes of vulnerabilities and risks in coastal regions, to improve the comprehension of the co-evolution of disasters due to extreme hydro-meteorological events, to develop new monitoring, modelling, forecasting and warning technologies tailored on the social, technical, institutional, organisational and economic realities of coastal communities, to provide the means to strengthen risk governance and empower all stakeholders and to build a pan-European knowledge to support capacity development for the delivery of cost-effective risk-reduction plans, PEARL project received funding from the European

Union's Seventh Framework Programme for Research, Technological Development and Demonstration, through which 7 case studies from across EU will be examined. The identified case study areas will offer significant potential and opportunities for improving European risk management (Boteler B. et al. 2014).

The expected outcomes of research within PEARL foresee at developing a framework which analysis the underlying factors of risk and vulnerability in coastal regions, in combination with a holistic and multiple risk assessment framework which incorporates social aspects and recognises interactions and interrelatedness between processes. Innovative flood modelling techniques along with early warning systems and technologies will enhance the preparedness of coastal communities towards imminent flood threat and will develop resilient strategies for coastal regions to be implemented by coastal communities. Stakeholders' involvement and science-policy interface and outreach add substantially to the implementation of disaster risk reduction strategies which are greater and more effectively adopted.

## 2. RETHYMNO CASE STUDY – PROBLEM DESCRIPTION

Rethymno city in Crete (Figure 1) is one of the seven coastal EU cases studies that will be examined within the PEARL project so that an integrated modelling framework will be applied which will enable active stakeholder involvement and will assist flood risk management in a coastal community. Rethymno city is sited at the Region of Crete in Greece and its population stands at 32,468 inhabitants (Census 2011) with a density 140.12 population/km$^2$. As the 3$^{rd}$ 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.


Figure 1: Rethymno city, Crete, Greece

Multiple stressors have always posed flood threats for the city of Rethymno causing an ongoing risk to its residents, homes, business and public infrastructure. The flow of storm water through the city, the large number of streams that cross it and the rapid transition from the steep slopes at the upstream rural areas to the flat urban zone imposed significant pressure to flood defences throughout the years. Major historical floods mainly related to heavy precipitation, exceedance of river's and drainage systems' capacity or inability of flow routing due to lack of maintenance, recorded on February 29$^{th}$ 1968, February 6$^{th}$ 1984, October 28$^{th}$ 1991(Figure 2) and November 10$^{th}$ 1999 (Archontakis D. 2006; Archontakis D. 2013), but others of less importance and destructiveness are encountered every year (Figure 3). The flood events 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 (Ganoulis I. et al. 2000).

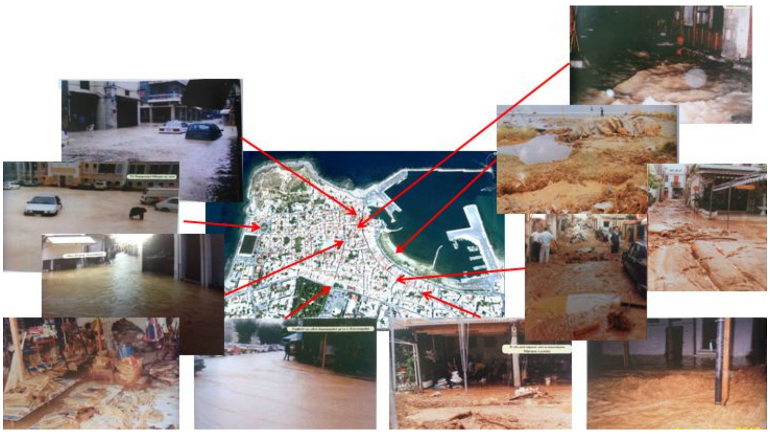

Figure 2: Historic flood in Rethymno, October 28th 1991 (Archontakis D. 2013)

However, pluvial, fluvial and flash floods are only part of the problem. Rethymno is exposed to strong North and North-West winds with great fetches resulting in extreme violent overtopping of the port facilities due to the development of great waves which eventually cause severe damages. The successive severe damages of the windward wave breakwater (Figure 4) and the increased significant repair cost concerns the Port Authority persons in charge who search for a more permanent solution. In addition, huge quantities of seawater penetrate from the west (Parking area), which overflow the harbour's surface area as well as the wider coastal area causing interruption in loading and unloading operations, damage to the port facilities and the cargo, traffic problems and damage to coastal shops and restaurants (Figure 5).

Adverse effect of the wave energy is also the erosion of the recreational beaches which highly affects tourism's contribution to the local economy rousing the interest of the local authorities for finding efficient solutions.

Even though mostly engineering measures have been implemented, so far, as flood defence for Rethymno, multiple forces from the urban and coastal area still result in flood problems as recently experienced and recorded in the local press/channels/social media (Figures 3-5). There is hence a growing realisation that focusing exclusively on engineering mitigation measures and treating problems in an ad hoc, isolated fashion is no longer a viable option. There is therefore a need to manage flood risk through more integrated solutions coupled with strong stakeholder involvement.


Figure 3: Roads inundated on October 25th, 2014


Figure 4: Damages of the base of windward wave breakwater (a) previous damages, photograph taken on January 4th, 2014, (b) new damages after structural repairs, photograph taken on January 14th, 2015


Figure 5: Penetration of seawater through overtopping to the wider area of port facilities and debris from the windward wave breakwater damages

## 3. METHODOLOGY

Risk assessment and evaluation of risk under multiple-hazard scenarios is one of the primary objectives for Rethymno case study. The development of an integrated modelling framework will enable the simulation of extreme hydro-meteorological events individually or in coincidence and will assist in understanding the formation of hazards. A desk based literature review and case study visits in combination with contacts made with local authorities highlighted the need for the estimation of hazard due to combined roots and causes that will be achieved through a model chain set for atmospheric, storm surge, flood plains, waves, riverine and pipe networks.

A number of resilient measures and strategies will be further on collected and evaluated that will be most suitable based on the case study characteristics and will include engineering, environmental and operational strategies and solutions for adaptation and mitigation. The impact of measures' implementation on the evolution of risk will be examined and evaluated through the use of multi-criteria optimisation algorithms. The Flood Resilient Index framework (FRI) derived from Corfu project (Batica J. and Gourbesville P. 2012) that will be enhanced and coupled with the vulnerability analysis framework within PEARL will distinguish the metrics and criteria which will assess the performance of measures in managing multiple hazards derived from the extreme hydro-meteorological events.

The alternative risk futures are highly influenced and shaped by the future land use change and urbanization scenarios. Application of fuzzy constrained cellular automata (Rozos E. et al. 2011) will serve as spatial urban growth model and will pinpoint the geographical location and spatial patterns of the predicted urban growth and will take into account the impact of spatial planning based on the perception of the local urban planners. The different socio-economic and planning control factors and the simulated spatio-temporal processes of urban growth will result in the generation and comparison of different future urban growth scenarios for urban planners and land managers to consider for a substantial urban future.

But incorporating the socio economic dimension in such holistic framework is of primary importance too and can be achieved through the development and use of Agent Based Models (ABMs). The latter will give answers on how a system's behaviour arises from and is linked to the characteristics and behaviours of its individual components, especially when the system is under risk. Stakeholder analysis and the methodology applied for stakeholders' involvement will identify key actors in flood risk management who will later form the agents of the ABMs.

Eventually, decision making and flood risk management is the ultimate goal. In order to be achieved, an interface between the developed tools and the ultimate users i.e. the stakeholders of Rethymno will be provided. An interactive platform will serve as that interface and will also enable visualisation of the effect of the alternative choices on Rethymno risk situations. In addition, it will assist in the exploration of different scenarios at any point of the chain e.g. in the formation of risk and its corresponding flood inundation outcomes, in the selected resilient measures and methodologies for flood defence or in the socio-economic, spatial-temporal urban growth scenarios and find out the consequences of their decision. By performing alternative multi-hazard scenarios with wide ranging parameters settings, a library of possible future will be created that will assist future analysis and decision making processes of the local authorities. Taking into consideration their needs, ambitions and perspectives within the whole framework and scenario development is of primary importance as this will eventually result in the development of a specific and actionable roadmap targeted to case study's conditions with a commonly agreed vision with local stakeholders. The Learning and Action Alliances framework will assist stakeholder analysis and will enable identification and engagement of key decision-makers and stakeholders in flood risk management.

Intriguing the interest of the citizens of Rethymno and keeping them familiar with PEARL projects' outcomes is one more objective that is foreseen to be accomplished. By circulating and giving at citizens' disposal a mobile application that will enable data collection, will actively engage them and will raise people's awareness against the flood risk. Volunteerism is also the most profound example of active stakeholders' involvement and which will be highlighted within PEARL project.

### 3.1 Estimation of atmospheric variables and development of climate change scenarios

Over the northeast Atlantic and Europe, the regional atmospheric model REMO, which is based on the Europamodel/Deutschland model system (Majewski D. and Schrodin R. 1994), was used in order to get a high resolution atmospheric forcing. Climatic analysis of the Mediterranean and the Greek sea area and eventually estimation of atmospheric variables was achieved by utilising the RegCM regional model (RegCNET: regional climate network 2003). Its spatial analysis is 25x25 km and for the future projections of atmospheric (10m wind, atmospheric pressure, air temperature) data the model is using the AR4-A1B emission scenario. Hindcast results for 1960-2100 are based on input from measured carbon dioxide emissions, while forecast results where produced on the basis of the IPCC SRES AR4-A1B scenario. Enhanced simulated data in the Greek Sea region have also been derived from the new version of RegCM3_10 regional model, with 10x10km spatial resolution (Velikou K. et al. 2014). RegCM3_25 model uses 18 vertical levels on a horizontal 192x108 grid of 25km resolution and a timestep of 60 sec. RegCM3_10 model, which is nested inside the RegCM3_25 model, uses 18 vertical levels on a horizontal 128x160 grid of 10km resolution and a timestep of 30 sec.

### 3.2 Estimation of wave characteristic

Estimation of Wave Characteristics is made using a 4-level downscaling approach by assessing climate change effects on the marine climate of the Aegean developed in the framework of Thales project CCSEWAVS: "Estimating the effects of climate change on sea level and wave climate of the Greek seas, coastal vulnerability and safety of coastal and marine structures" (Athanassoulis G. et al. 2014). Within PEARL, the SWAN model was used to analyse wave conditions on different temporal and spatial scales from the long-term overall wave conditions at the ocean model scale to the local extreme event wave conditions at the scale of the flood protection constructions. Temporal and regional distribution of the wind with a time resolution of one hour will be used for the simulation of the wave spectrum with SWAN. Numerical simulations with the latter have been carried out in order to collect the wave characteristics (significant height, peak period, direction). The simulations carried out in 3 levels (Figure 6), starting from the Mediterranean Sea, focusing on the surrounding seas of Aegean in the second level and finally calculating the wave data in Rethymno area in the third level. Climatic simulation and predictions were produced for the periods 1961-2000 and 2000-2100. Finally, local coastal area wave conditions were simulated at the area of Rethymno's Port at Level IV.

By providing SWAN, a third generation wave model that computes random, short-crested, wind generated waves in open sea, coastal regions and inland waters, with bathymetry in the area of Rethymno and the wave climate input from previous levels (I and II), time series of significant wave height, wave period and mean wave direction every 3 hrs (1960-2100) were extracted and eventually resulted in the selection of storm events and critical scenarios. The maximum wave height per year for the two periods (1960-2000, 2000-2100) was provided through wave data analysis, as well as the relation between significant wave height and peak period for the two periods and 3 directions North, North West, North East. It was noticed that the highest waves tended to have greater period. The categorization of storm events achieved by following the procedure proposed by Dolan R. and Davis R. E. (1992) which estimates the energy of the storm event and classifying it in 5 classes (weak, moderate, significant, severe, extreme). This technique was also applied by others researchers in regions close to Rethymno e.g. Chania, on the Crete Island (Kokkinos D. et al. 2014). The analysis is done at this stage for the North wind direction since is the dominant one that generates incident waves to the Rethymno coast.

Finally, local coastal area wave conditions were simulated at the area of Rethymno's Port at Level IV by using MIKE 21. MIKE21 PMS module was feed with the offshore wave characteristics and the bathymetry in order to simulate the spatial wave evolution in the whole coastal area taking into account phenomena such as wave diffraction and refraction (Figure 7). The same bathymetry as before was constructed in a similar rectangle grid with appropriate spatial steps. MIKE21 FM will then be constructed to simulate the two-dimensional flow with free surface and to describe the hydraulic and environmental processes that occur in the coastal area. The numerical model is based in finite differences describing the two-dimensional unsteady flow simulating the free surface elevation and flow in both directions at each point of the grid. By taking advantage of MIKE21 Sediment Transport module (MIKE21 ST), estimation of sediment transport and movement can be accomplished for each storm event, whereas LITPACK module could be implemented to further calculate the long term sediment transport. The evolution rate of bed morphology in short and long terms of time will assist in depth comprehension of coastal dynamics and will result in proposing solution on erosion phenomena too. Second step to be accomplished is the estimation of wave run up in the beach of Rethymno area. Empirical formulas (e.g the one derived by Stockdon H.F. et al. (2006) and equations provided by the Coastal Engineering Manual, 2008) and numerical model (MIKE 21 BW) such as Boussinesq wave model could be used to calculate the wave run up as well as wave overtopping in any bathymetry profile and chosen sections by taking advantage of the simulated wave propagation into shallower water regions. At this stage the wave run-up is calculated in two bathymetric profiles, east and west of the port (Figure 8a) with a mean bottom slope equals to 3%, while the overtopping is calculated in the upwind breakwater of the port (Figure 8b). Calculation of mean overtopping discharge rate is of great importance, as stated in the problem description section, to further estimate the inland flood from the storm events. By using Eurotop manual (Pullen T. et al. 2007) with empirical relationships and artificial neural networks, estimation of wave overtopping will be performed especially in the port facilities areas. Specifically, inserting the wave ($H_{m0}$, height at the toe of the structure; T, period) and geometrical characteristics ($R_c$, the height of the crest of the wall above still water; $G_c$, width of the structure crest; γ, coefficient for reduction factors depending on the permeability) into the EurOtop tools (Figure 8c), such as the parametric equations and the artificial neural networks, one can calculate the overtopping. The section A-A' of the breakwater (Figure 8b) is similar to the one of Figure 8c and thus one can calculate the mean discharge rate Q (l/s/m) as shown in Table 1.

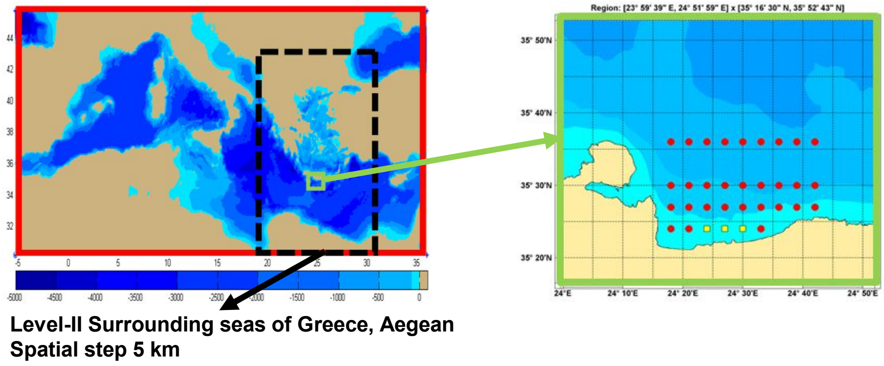


Figure 6: Estimation of wave characteristics using a 4-level downscaling approach

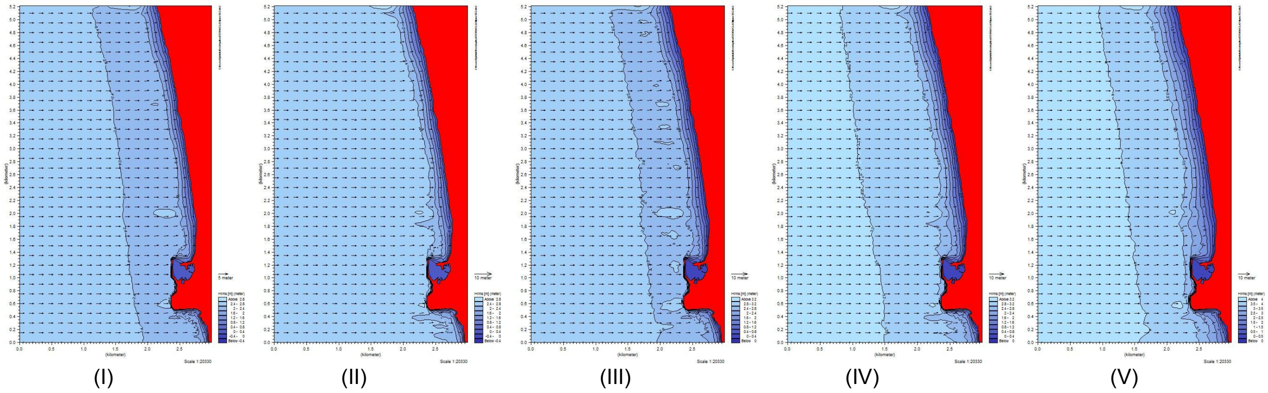


Figure 7: Spatial evolution of wave height of hydrodynamic field for the 5 storm classes (I-Weak, II-Moderate, III-Significant, IV-Severe, and V-Extreme)

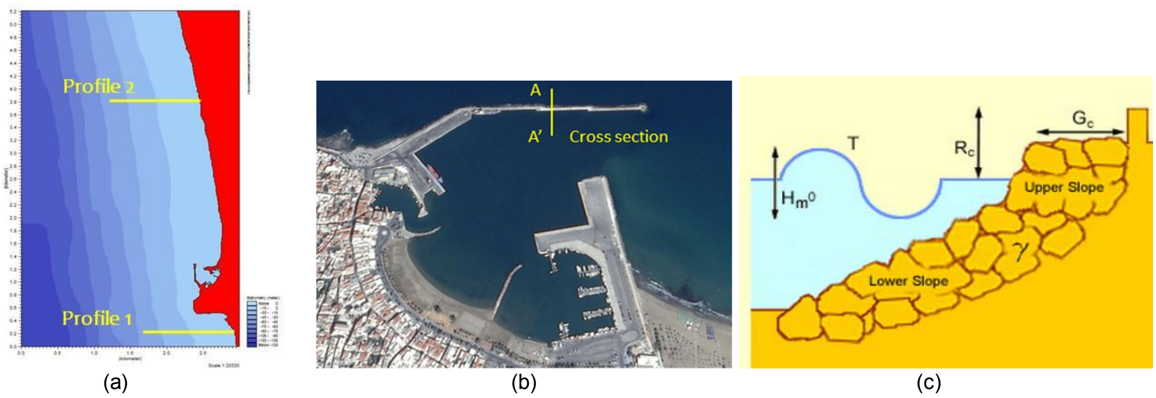


Figure 8: Currently selected bathymetric profiles for estimation of wave run-up (a), selected cross section of the breakwater for estimation of wave overtopping, (c) Input parameters of EurOtop for calculation of wave overtopping

Table 1: Mean overtopping discharge rate Q (Section A-A')

| | Input data | | | | | Output data |
|---|---|---|---|---|---|---|
| **Storm class** | **$H_{m0}$ (m)** | **$T_p$ (s)** | **$R_c$ (m)** | **$G_c$ (m)** | **γ** | **Q (l/s/m)** |
| **I** | 2.50 | 7.68 | 6.1 | 4 | 0.55 | 0.008 |
| **II** | 2.79 | 7.99 | 6.1 | 4 | 0.55 | 0.032 |
| **III** | 3.00 | 8.19 | 6.1 | 4 | 0.55 | 0.075 |
| **IV** | 3.24 | 8.24 | 6.1 | 4 | 0.55 | 0.147 |
| **V** | 4.17 | 9.08 | 6.1 | 4 | 0.55 | 2.075 |

### 3.3 Flood modelling

Production of flood inundation maps under extreme events individually or in coincidence is the starting point for the assessment of risk. Use and application of existing models will enable hazard assessment for Rethymno case study by simulating integrated flooding from the sea, rivers, urban, drainage and sewer systems and will finally result in flood inundation maps. Within PEARL, two different holistic modelling approaches will be implemented. On the one hand, free available software and tools will be used i.e. products of the Hydrologic Engineering Center and the US Army Corps of Engineers along with the Storm Water Management Model (SWMM) of the United States Environmental Protection Agency. Additionally, a wave toolbox constructed in ArcGIS will be used so that the simplified coastal pressures will be incorporated into the flood modelling (Rohweder J. 2012a). One the other hand MIKE FLOOD, the most complete commercial toolbox for flood modelling will be applied by enabling 1D and 2D hydrodynamic simulations. The final outcomes of the two methodologies will be compared.

In more detail, the Hydrologic Modelling System (HEC-HMS) was first used to simulate the complete hydrologic processes of the watershed systems of Rethymno case study, the output of which will be used as input in urban flood modelling (Papathanasiou C. et al. 2013). The open source hydrological model was used to simulate the precipitation-runoff processes of the river basins of Rethymno through the computation of hydrological parameters such as hydrological loss, direct runoff, base flow and channel flow routing. HEC-RAS (Hydrologic Engineering Centers River Analysis System) was later on used to perform one-dimensional hydraulic calculations of the main river bed of natural channels, which also has the capability to perform inundation mapping of water surface profile results directly through the use of RAS Mapper.

Essential geospatial information of the case study area is available, such as Digital Elevation Model (DEM) and Digital Surface Model (DSM) with 2 m and 0.80 m grid resolution respectively, land use, topographic and geological characteristics, hydrographic and hydro-meteorological monitoring network. Through the use of the geospatial tools HEC-GeoHMS and HEC-GeoRAS and ArcGIS functionalities in general, available geospatial data have already been pre-processed, modification of DEM in specific locations has been made and the delineation of river basins and networks has already being fulfilled (Figure 9). The case study is constituted by 13 river basins of a total area of 145 $km^2$ whereas the total length of the river network arises at approximately 390 km. Hydrologic and 1D hydraulic simulations have been performed through HEC models for events with 12 hr duration, 15 min time interval and for return periods 10, 50, 100 and 1000 years and initial results have been produced. The method of SCS Curve Number was used for the estimation of the hydrological loss, the SCS Unit Hydrograph method for the direct runoff and the Lag routing method for the channel flow routing. Due to absence of data, the base flow was ignored in combination with its little influence during a precipitation event. Initial peak flow results for every stream are summarized in Table 2 and the inundated areas are depicted in Figure 10.

The SWMM model will be the next in line and will enable flood simulation in the urbanized area of Rethymno case study and especially the flow in the drainage system. The latter conceptualise a drainage system as a series of water and material flows between several major environmental compartments, those are the Atmosphere, the Land Surface, the Groundwater and the Transport Compartment. The generation of the 1-dimentional (1D) model of the overland network (or urban surface) will be accomplished through the use of a GIS tool, the Automatic Overland Flow Delineation (AOFD) (Leitão J.P. 2009) which was developed by the Urban Water Research Group of the Imperial College London (Maksimovic C. et al. 2009). Since AOFD tool is more suitable for representing the overland network on urban cells of the catchment e.g. roads, Inp.Pins will be applied for better representation of river's cross sections (Aivazoglou M. 2014). The aforementioned tool enables the integration of SWMM with GIS by generating SWMM input files (shape and DEM grid files) and also by combining SWMM results file with a DEM grid for flood plain delineation (Pina R.D. et al. 2011).

The waves' toolbox for ArcGIS and its scripts were originally developed by Finlayson D. (2006) and later on updated by Jason Rohweder. Those models have been based upon coastal engineering equations and have been developed to quantify wind fetch length and several physical wave characteristics including significant height, length, peak period, maximum orbital velocity, and shear stress (Rohweder J. 2012b). The method used is defined in the Shore Protection Manual (Coastal Engineering Research Center of US Army Corps of Enginners 1984)

The generated results from the hydrological modelling of Rethymno's river basins will be used as upstream boundaries conditions, whereas at the outfalls i.e. the terminal nodes of the drainage system, final downstream boundaries conditions will be defined based on the fluctuation of sea surface elevation and the estimated wave characteristics.

In contrast with the above models, MIKE FLOOD by (DHI) includes a wide selection of 1D and 2D flood simulation engines, which will enable the integrated modelling of flood problem involving all flood components e.g. rivers, floodplains, floods in streets, drainage networks, coastal areas etc. of Rethymno case study.

The dual drainage approach in the urban area will be implemented i.e. an approach to rainfall-runoff simulation in which the numerical model takes into account not only the flow through the sewer system, but also the flow on the surface (Djordjević S. et al. 1999). The level of analysis is heavily dependent on the available sewer network information. The connection of the major system (open channels and ponds) with the minor system (sewer system) will be accomplished through 1D/1D modelling approach, which enables faster simulations for real time purposes but sometimes less detailed and accurate compared to 1D/2D approaches (Simões N. et al. 2011). The latter approach will be implemented through the use of MIKE's modelling suite.

Table 2: The peak flow discharge (in $m^3$/sec) at the outlet of each basin

| T | FOURNOS | GALLIANOS | DOGA | KRIARI | KAMARAKI | SINATSAKI | STREAM 4 | KORAKA | STREAM 1 | STREAM 2 | KOUTSOLIDI | STREAM 3 | PLATANIAS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **10** | 6.39 | 19.37 | 4.00 | 2.19 | 7.11 | 12.36 | 3.46 | 35.44 | 1.53 | 1.43 | 16.12 | 2.50 | 136.92 |
| **50** | 12.10 | 38.36 | 7.77 | 5.21 | 14.31 | 23.35 | 5.93 | 49.46 | 2.91 | 2.73 | 30.54 | 4.77 | 252.23 |
| **100** | 15.07 | 48.42 | 9.75 | 6.95 | 18.13 | 29.09 | 7.17 | 56.28 | 3.63 | 3.42 | 38.07 | 5.95 | 309.95 |
| **1000** | 27.29 | 90.44 | 17.94 | 14.57 | 34.13 | 52.74 | 12.11 | 83.02 | 6.60 | 6.22 | 69.17 | 10.85 | 531.64 |

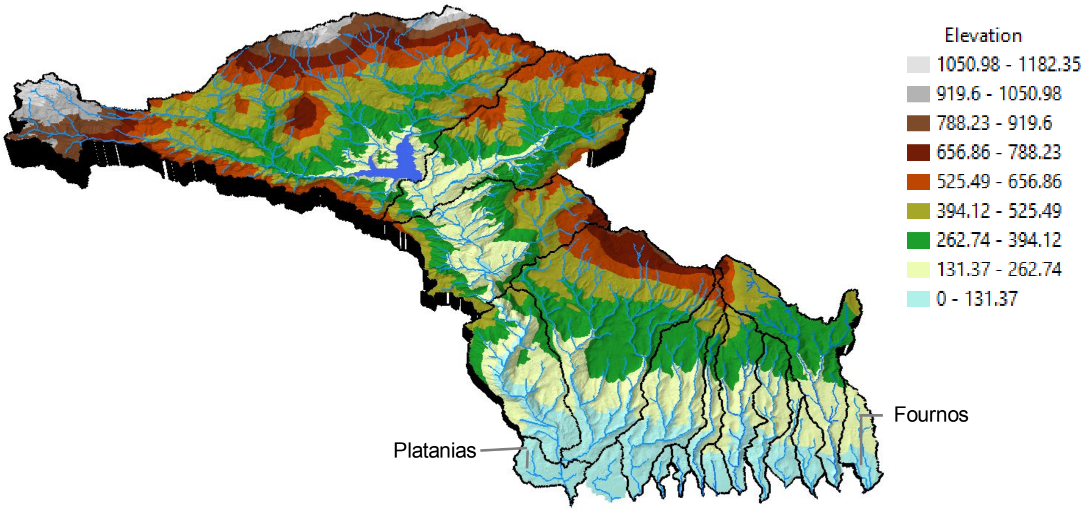


Figure 9: River basins and river network of Rethymno case study

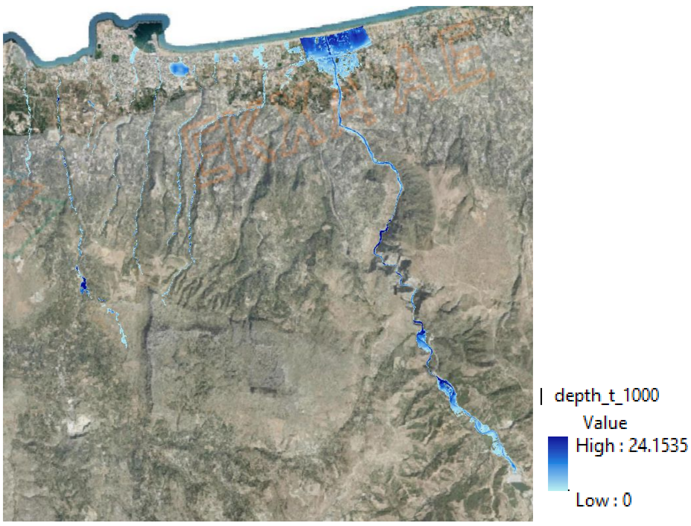


Figure 10: Initial results of inundated areas from 1D hydraulic simulation with return period 1000

## 3.4 Urban growth modelling using Cellular Automata techniques

Initial future urban growth scenarios (Figure 11) have already been produced for the case study area of Rethymno. A Cellular Automata (CA) model equipped with fuzzy interface, which was re-engineered by (Bouziotas D. et al. (2014)), was used so that the dynamics of the urban growth of the case study to be examined. The multi-state urban growth logic behind the urban growth model enables the generation of future urban growth scenarios by incorporating suitability factors through the use of a fuzzy set and land cover data. Proximity to the sea and accessibility to road network are two of the main factors which affect urban growth patterns and define the desirability of the future spatial urban growth. The over suitability factors that are formed in combination with velocity factors that were implemented in transition rules are parameters which define and control the dynamics of the system. The latter, especially, defines the speed at which each rule in applied. The above parameters vary spatially and temporarily and need to be calibrated but also incorporate the human and socio-economic aspects.

The final derived results of the model used were generated raster images of urban growth patterns with cell dimension equal to the resolution of maps used e.g. 100x100 $m^2$ for Corine 1990. As input for calibration and validation of the model's parameters Corine 2000 data were used and in a latter step the General Planning of Rethymno 2013 will be utilised. Spatial performance that has already been achieved is satisfactory and is approximately 75%. Thorough calibration/evaluation will be undertaken with detailed census data and its spatial distribution that will be collected from the National Statistical Service of Greece e.g. residents per block.

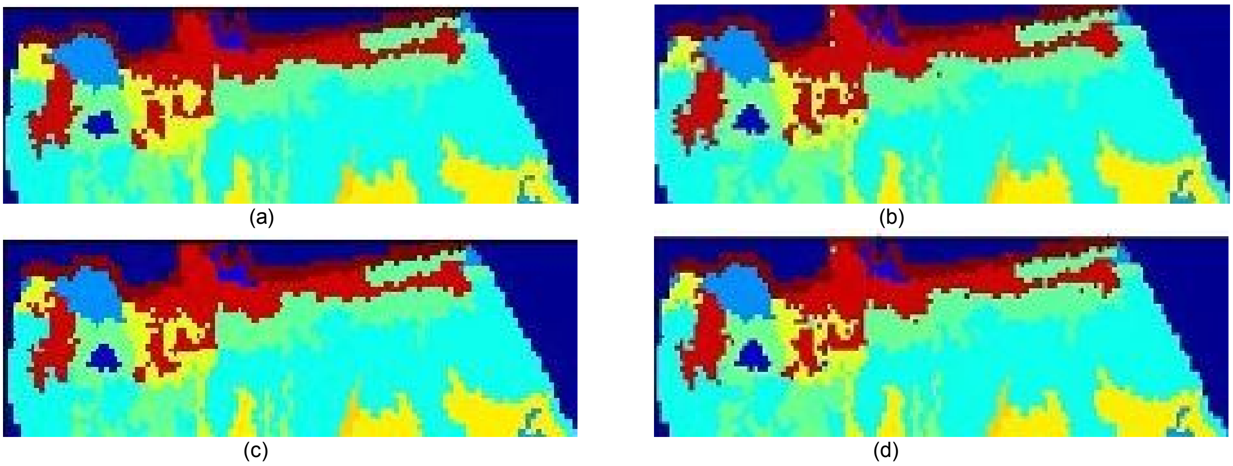


Figure 11: Initial urban growth results (a) Corine 1990, (b) projection in 2000, (c) calibration using Corine 2000, (d) projection for 2010

The ABM models will enable the understanding of the complex adaptive system of Rethymno city, will serve visualisation purposes and will support risk assessment. The developed models will be used for the simulation of long term processes e.g. decision making processes and plans made by local authorities, whereas a short-term model will enable the simulation of evacuation processes and social behaviour comprehension during a flood event. Therefore, possible agents could be "Formal stakeholders" e.g. the Civil Protection Agency whose decisions affect the evolution of risk and "Informal stakeholders" e.g. simple citizens who passively accept the outcome of the formal's stakeholders decisions.

### 3.5 Stakeholders' involvement through the LAAs Framework and the developed tools

Significant increase of flood risks of Rethymno city and relative threats need to be addressed not just in terms of flood prediction and control, but taking into account governance and socio-economic issues. Decision making processes in urban planning are multi objective, and complex and increased stakeholders' involvement is required in order to achieve effective flood risk governance, flexibility in crucial decision making and preparedness of local societies to manage extreme events (Ashley R. M. et al. 2012). Learning and Action Alliances (LAAs) are discussed in the literature as supporting building capacity, trust, and legitimacy (Dudley E. et al. 2013) that are needed to solve wicked problems as flood risk management needs.

Rethymno's LAAs, will be used as a tool for supporting and enhancing the participatory process in flood risk governance. The initiative aspires to establish an alternative approach in flood management based on involvement of all different parties and local community. The LAAs will aim to generate and apply knowledge towards capacity building for flood resilience of coastal communities, by enabling the engagement of all key stakeholders including the civil society (Municipal and Regional authorities, NGOs, Ministry of Environment, professional unions, etc.). Main objective of the Rethymno's LAAs is to establish a participatory process among all involved or influenced parties related to flood management. The decision making process in urban planning is multi objective and complex and therefore needs "[…] decision makers who are capable to accommodate uncertain futures" (Van Herk S. et al. 2011). At the same time there is not such a case of a single stakeholder that has the absolute control over an urban or spatial development plan (Sellers J.M. 2002; Van Herk S. et al. 2011). Interactive decision making with increased and wide stakeholders involvement is required in order to achieve consensual decisions (Ashley R.M. and Blanksby J.R. 2009; Van Herk S. et al. 2011).

In order to accomplish this goal, the LAAs will be organized on a democratic basis of equity, knowledge sharing and promotion of innovation, while the participants will be both key decision makers and citizens, all involved on a voluntary basis. Participatory procedure methods will support the evolvement of the LAAs along three axis: establish facts, create common images and set shared ambitions (Van Herk S. et al. 2011). According to this approach, the organizing of the LAAs is built around three groups of interactive activities: i) System analysis; ii) Collaborative design and iii) Governance (Figure 12). By establishing facts, coherent knowledge will be generated that will reduce uncertainty and will be established from the parties involved. Creating images supports frame reflection in which parties identify their view of reality and discuss it, look for images or meanings that they share, and create renewed and more creative images as a result of the interaction. Shared ambitions support the negotiations on aspirations of the parties towards implementation. The effective functioning of the LAAs requires the understanding of complex decision making processes related to urban development and planning. Van Herk S. et al. (2011) propose Kingdon's stream model (1984), who defines decision making as the interconnection of three concurrent streams of problems, policies/solutions and politics or participants. Following this approach the LAAs is to be organized in order to: i) Analyse and address problems; ii) Develop and propose solutions and iii) Influence politics by seeking political commitment or bringing participants together.

Rethymno's LAAs will act as a bridge among science, politics and key stakeholders to gain insights into local decision making processes, to communicate the constraints, needs and goals of single stakeholder and to reach finally a surrounding that guarantees decisions that are built on a broad discussion on flood management and relative risks in coastal zones. The main tool for the stakeholder involvement in the LAAs will be interactive participatory workshops that will aim at spotting the people and institutions that are affected by the hazards, that are responsible for early warning, evacuation, disaster management, etc. and that are in charge of (future) planning processes. The workshops will be structured in a way to enhance the interaction among stakeholders. Several techniques will be used, from round tables and open discussions to interactive social games and role playing in order to gain engagement and commitment of stakeholders in LAAs and to achieve the final aim which is the creation of a common vision (WAREMA INTERREG IIIB Methodological procedures 2007). In order to reach these goals there is the need of setting up a frank atmosphere where representatives from different organizations will be able to overcome their personal, structural and institutional barriers in order to interact, gain knowledge, share experience and finally create a common vision under a feeling of mutual trust. Workshops need to be attractive and not boring to the participants, especially during the initial establishment stage. Since participants will be engaged on a voluntary basis, they do not have clear tangible profits from this procedure. All benefits are in terms of knowledge and innovation (Dudley E. et al. 2013). Consequently they need to have the feeling "it worth's to spend my time here". Blended workshops with a mix of interactive activities usually are more interesting for participants than plain speeches or presentations (INMARK EMF 2010).

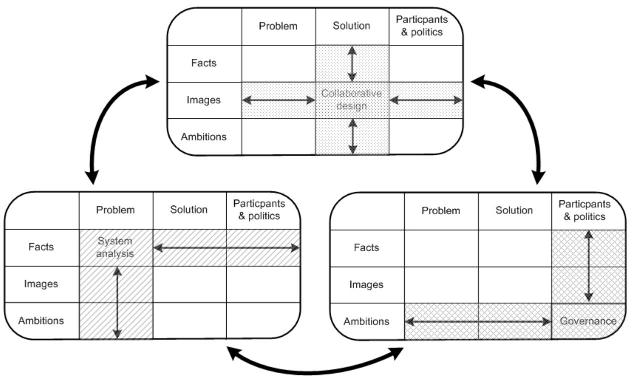


Figure 12: Interactive LAAs activities contributing to collaborative planning via 3 threads (facts, images and ambitions) and 3 streams (problem, solution, participants and politics), (Van Herk S. et al. 2011)

One more task that will be fulfilled through PEARL project and will enhance stakeholder involvement is a mobile application for crowdsourcing citizens' report, developed by Hydrologic research (Velickov S. 2014). Volunteers of Rethymno have already been provided and produced initial reports (Figure 13). Additionally to flood reports, initially feedback is gained related to the application's functionalities that will be taken into consideration for the release of the next version.

It is important to note that a volunteer culture plays an important role in Rethymno's society. Within the LAAs context, the Civil Protection Volunteer Team of Rethymno was identified and approached, the member of which expressed particular interest in PEARL outcomes and a strong wish to be actively engaged. Apart from assisting with the collection of existing data, the team proposed a plan of additional data collection based on the use of Unmanned Aerial Vehicles (UAV). Collaboration of the members of the volunteer team with the Ucandrone Company will make possible the collection of remote sensing data and finally the production of exploitable data such as Digital Surface Models (DSM) that will be used for flood modelling simulation. The areas that will be covered will be the river bed of Platanias, the coastal zone along the whole area under study and the Old Town of Rethymno. Hence, hydraulic simulation for riverine floods will be more accurate, the evolution of the coastline will be under surveillance and will assist in depth comprehension of the coastal dynamics and the coastal simulations outcomes will be calibrated / validated. Finally, the high resolution DSM of the Old Town will enable the hydraulic simulations through the use of 3D models (such as the Fluidity modelled, developed by Imperial College of London, (Zhang T. et al. 2014)). Detailed description of the mission regarding its organization and implementation was prepared by the volunteers (Figure 14). Apart from the above mentioned members, the Sailing Club of Rethymno will assist the UAV mission by proving 2 sailing boats for necessary control points in the sea.

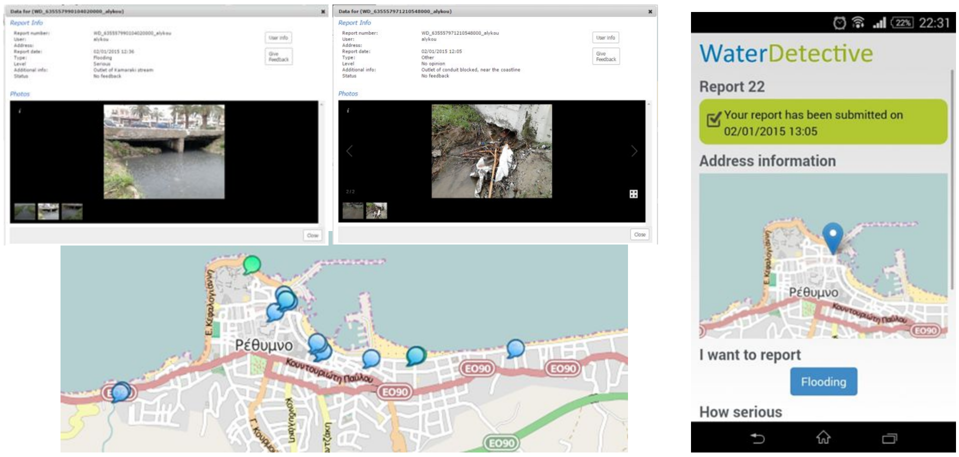


Figure 13: Interface of crowdsourcing citizens' report application used by volunteers of Rethymno

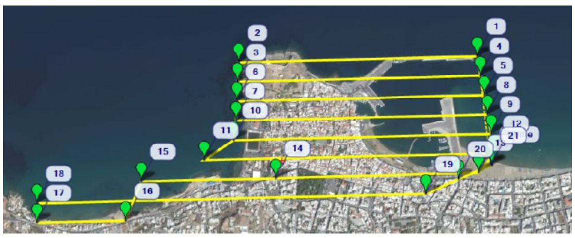

Figure 14: Control points for remote sensing through drones for the Old Town of Rethymno

## 4. CONCLUSIONS

The significant flood risk especially in coastal communities due to climate variability and human related factors prompts for the development of more integrated and inclusive disaster risk reduction strategies which will incorporate not just prevention and mitigation technical measures but they will also highly engage stakeholders towards the implementation of careful planned, specific and actionable roadmaps. Towards that direction, PEARL, an FP7 project, is developing an adaptive risk management approach for coastal communities against extreme hydro-meteorological events to minimise social, economic and environmental impacts and increase the resilience of coastal regions in Europe.

In this paper the City of Rethymno, one of PEARL's case study areas, was briefly presented and a more integrated framework to analyse and respond to multiple threats posed by extreme hydro-meteorological events was presented. The framework will enable a better understanding of flood hazard's formation by simulating climatic, atmospheric, hydrologic and hydraulic processes for the entire domain from the Mediterranean sea all the way upstream to

Rethymno's river basins. An approach and initial results of modelling land use change, urban growth and socio-economic scenarios was also briefly outlined. Furthermore, an approach towards stakeholders involvement based on the LAAs concept was presented and initial milestones engaging the local society were discussed.

The overall result of the work is expected to be the development of an actionable roadmap for flood risk management for Rethymno, integrating different risk perceptions to support commonly agreed visions in collaboration with local stakeholders, supported by an interactive web-based, learning and planning platform. It is suggested that such a roadmap and supporting tools, methods and frameworks can assist stakeholders to enhance flood resilience in coastal areas across Europe while providing a robust framework for integrating lessons and ideas from the global effort to decrease vulnerabilities in coastal zones.

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