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Implementing digital tools and stakeholders' engagement in addressing flood protection in CI. The Sitia case study

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The Municipality of Sitia, in eastern Crete, has experienced flash floods, especially during intense, short storms. The region has faced, and is becoming more prone to, disastrous flood events, as shown by serious incidents in October 2022 and April 2019. The area's very complex geomorphology, marked by small, steep catchments connected to dried and partly blocked torrents that fill quickly, makes it highly vulnerable to severe urban flooding. Within the context of the EU-funded Med-IREN (Mediterranean Critical Infrastructure Resilience Engineering with Nature-Based Solutions (NBS)) project, Sitia is addressing the implementation of NBS to reduce the impact of flooding caused by extreme precipitation upstream from the river or torrent that flows through the city. During the Public-Private-Civil Partnership (PPCP®) workshop, local stakeholders of Sitia engaged in discussions supported by advanced flood modelling tools about a) the role of models in CI resilience assessment, b) planting of endemic species for flood reduction, and c) the role of the municipality in responding to such disasters and improving coordination between different stakeholders.

Keywords: Nature-based solutions; Public-Private-Civil society Partnership; Critical Infrastructure; resilience.

1. Introduction

The Municipality of Sitia is the European region most exposed to climate pressures, primarily heat and droughts. This situation puts pressure on freshwater levels, especially during summer, due to tourism and agriculture. It could worsen with extended droughts and sudden precipitation downbursts. Documented floods in Sitia occurred in 1932, 1986, 2019, and 2022.

The most recent catastrophic flood in Sitia occurred on 15 October 2022. This event flooded nearly 50% of the city, which is situated at an elevation of 2-3 metres above the riverbanks. The entire city was devastated, and within less than an hour, the harbour was filled with debris and destroyed vehicles. The town itself experienced widespread destruction, with many buildings and shops suffering total damage. The low-lying coastal areas and zones where urban development has encroached upon natural drainage pathways are particularly vulnerable. Recent studies (Golemi et al.) indicate that the region faces risks from both flash floods and severe droughts.
This work presents the process and results of the second public-private-civil society partnership (PPCP®) workshop held within the Sitia Municipality as part of the Med-IREN project. Basically, PPCP® serves as a vital stakeholder engagement framework in the Municipality of Sitia case study, facilitating a transition from a conventional top-down approach to a collaborative governance model co-developed by local stakeholders and focused on climate resilience (Vlachogiannis et al 2026).

2. A short overview of the Med-IREN project

The EU-funded Med-IREN project aims to demonstrate how to climate-proof the Mediterranean CI through NBS across vital sectors, such as energy, transportation, information and communication technologies (ICT), water, and social services. Within the context of Med-IREN, the Municipality of Sitia is focusing on implementing NBS to reduce the impact of flooding caused by extreme precipitation upstream of the river or torrent that flows through the city. During the recent public-private-civil society partnership (PPCP®) workshop (Rimlinger 2026), local stakeholders in Sitia discussed, with the aid of advanced flood modelling tools, a) the role of models in CI resilience assessment, b) planting endemic species to reduce flooding, c) constructing dams using NBS-based products, and d) the municipality's role in responding to such disasters and enhancing coordination among different stakeholders.

Building on the objectives established in Lab 1, Lab 2 aimed to address a crisis scenario affecting multiple critical infrastructures and to examine various landscape management approaches as a foundation for discussion in Lab 3. It brought together land and critical infrastructure managers, as well as operational services.

The workshop fully supports the objectives of the MED-IREN project, concentrating on improving the resilience of critical infrastructure in the Municipality of Sitia against flood risks exacerbated by climate change. By showcasing flood simulation tools and analysing historical flood incidents, the workshop fostered evidence-based decision-making and the development of preventive strategies.

In parallel, exploring Nature-Based Solutions, such as developing natural barriers and planting native vegetation, supports the principles of green transition and sustainable water resource management promoted by MED-IREN. The active participation of institutional stakeholders and civil protection agencies strengthens the PPCP participatory approach and cross-sector collaboration.

3. Flood modelling in the Municipality of Sitia

Recent studies on climate events in the area of interest (Golemi et al., 2023) have revealed that, to address the highly complex geomorphology in such areas, it is necessary to adopt a finer resolution of 5 × 5 km² to accurately portray the actual precipitation situation. Figure 1 displays high-resolution estimates of annual precipitation based on the data and methodology introduced by the modelling study of Politi et al. (2022).

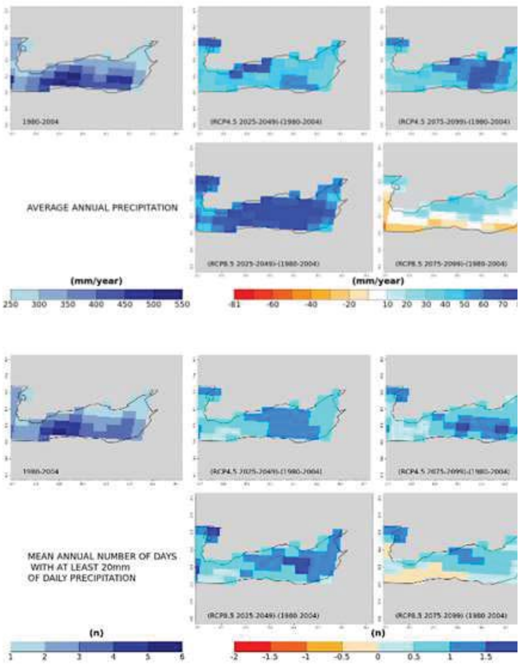

Figure 1. High resolution annual precipitation and number of days with rainfall over 20mm.

The model is a two-dimensional, raster-based overland-flow model implemented in the Landlab framework (Hobley 2017, Barnhart 2020) and driven by a temporally varying design storm. A high-resolution digital elevation model (DEM) of the Sitia area is read from a GeoTIFF and used to construct a regular Landlab `RasterModelGrid` with cell size d_xy and dimensions n_rows×n_cols . DEM no-data cells are mapped to closed boundary nodes, so they do not participate in flow routing or overland-flow calculations. Artificial dam structures are embedded directly in the DEM before the hydraulic simulation: dam centrelines from a polyline shapefile are buffered to a specified structural width, rasterised, and used to identify dam cells. For each dam, the crest elevation is set to the maximum existing ground elevation along the dam plus the prescribed dam height, and all cells within the dam polygon are raised to this crest, with a narrow transition zone generated via binary dilation and distance transforms to smooth the elevation from the original DEM to the dam crest. Open boundaries are defined primarily by topography: cells at or below sea level are tagged as coastal nodes, and a thinned subset of these is set as fixed-stage boundaries to represent the coastline. In the absence of coastal cells, the lowest-elevation boundary node is designated as the outlet and assigned fixed-value conditions. Building footprints from a polygon shapefile are rasterised to a binary mask; corresponding nodes are treated as closed (no-flow) obstacles, and their runoff coefficient is increased to near-impervious values. An optional polygon shapefile of initial water depth can be rasterised to prescribe pre-existing ponded water; if such data are unavailable, a small uniform initial depth of 0.001 m is applied only within rainfall-affected zones, while coastal nodes start dry.

The model is forced by a time-variable rainfall histogram provided as a CSV series of rainfall depths per 10-minute interval. This discrete hyetograph is converted into a continuous intensity function i(t) by linear interpolation and transformed to SI units, and the simulation length is set to the rainfall duration plus an additional three hours to capture flood recession. Spatial variability in rainfall is represented via a rainfall-zone polygon layer that is rasterized to a field of rainfall multipliers; if no such layer is available, a uniform multiplier of one is assumed. Curve Number (CN) values from a land-use/soil shapefile are converted to dimensionless runoff coefficients (CN/100, constrained between 0.01 and 0.99) and rasterized to the computational grid, with building cells assigned nearly impervious coefficients. At each time step, for interior nodes within rainfall zones, the effective rainfall rate is computed asi_eff=i(t),m_rain,C_r, where m_rain is the local rainfall multiplier and C_r the runoff coefficient, and this effective rainfall is added directly to the local water depth as a vertical source term.

Surface flow routing is handled by Landlab's D8 `FlowAccumulator`, which computes drainage directions and contributing areas over the modified DEM. Flow accumulation is calculated at the start of the simulation and can be updated periodically to remain consistent with evolving water surfaces. The shallow-water dynamics of overland flow are simulated using Landlab's `OverlandFlow` component configured for steep slopes, which solves a simplified form of the shallow-water equations using a kinematic/diffusive wave approximation with Manning friction. A uniform Manning roughness

of 0.03 and a weighting parameter a = 0.7 are adopted, representing mixed urban–peri-urban terrain with relatively steep gradients. The component updates water depth at core nodes in an explicit time-stepping scheme, while closed nodes (buildings, no-data) enforce no-flow conditions and fixed-value nodes (coastline or outlet) represent stage-controlled boundaries.
Time integration uses an adaptive explicit time step Δt computed internally by the OverlandFlow component, further constrained not to exceed 60 s and not to fall below 10-6s, and statistics of Δt (minimum, maximum, mean, variability) are recorded for later analysis. Numerical stability is monitored by checking each updated depth field for NaN, infinite, or negative values, and a counter of stability warnings is incremented when such anomalies occur. When rainfall begins, a "baseline" depth field is stored; subsequent outputs subtract this baseline and truncate negative values, so that reported flood depths represent rainfall-induced inundation rather than pre-existing water in depressions or coastal cells. A water mass balance is constructed by tracking total water volume on the grid (depth integrated over cell area) and cumulative rainfall input volume at each step, enabling quantification of retention and storage effects, including the influence of dams. At user-defined intervals (typically every 10 minutes after rainfall onset), the model writes gridded GeoTIFF outputs of corrected water depth and water-surface elevation (DEM plus depth), as well as maps of flow accumulation, runoff coefficients, rainfall zones, building masks, dam locations, and initial/baseline depth fields, together with high-resolution visualization products that overlay flood depths on hillshaded terrain with buildings, rainfall polygons, and dam centerlines.

The next step in the assessments if the implementation of flood models. Table 1 contains the simulated scenarios considering a) rainfall location of the 2022 historical flood event and b) the 95th percentage percentile rainfall amount from the high resolution simulation models. Thus, the following set of 9 simulations were conducted.

Table 1. Flood scenarios.

Business as usual	
	Historical, 1980 - 2004
	RCP4.5, 2025 - 2049
	RCP8.5, 2025 – 2049
NBS implementation	
	Historical, 1980 - 2004
	RCP4.5, 2025 - 2049
	RCP8.5, 2025 – 2049
Dams in water catchment areas	
	Historical, 1980 - 2004
	RCP4.5, 2025 - 2049
	RCP8.5, 2025 – 2049

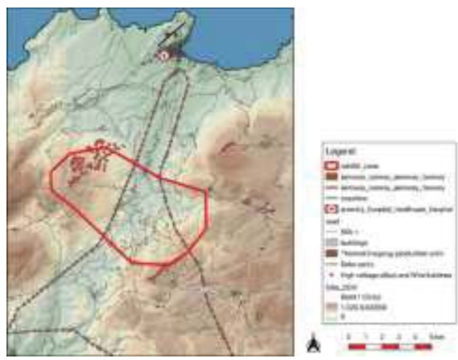

Figure 2. Sitia geomorphorology, rainfall area and critical assets of the area.

The scope of the integrated simulation models was to assess the impacts of the two phenomena on critical infrastructure, residential areas and natural formations, trying to simulate the impacts of the historical extreme event. Secondly, the focus shifted to the implementation NBS such as a) creating dams with natural materials and b) planting of endemic plants. (Figure 3)

Figure 3. NBS dams localization and Land Changes with endemic species.

The event also examined environmental and ecosystem measures to address flood risks, in accordance with the principles of the green transition and sustainable water resources management. The scientific focus with the specific simulations was to a) examine interventions for natural retention and delay of surface runoff, b) development of green infrastructure with a low environmental footprint, c) reinforcement of natural barriers and wetland formations and d) mild stream protection and management projects in accordance with European standards.

These approaches would collectively support adaptation to the climate crisis and promote an integrated resilience model for the region.

4. PPCP Lab

The Municipality of Sitia, in collaboration with the National Center for Scientific Research Research "Demokritos", organized the 2nd PPCP lab within the framework of the European MED-IREN program, on Thursday, November 27, 2025. The main focus was to strengthen the resilience of Mediterranean regions against the climate crisis and extreme weather phenomena, building on the outcomes of the first PPCP lab conducted in March 2025, and expanding the public debate with new scientific and technological data.

During the event, the results from the flood simulations. The NCSRD team analyzed the simulation of historical episodes (Figure 4) highlighted the vulnerabilities of the area, but also the needs of the Municipality in making future decisions, in the timely identification of risks and in the optimization of response procedures. Study of environmental solutions and prevention approaches (Figure 5 and Figure 6)

Figure 4. Flood simulations – a) 240 mins and b) 420 mins from start

Figure 5. Flood simulation with dams 420 mins

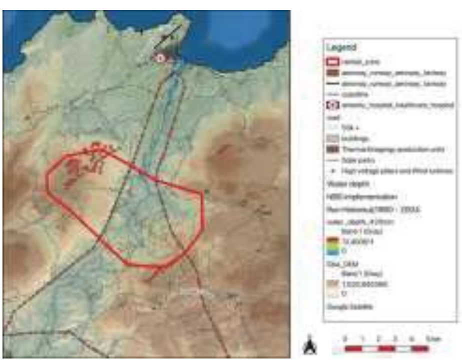

Figure 6. Floods with endemic species – 420 mins.

The event, which was coordinated by the Municipality of Sitia Civil Protection was attended by 30 representatives from national and municipal services (Police, Fire Corps, Ambulance, Hospitals, EDEAK and Red Cross Volunteers, Schools), and local stakeholders (farmers, tourism industry, which confirmed the importance of local participation and coordination in disaster management.

Figure 7.Photos from the 2nd PPCP Lab

5. PPCP Lab key findings

The participants underlined that the climate crisis requires modern simulation and forecasting tools, scientifically validated methods and continuous training of all stakeholders involved. At the same time, the need to strengthen institutional cooperation and the participation of the local community in adaptation and prevention actions was highlighted. The Municipality of Sitia confirmed its commitment to exploit the results of the MED-IREN program for the shielding of the region, the upgrading of operational planning and the protection of citizens.
The integration of advanced simulation tools into local and regional planning processes has emerged as an important capability requirement of modern flood risk management, specially in areas like Sitia that are isolated. It is no longer sufficient to rely solely on historical records or static maps; dynamic modeling would be needed to allow disaster management teams to visualize a range of flood scenarios. As commented by participant's incorporating these sophisticated digital tools, municipalities can move beyond reactive disaster response to proactive, data-driven planning, more efficient and organised response and infrastructure protection. Other participants stated that simulation tools can support urban actions and infrastructure planning through a clear understanding of potential hydrological risks, ultimately building more resilient communities.

Valuable insights into the vulnerabilities of existing infrastructure and the adequacy of emergency response protocols was gained. The participants revisited the historical 2022 flood and especially its dynamics, lessons learned and key vulnerabilities from the participants experience.
The participants identified with accuracy, supported by the models, where defenses failed, lagging response times, trapped persons, evacuation and provision of first aid and recovery to the events.
The participants noted the application of simulation technology as a diagnostic tool, revealing hidden challenges in the design and functioning of the Papandreou str drainage and flooding, impact on bridges and transportation networks, communication channels. As one participant mentioned is important to learning from these digital representations of the past for fortifying the municipality against the floods of the future.
Concerning the implementation of NBS there was a growing consensus that these solutions offer a significant and sustainable complement, although presently and for the Sitia characteristics traditional grey infrastructure is also essential for response. Approaches such as restoring wetlands, creating floodplain bypasses, and implementing sustainable urban drainage systems can absorb excess water, reduce flow velocities, and enhance water infiltration. As one participant from volunteering groups mentioned soft measures bolster flood protection but also deliver co-benefits, including improved water quality, enhanced biodiversity, and the creation of green spaces for communities.
Another domain of discussion was focused around the effective preparedness and response which as unanimously agreed are fundamentally dependent on seamless institutional coordination and open data sharing. As was highlighted in the meeting, flood events do not respect administrative borders, making it imperative that neighboring municipalities, water management institutions, and civil protection agencies operate from a common operational picture. Participants commonly acknowledged that breaking down data silos and establishing clear communication protocols will nsure that all stakeholders have access to real-time information and predictive models would be a positive element.

In a significant step forward, the Municipality of Sitia has formally confirmed its commitment to embedding the findings and methodologies of the MED-IREN outcomes into its future flood protection strategies and planning tools. By integrating these results into official civil protection protocols and flood risk management plans, Sitia is anticipating that the investments in research will have a tangible and lasting impact on the safety and sustainability of the community.

5. Conclusions

The present work presents the key proceedings and findings from the 2nd PPCP lab conducted in the Municipality of Sitia within the framework of the Med-IREN project. The main study was conducted with the implementation of a state of the art flood model to simulate historic scenarios and future projections considering the implementation of two types of NBS solutions. The lab main findings is that strategic integration of these ecological approaches represents a shift toward working with natural processes rather than against them and this collaborative framework is critical for issuing timely warnings, coordinating evacuations, and deploying resources efficiently during a crisis, thereby minimizing both economic losses and threats to human life

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