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Abstract

This paper contributes to addressing the escalating challenge of post-wildfire flood hazards – a growing threat to people and nature under climate change – by integrating advanced flood modelling within a governance framework to support proactive flood-protection planning. The coastal community of Kineta, in Greece, is used as a case study to demonstrate the combined application of the multi-disciplinary modelling approach and the governance assessment framework. The modelling approach analyses post-wildfire floods, and guides the design of post-wildfire erosion and flood protection treatments (PEFTs). It combines remote sensing analyses, atmospheric and hydraulic simulation models like WRF-ARW and HEC-RAS, and the geospatial application of targeted PEFTs, such as log-erosion barriers and wooden check dams. The need to bring such model-driven insights into policies implementing PEFTs, led us to augment the modelling approach with a governance framework followed in Australia, which has many similar hazard and governance characteristics to those of Greece. The governance framework is based on the values-rules-knowledge (VRK) model of decision-making contexts, and identifies key barriers that lead to insufficient flood protection. Robust insights are generated from this process about how to effectively apply integrated modelling approaches within decision-making contexts for knowledge and policy co-production to address institutional, behavioral and knowledge barriers impeding timely investments in flood risk mitigation. The proposed framework is suggested as a comprehensive science-to-policy approach that can support more proactive post-wildfire flood risk management.

Keywords: Post-wildfire floods; Flash-floods modelling; Protection works design; Values; Rules; Knowledge; Governance; Greece; Australia.

1. Introduction

The increasing frequency and intensity of wildfires, driven by climate change, present significant challenges with broad impacts on ecosystems and human populations (Goss *et al* 2020). While wildfires are most acute during summer and dry periods, their effects extend well beyond, causing long-term environmental degradation (Merz *et al* 2021).

The wildfires drastically alter land cover, vegetation, soil properties, and the hydrological response of impacted catchments, particularly during intense storm events (Soulis *et al* 2021). Burnt areas often become highly vulnerable to flash floods due to decreased infiltration, increased runoff, and heightened sediment transport (Xu *et al* 2023).

There is considerable evidence of extended droughts and heatwaves (i.e., extreme weather conditions that favor the ignition and spread of fire) followed by intense rainfall and flash flooding across various ecoregions, particularly in temperate climate zones. Notable instances are observed in southeastern Australia, California, and Southern Europe, where extensive wildfires (mega-fires) are occurring with increasing frequency, shifting from once every 25 to 30 years to currently occurring every 5 years (Bhola *et al* 2023, Ide 2023, Newman and Noy 2023)These mega-fires are not restricted only to dry and hot summer periods. They can also occur during cooler temperatures and are often followed by flash floods and heavy rainfall.

The combined effects of wildfires and post-wildfire events have severely impaired vital ecosystem services (e.g., soil stability, water filtration, etc.), supporting community assets and infrastructure while posing serious threats to human life. Several studies focus on the risks and impacts of wildfires and post-flooding, particularly in urban environments, by addressing the need for better modelling capabilities and adaptive governance mechanisms (Alamanos and Linnane 2022). The establishment of resilience-building mechanisms needs to overcome three major challenges:

a) Modelling post-wildfire floods still requires refinement and greater precision, as the effect of wildfires must be integrated into hydraulic models to ensure highly accurate and reliable simulations (Gorddard *et al* 2016, Colloff *et al* 2020). The existing modelling studies primarily refer to design storms or various storm scenarios (rather than actual events that would enable the validation of the models) (Hasan *et al* 2020, Havel *et al* 2018), or focus mainly on hydrological responses, such as post-wildfire runoff, along with soil properties and sediments (Ebel and Martin 2017).
b) There is limited information on the precautionary measures, specifically post-wildfire erosion and flood protection treatments (PEFTs), needed to enhance hydrological stability and proactively mitigate flood hazard impacts. The main and most common PEFTs are land-based (installing barriers to reduce runoff and erosion), and channel-based (in-stream interventions for water control) (Papaioannou *et al* 2023, Napper 2006). However, the literature on their design and costs is scarce and not concise (and underrepresented in countries outside the US, Spain and Portugal) (Ebel *et al* 2023).
c) There is inertia in the adoption and implementation of PEFTs by local actors responsible for managing natural hazards and disaster risks (Birchall *et al* 2025, McNaught *et al* 2024). The response of local governance and the necessary behavioural changes to adapt to combined hazards often lag, resulting in numerous instances of inadequate flood protection. Integrating modelling insights with local governance and stakeholder perspectives poses significant challenges, necessitating multidisciplinary and transdisciplinary approaches. These approaches require qualitative, discursive methods intended to understand the complex factors—such as values, psychology, norms, and regulations—that influence human responses to new and highly uncertain risks, that are driven by climate change.

The challenges mentioned highlight the need for comprehensive assessments of post-wildfire floods and PEFTs design. Additionally, it is vital to account for the decision contexts—defined by the interconnected systems of values, rules, and knowledge—into which scientific information must be integrated for it to be credible, legitimate, and relevant in policy and planning processes. Addressing the knowledge-to-policy gaps by combining improved quantitative and qualitative tools is crucial for creating resilient societies.

In this manuscript, we explore the issues, challenges, and opportunities associated with scientific tools and decision-making regarding emerging post-wildfire flood and disaster risks under climate change by drawing on experiences from Greece and Australia. Greece and Australia were selected because they have similar conditions of local governance-led flood protection approaches and projections of increasing wildfire and flood hazards under climate change (Cunningham *et al* 2024, Jones *et al* 2022).

We present a best-practice multi-disciplinary modelling approach to simulate post-wildfire flood risks, impacts and design mitigation measures (i.e., PEFTs) in a typical Mediterranean catchment (Kineta, Central Greece). We use this as the necessary scientific information for informing post-wildfire flood protection. We then apply a governance assessment framework called the values-rules-knowledge (VRK) model of decision contexts to the Kineta case study, to identify potential science-to-policy gaps that constrain timely and science-supported flood protection action. The VRK approach has been applied in a range of Australian and global case studies as an analytical lens to identify barriers to decision making, and to reveal levers for governance and social change and resilience-building (Dubo *et al* 2023, Fleming *et al* 2017). We describe an approach combining the modelling insights (Greek case study) with the VRK approach (including drawing upon Australian experiences with similar climate, hazard and decision-making characteristics) to develop a science-to-policy roadmap supporting more proactive and timely adoption of PEFTs. The suggested roadmap offers significant contributions to a relatively limited body of literature on the topic, especially considering the increasing occurrence of, and contestation about how to address, wildfire-flood hazards and impacts worldwide (Touma *et al* 2022).

2. Materials and Methods

2.1 Case studies

For the modelling application, we selected a recent flooding disaster that took place in Kineta, a coastal town located in the south of Greece. Kineta is a small community of approximately 1,500 inhabitants, which, however, increases tenfold during the summer season (June-August). Administratively, Kineta is part of the municipality of Megara, which has an area of 330,000 sq.m. and a population of 38,033 according to the 2021 census (Hellenic Statistical Authority 2024). The municipality also falls under the jurisdiction of the Attiki region, the most densely populated area in Greece, with nearly 3.8 million inhabitants due to the presence of Athens, the capital, and its surroundings.

The town is located in a hydrological catchment covering approximately 40 km^2, extending from the mountainous northern Geraneia to the coastal town of Kineta in the south, with water flowing through a primary stream and smaller tributaries (Fig.1A;1B). The climate is typically Mediterranean with hot and dry summers and annual precipitation ranging between 350-400mm mostly in winter season (Fig.1C). In recent years, the area has experienced escalating wildfire risks during the summer months, exemplified by the ones of 2017 and 2018. The 2018 wildfire, in particular, devastated the pine forest in the Geraneia mountains, destroyed nearby settlements, and caused extensive damage to homes in Kineta (Fig.1D). Following these wildfires, an intense storm in November 2019 triggered a flash flood, resulting in significant destruction across the town (Fig.1E-J). In this study, we evaluate the wildfire that occurred in July 2018 and the post-flood events in November 2019 that affected the town of Kineta.

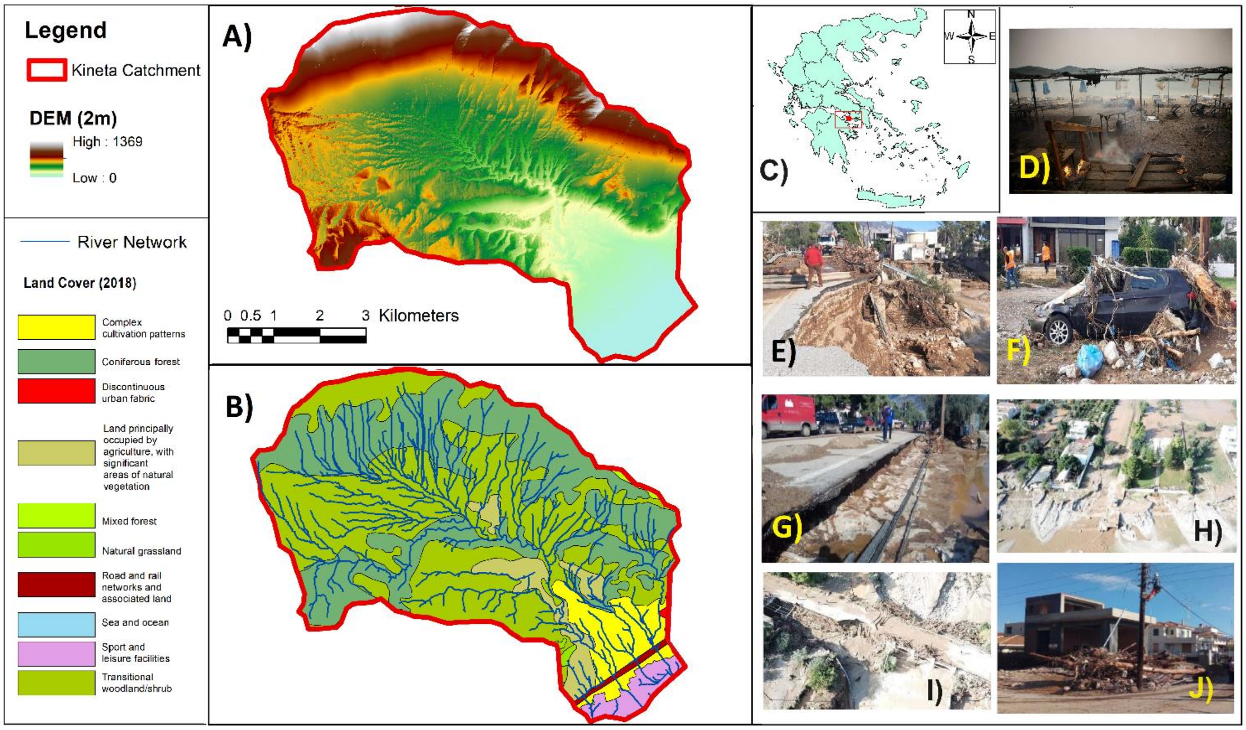


Figure 1: The Kineta catchment, A) digital elevation model (DEM). B) The main land cover types and the river network. C) Kineta's location in Greece (marked dot). D) A picture from the wildfire of 2018, showing that from the mountainous part it reached the coast. E-J) Damages caused by the flood of 2019, affecting critical infrastructure and properties. Sources: (Lekkas *et al* 2019, Protothema 2019).

Similar to Greece, many fire-prone regions of Australia have been experiencing increasing wildfire threats due to climate change. Many of these regions also have Mediterranean climates characterized by hot, dry summers and mild, wet winters. (Seager *et al* 2024). These conditions, coupled with dense vegetation and rugged terrain, create an environment highly susceptible to wildfires – which are called bushfires in Australia – during the dry season and flash-floods during the wet season (Bradshaw *et al* 2018).

The frequency, extent and intensity of mega-fires across Australia have increased in recent decades due to climate change. The most recent of these occurred between November and February 2019/20 in southeast Australia, where more than 23% of temperate forests in the region were burned (Abram *et al* 2021). In mid-February 2020, a severe rainstorm occurred in the region, which combined with the absence of vegetation cover due to years of drought and the widespread wildfires, led to severe flooding, landslips and landslides across the southeast coast. The post-wildfire floods significantly impacted residential and commercial properties in New South Wales (NSW), resulting in over 98,000 insurance claims and an estimated insured loss of about $1.67 billion (Australian Parliament 2022).

Because of these similarities in the climate, topography, vegetation and natural hazard behaviours, we draw upon Australian wildfire-flooding experiences to inform lessons for Greek policymakers on the importance of timely and proactive flood mitigation measures. Additionally, both countries have similar governance approaches making comparisons of lessons useful for enhancing practice in each country. In Greece, the Ministry of Environment provides at the national level generic guidelines for hazard protection, and the Regions are responsible for implementing such plans. In Australia, the governance arrangements involve the Federal Government establishing the overall strategic policy environment and providing funding support for pre- and post-disaster activities, which include emergency management, disaster recovery, and strategic disaster risk reduction. The State and Local governments are responsible for local land-use planning, approving development applications, disaster management, and the supply of local services (e.g., water, sewerage, local roads, etc.). In both countries, local authorities (i.e., municipality-level), individually or in groups, are the first to take the initiative to design and implement PEFTs.

2.2 Modelling framework

The ability to model post-wildfire flash-flooding is an essential element for informing the design of flood prevention and mitigation responses. The developed modelling framework is illustrated in Fig. 2, as it was used to represent a real post-wildfire flood event in Kineta November 2019.

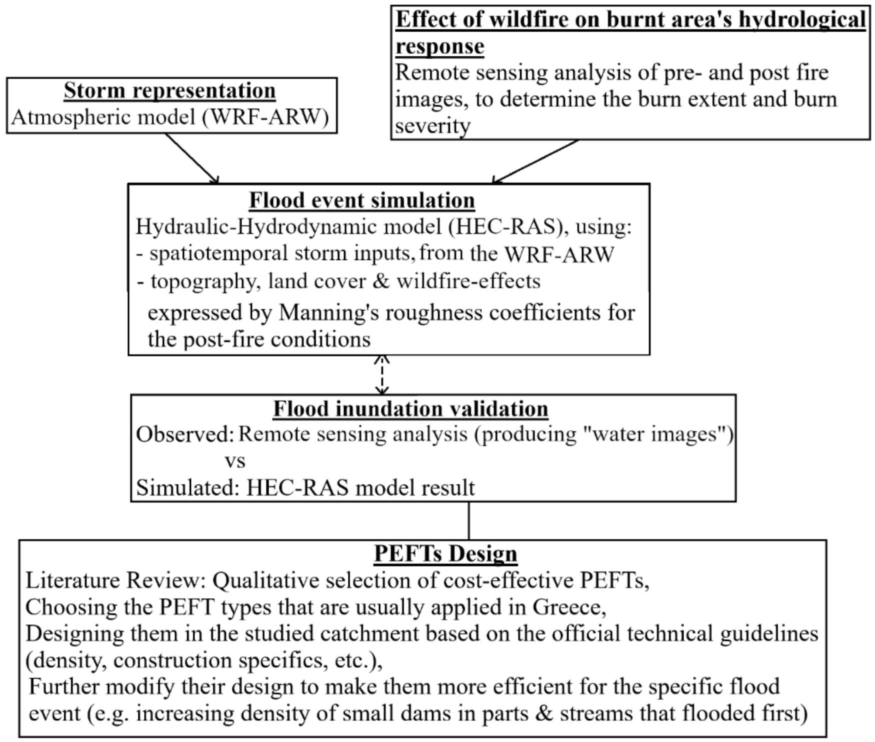


Figure 2: The conceptual flowchart for the modelling/representation of post-wildfire flash-flood events.

We use Remote Sensing (RS) techniques to assess the burnt extent and severity. The burn extent provides us with the areas (spatially) that have been affected by the wildfire. This analysis also provides the burn severity of these areas (e.g., low, moderate-low, moderate, moderate-high, high). This information, together with the land cover classes, allows us to use Mannings's roughness coefficient (*n*) for each combination of land cover and burn severity type (Harun-ur-Rashid 1990). The *n* values are useful inputs for the hydraulic model that simulates the flood inundation, as they actually represent the effect of the wildfire on the flooding (burnt areas' hydrological response) (Alamanos *et al* 2024a).

As we applied the framework to a real storm, we represented this exact storm through the atmospheric model "Advanced Weather and Research Forecasting" (WRF-ARW) v4.2 (Varlas *et al* 2024). It simulated the meteorological conditions that led to the examined storm, which caused the flood.

Subsequently, we developed a hydraulic-hydrodynamic model in HEC-RAS (Hydrologic Engineering Center's River Analysis System) ssoftware, to simulate the flood inundation. The model uses the catchment's topography (elevation model), the Manning's *n* values, and the spatial distribution of the precipitation generated by the WRF-ARW model. This was treated as a set of distinct spatial datasets using HEC-RAS's rain-on-grid technique to effectively represent the storm's progression (Alamanos *et al* 2024a). HEC-RAS's flood-inundation results are then validated over the actual flooded area, which we obtained as a "water image" from the RS analysis, at the time of the flood event (more details on the modelling framework can be found in the Supplement and Alamanos *et al* 2024a).

Next, we evaluate the most suitable PEFTs, allowing for a more informed selection and design process guided by the hydraulic model's results. In particular, after a literature review assessment (Papaioannou *et al* 2023), we selected the most cost-effective PEFTs out of the most commonly used in Greece, ensuring that they align with the relevant official guidelines for technical catchment works. The results of the hydraulic-hydrodynamic model indicate which specific streams and parts of the catchment flooded first or contributed most to the water accumulated in the flooded area. This allows us to refine further the selected PEFTs (e.g. using denser works, like wooden check-dams to block the flood-water coming from these parts). More details on the PEFTs and the detailed design for Kineta can be found in the Supplement and Alamanos *et al* 2024b.

2.3 Governance framework

Integrating the proposed modelling approach and the insights about flood risks and PEFTs into relevant decision making processes is challenging and has not occurred in the case study of Kineta. Increasing the awareness and use of this modelling approach and outputs requires understanding the formal and informal rules governing how decisions are made, the values, preferences, interests and priorities of relevant decision-makers, and the knowledge bases that these decisio- makers consider to be credible and legitimate. A deeper understanding of these three dimensions – values, rules and knowledge – and their interactions, has been repeatedly shown in a range of context to be effective at revealing strategies for how these can be 'shifted' to accommodate new knowledge (e.g., about novel risks and interventions) or value priorities. This perspective on decision contexts is the values-rules-knowledge (VRK) perspective/model and is applied to the Kineta case study to reveal leverage points for improving the uptake and use of the modelling insights in flood risk management (Fig.3).

The VRK model of decision contexts assists in diagnosing constraints and barriers to interventions or decisions, particularly novel ones, and better prepare decision-makers for significant and uncertain changes (Gorddard *et al* 2016). The VRK framework emphasises that prevailing systems of values, rules and knowledge can affect (positively or negatively) the options available to decision-makers. The effects merge over time through complex social, cultural, behavioural processes in organisations or communities. The intersection of these three factors, which is called the decision context, forms the envelope or space for a set of practical and permissible (legitimate–V, legal–R, and credible–K) decisions/interventions that can be made. When these three factors are aligned, a decision-maker is legally able to choose from a variety of options that are also viewed to be credible and legitimate amongst relevant stakeholders. However, when the societal values, rules or knowledge are misaligned, decision-makers may find themselves constrained by their decision context and forced to select from a limited array of less effective options. This includes the rejection of potentially effective novel solutions and a reliance on business-as-usual options. A fundamental assumption of this model is that shifts in decision-making can only arise after modifications in values, rules, and knowledge occur at the organisational, community or societal levels.

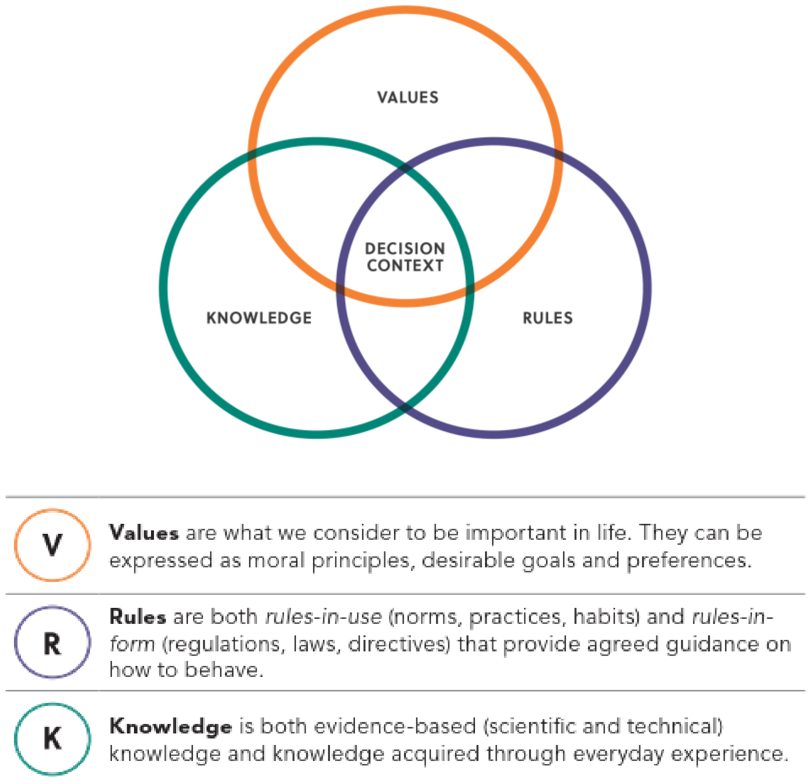


Figure 3: Illustration of decision contexts as the intersection of the societal systems of values, rules and knowledge (VRK). Adapted from Gorddard *et al* (2016).

The entailments of this approach for situations of emerging risks such as post-wildfire flooding, where novel solutions need to be adopted (e.g, PEFTs), are (Prober *et al* 2017): i) the application of the VRK model as a diagnostic tool to identify the main V, R, or K barriers and to indicate leverage points that overcome these barriers and ii) the need for proactive inclusive engagement with stakeholders that supports the deliberative co-production of knowledge about risks and adaptive learning about the effectiveness of novel responses.

We use the VRK model in this study as a lens on the local decision contexts in Kineta to help diagnose the constraints (and opportunities) leading to the inaction and to reveal transferable insights and lessons that can encourage and support similar changes and initiatives in other areas of Greece (Word Bank 2018, Alamanos and Koundouri 2022).

3. Results and Discussion

3.1 Simulation of post-wildfire flood, and design of the most suitable PEFTs

For the identification of the wildfire impacts, the RS analysis showed the burn severity and extent of the wildfire in July 2018, as well as changes between the wildfire and the flood event that occurred on 24-25 November 2019. The results indicated vegetation regrowth from August 2018 to October 2019, just before the flood. Moderate-high and moderate-low burn severity dominated in 2018, while by October 2019, moderate-low and low severity, along with unburnt areas, prevailed (Fig.4A). The WRF-ARW model simulated the meteorological conditions of the storm in November 2019, causing the flash-flood in Kineta. The results indicated the severity of this extreme storm evident from the pattern and intensity of the 1-hour accumulated precipitation of November 25 from 03:00 to 04:00 local time (Fig.4B). The actual flood-inundated area and its boundaries were also captured by RS, analysing an image dated November 25, 2019. The result (Fig.4C) served as a polygon to validate the HEC-RAS flood model (Fig.4D;4E). The total simulated flood inundation area was 595,246m^2, covering almost 25% of the town's total residential area (Alamanos *et al* 2024a).

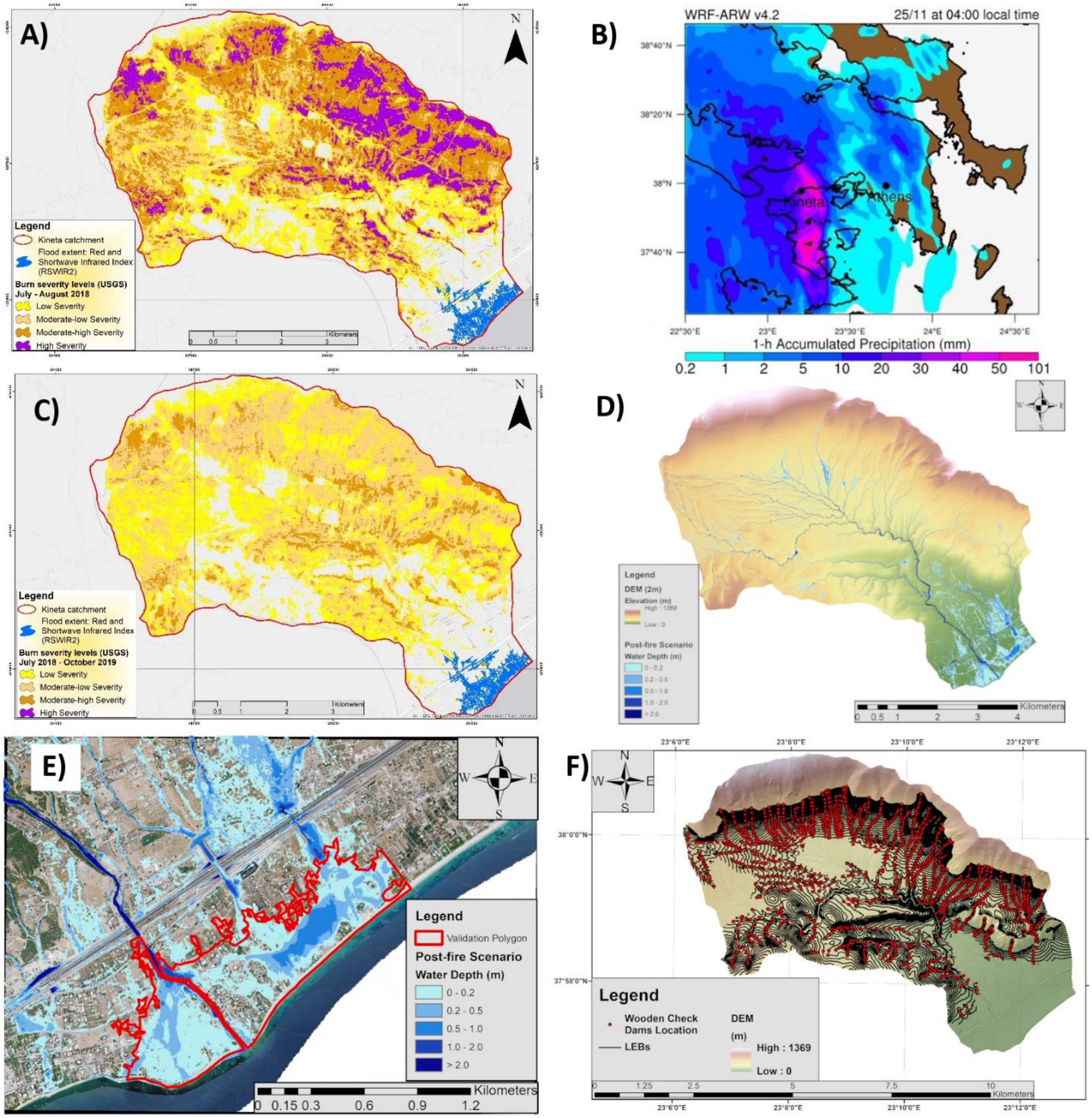


Figure 4: The framework's results for Kineta catchment: A) The burn extent and severity as obtained by the Remote Sensing (RS) analysis, for the pre-wildfire period (July-August 2018). B) The results of the WRF-ARW model of the simulated 1-h accumulated precipitation (in mm), indicatively for 25 November at 04:00 local time. C) The results of the RS analysis, regarding the burn extent and severity at the post-wildfire conditions, along with the November 25 flood extent at the coastal Kineta town. D) The flood inundation results of the HEC-RAS model for the catchment. E) The flood inundation results over the validation polygon in the Kineta town. F) The designed PEFTs (LEBs and WCDs) within the catchment.

Regarding the design of PEFTs in Greece, the most commonly used PEFTs include barrier-based log-erosion barriers (LEBs) and channel-based wooden check-dams (WCDs). Based on the official Greek guidelines and technical specifications concerning their height and spacing, as well as cost insights from recent Greek cases similar to the Kineta catchment applying PEFTs, and a cross-check with our previous literature review (Papaioannou *et al* 2023, Koudoumakis *et al* 2024, Greek Ministry of Environment and Energy 2023), we designed: a) 0.2-meter high LEBs (in moderate to high burn severity and slopes between 10%-50%), installed every 10m along the contour lines, and b) 1-meter high WCDs (in slight slopes <20%) installed in the 1st, 2nd, and 3rd order streams at intervals of 50-100m (Fig.4F) (Alamanos *et al* 2024b).

3.2 The governance gap

The total cost of applying the suggested PEFTs in Kineta has been estimated at €5 million (2023 values) based on the sum-product of the unit cost of each PEFT and the number of each PEFT implemented (Alamanos *et al* 2024b). The Technical Works Observatory of West Attica Region (responsible for infrastructure works at the regional level) reported a total repair cost of around €25 million (2023 values) for the flood damages to assets and infrastructure only. This means that the suggested preventive costs for the flood mitigation measures could amount to only 1/5 of the post-flood damages reported by the official authorities, assuming a high effectiveness of the proposed PEFTs. Even if the indicated PEFTs would be effective for lower effectiveness rates, the cost difference with the rehabilitation costs remains significantly lower. In retrospect, insufficient PEFTs have been installed after the wildfire to intercept possible forthcoming flood events. Also, no compensation has been granted from the government to the regional authorities for the flood-affected communities (Papadopoulou 2021). At the end of 2024, after extended protests, the case was brought to court, with the primary defendant being the Former Regional Governor of Attica (Protothema 2024). This situation demonstrates a perverse outcome whereby the government has avoided both the cost of risk protection and post-disaster compensation, transferring these risks and costs to the impacted communities and businesses. This has happened in other Greek cases suffering from catastrophic flood damages due to insufficient protection, e.g. the region of Thessaly in Cenrtal Creece in September 2023, where the Former Regional Governor was found guilty and convicted (ERTnews 2024).

3.3 Bridging the knowledge and implementation gaps

The VRK assessment was introduced in Kineta. After informal communications of the Greek-modelers team with local authorities, we identified certain gaps in V(alues), R(ules) and K(nowledge) that can help explain the limited awareness and adoption of sufficient flood mitigation measures, as presented in Table 1.

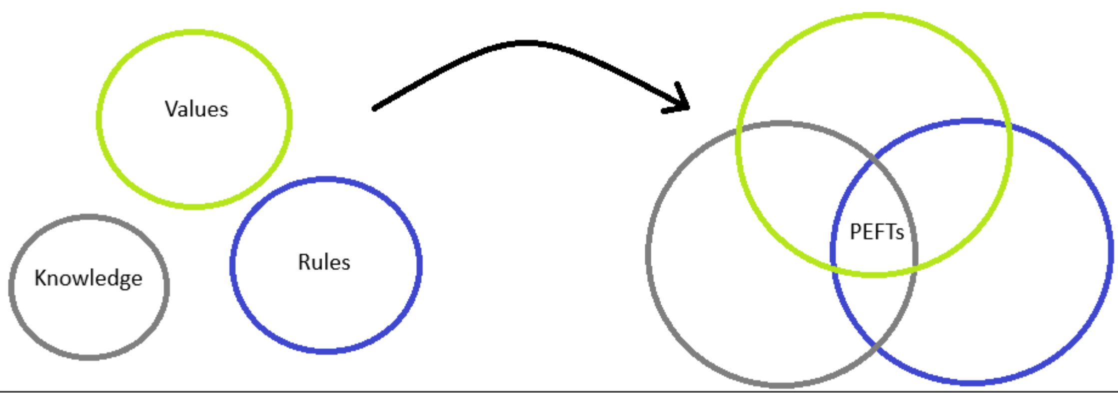
Table 1: Factors limiting the VRK decision context for the Kineta case, which should be targeted in stakeholder engagement processes.

Factors reducing the VRK intersection spaces and hence constraining the decision context	Intersection space limited
Policymakers set low priorities (R & V) for PEFTs because they feel that they are unlikely to be widely publicised ("the media come for the disasters, but afterwards they don't care").	Values & Rules (VR)
Policymakers set low priorities (V) for PEFTs because their effectiveness will not be immediately evident (K) after implementation but after the first storms. In contrast, policymakers tend to prioritize (V) measures that have immediate results (K), to build their legacy quickly through advertising.	Values & Knowledge (VK)
Existing regulations (R) continue to require that flood-damaged infrastructure be restored to pre-disaster standards (R), which are generally based on outdated storm data (K) (+50 years ago) that no longer reflect the current and future (changing) climate (K).	Rules & Knowledge (RK)
The funding, staffing and training levels (V & K) of those responsible remain insufficient to support effective mitigation of the growing magnitude and frequency of the hazard risks.	Rules & Values (RK)
Unclear roles and responsibilities (i.e., accountability) (R) and siloed communications within and across organisations lead to uncoordinated decisions and inaction, particularly in diverse areas with uneven disaster impacts (V) and complex property rights (R & V). This is also often used as an excuse by local authorities that are responsible for implementing flood protection measures but feel unsure how to act.	Rules & Values (VR)
Although there are regulations (R) and national plans (R) for hazard mitigation and adaptation in place, there is little available information or assessments on the suitability and cost-effectiveness of PEFTs (K). This is especially the case in specific instances requiring novel PEFTs that are more effective at mitigating the changed hazard risk profiles. This knowledge gap (K) leads to generic regulations (R) around risk mitigation and leads to poor/limited implementation.	Knowledge & Rules (KR)
The widespread lack of awareness (K) about post-wildfire effects on the hydrological response of a burnt site to a subsequent storm or flood.	Rules & Knowledge (RK)

The timely application of appropriate PEFTs can have many co-beneftisto flood protection (e.g. rapid recovery, reduced soil erosion, avoided damage etc.) but these are overlooked due to the lack of incentives (R) and awareness (K).	
Local authorities continue with BAU mitigation practices (e.g., clearing the streams from sediment and rubbish) because these are associated with simple and easy implementation requirements (K) and levels of accountability (R), even though these are no longer as effective as they used to be.	Knowledge & Rules (KR)
Policymakers' ways of thinking and behaving (V, R & K) (i.e., prevailing poor or anachronistic understanding of compounding extreme hazards) have not changed to account for the "new normal" of radically different hazard behaviours under climate change (K). This is reflected in these 'extreme events' being considered exceptions and justifying BAU, which is hindering the adoption of necessary mitigation efforts.	Values, Rules & Knowledge (VRK)

It is evident that when it comes to the local stakeholders that are responsible for the implementation of protection measures, a combination of factors has been causing several issues, which can be summarized as: policymakers tend to be unaware or deprioritise PEFTs (VK); the lack of analytical depth and previous experiences with PEFTs (KR); low levels of awareness and acceptance that such extreme storm events are not exceptions but constitute the "new normal" in the context of climate change. This is sustained by a consistent lack of flood modelling insights and PEFT-design approaches or an insufficient level of detail) (KV). The above examples illustrate how prevailing interactions between 2 or more of the VRK elements of the decision context are excluding PEFTs from the set of options considered credible, legal and legitimate, as presented in Fig.3. This raises salient questions about what actions are taken, when, where and why, and helps explain the decision-making inertia around the novel PEFTs that has finally happened in the case of Kineta. This decision-making inertia is further aggravated by inadequate investment and lack of human and institutional capabilities needed to support hazard risk reduction initiatives.

Bridging the existing science-policy and knowledge-action gaps in Kineta requires participatory processes and knowledge co-production, including the adaptive development and testing of the simulation modelling approach that draws upon stakeholders' experiential knowledge and enhances their understanding and awareness. The engagement process also needs to target the specific factors listed in Table 1 in ways which increase the overlaps between V, R and K through shifting prevailing and predominant paradigms, norms, practices, perceptions, and policies so these better account for the new and emerging dimensions of post-fire flood risks and PEFTs.



Values - low priority for PEFTs	Potential argumentation on the benefits and the policy co-benefits (e.g. protection, small and easy local scale works of low cost, creation of local jobs, etc.
Rules - lack of accountability & poor integration of PEFTs in the regulations	Potential argumentation on enhancement of communication skills, clarification of the governance processes, and use of tools like the modelling framework, or previous applications for the design of PEFTs.
Knowledge - awareness for combined hazards	Use of modelling tools, such as the one presented, to raise awareness on the interactions among wildfires - extreme storms - floods - protection works

Figure 5: An illustration of the values-rules-knowledge perspective on the decision context of those responsible for flood risk management in Kineta. The separation of the systems of v, r, and k on the left-hand side illustrates the prevailing situation where PEFTs are not seen by decision-makers to be credible or legitimate and policies don't exist to prioritise their adoption. The overlapping v, r and k on the right-hand side illustrates

the situation where the simulation modelling insights about flood risks and suggested PEFTs for the Kineta case study are being effectively considered in policies and inform investment priorities.

The combined use of the modelling insights and the VRK application can assist decision-makers in recognising the need to focus on certain actions required to alter the boundaries of their decision context (i.e., increase the VRK overlap) to achieve the necessary adaptations (in this case, the PEFTs) for coping more effectively with the changed hazard risk profile (Fig.5).

As indicated above, there are several notable examples demonstrating the application of the VRK model with a range of government and non-government stakeholders in Australia and globally (Gorddard *et al* 2016, Dubo *et al* 2023, Fleming *et al* 2017, Colloff *et al* 2020). We believe that it is likely that Greece can also adopt such approaches, and utilize combined modelling-governance insights in stakeholder participatory approaches. Recently, in Greece, the municipal authorities of the second largest city and its metropolitan area – Thessaloniki (1.1 million) - have made significant efforts to engage citizens in disaster risk reduction and resilience planning in the region (World Bank, 2018). However, more coordinated policies must be established by local, state, and national governments, as well as the private sector, focusing on redirecting funding mechanisms towards resilience planning, informed by deeper understanding of the VRK dynamics of the decision-making contexts of relevant stakeholders.

4. Concluding Remarks

In this study, we integrated two methodologies developed independently in different nations, both aimed at addressing the common challenge of post-wildfire flooding. The post-wildfire flood modelling framework, including insights for the design of PEFTs, was conducted in Greece to evaluate combined hazards and offer guidance on protection measures. However, this analysis alone cannot guarantee the implementation of the proposed measures or any other type of flood protection. The situation has revealed that policymakers did not invest in preventative measures nor compensatory actions after disasters occur. The Australian experiences of consultation with local and state governments, informed by the values-rules-knowledge model of decision contexts, have led to the collaborative development of comprehensive risk assessments, adaptation plans, and investment strategies. Again, this approach alone, lacks the modelling explicability that can show the effects of the wildfires to floods, the storm and flooding behaviours, and the detail in the specific measures proposed.

This paper proposes a holistic approach to effective flood risk assessment and mitigation planning, combining sophisticated technical modelling capability within a governance and decision-sciences framework. The proposed combination of advanced modelling and decision frameworks can be useful for similar regions that need to overcome obstacles in a structured way to face such hazards effectively. Due to the inherent uncertainties associated with future disaster risks and responses, there will always be a policy-making debate on “prevention versus cure”, and contestation about the problem and solutions. Building resilience to future similar hazards requires a fundamental shift in how knowledge about problems and solutions is viewed, produced, and used. We believe that a key point here is the awareness of extreme and combined hazards as a regular situation that policymakers should seriously address, supported by model-based assessments. To effectively confront complex problems like post-wildfire flood risks, researchers and policy makers shall co-develop and apply tools and frameworks to generate policy-relevant and scientifically robust insights. This urgency cannot be understated due to the high and growing stakes as climate change speeds up and exposure levels continue to grow.

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