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A METHODOLOGICAL APPROACH FOR FLOOD RISK MANAGEMENT IN URBAN AREAS: THE VOLOS CITY PARADIGM

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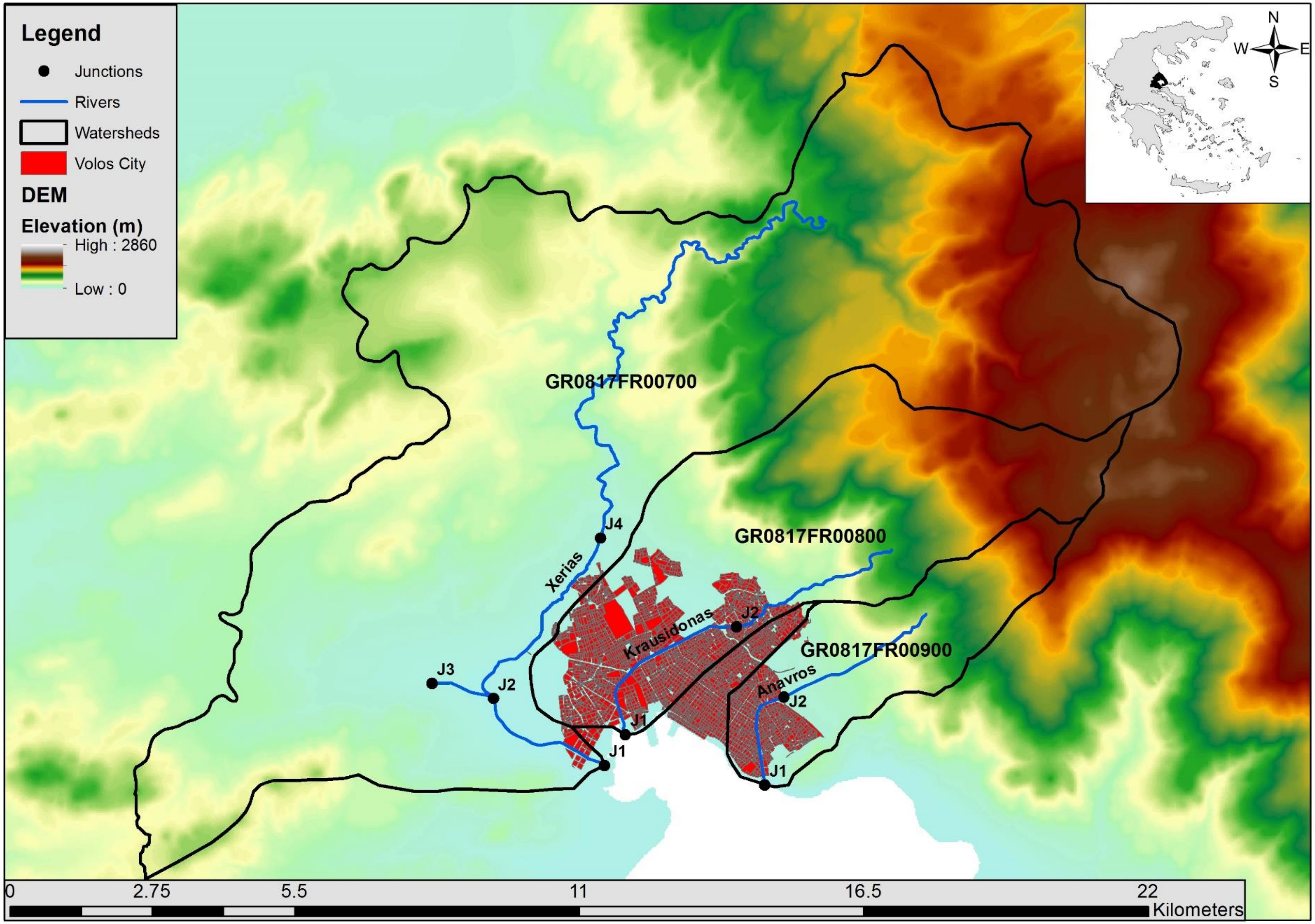
OBJECTIVES

- Establishing **flood hazard** and **flood risk** maps showing the potential adverse consequences to human health, the environment, cultural heritage and economic activities, for three characteristic design return periods (T = 50, 100, 1000 years).
- **Modelling framework**:
  - Event-based deterministic approach, comprising three modelling components:
    - (a) synthetic storm generator;
    - (b) hydrological simulation model; and
    - (c) hydraulic simulation model.
  - Key assumption: Flood risk is determined in terms of return period of input rainfall.
  - Final outcome: Flood risk maps (one for each return period), corresponding to the "average" hydrological scenario and its uncertainty bounds (upper, lower).

FLOOD MODELLING APPROACH

- The study area has been divided into 3 river basins, each one represented through conceptual semi-distributed modelling schemes, comprising sub-basins, reaches and junctions.
- **Hydrological analysis** across each river basin, using the HEC-HMS software;
- **Hydraulic analysis** along selected reaches (specifically, those crossing flood prone zones), using 2-D numerical schemes of HEC-RAS.
  - Input of the hydrological simulation of each sub-basin was the synthetic hyetograph of each return period of interest (using the alternative blocks method, for T = 50 and 100 years, and the worst profile method, for T = 1000 years), while input for the hydraulic simulation of each reach of interest was the simulated hydrograph of the corresponding upstream junction.
  - The method uses as overall input intensity-duration-frequency (IDF) relationships, referred to the sub-basin scale, which have been estimated through statistical analysis of the observed extreme rainfall data across the broader study area (Koutsoyiannis, 2004; Papalexiou & Koutsoyiannis, 2013).

STUDY AREA: THE EXAMPLE OF VOLOS CITY

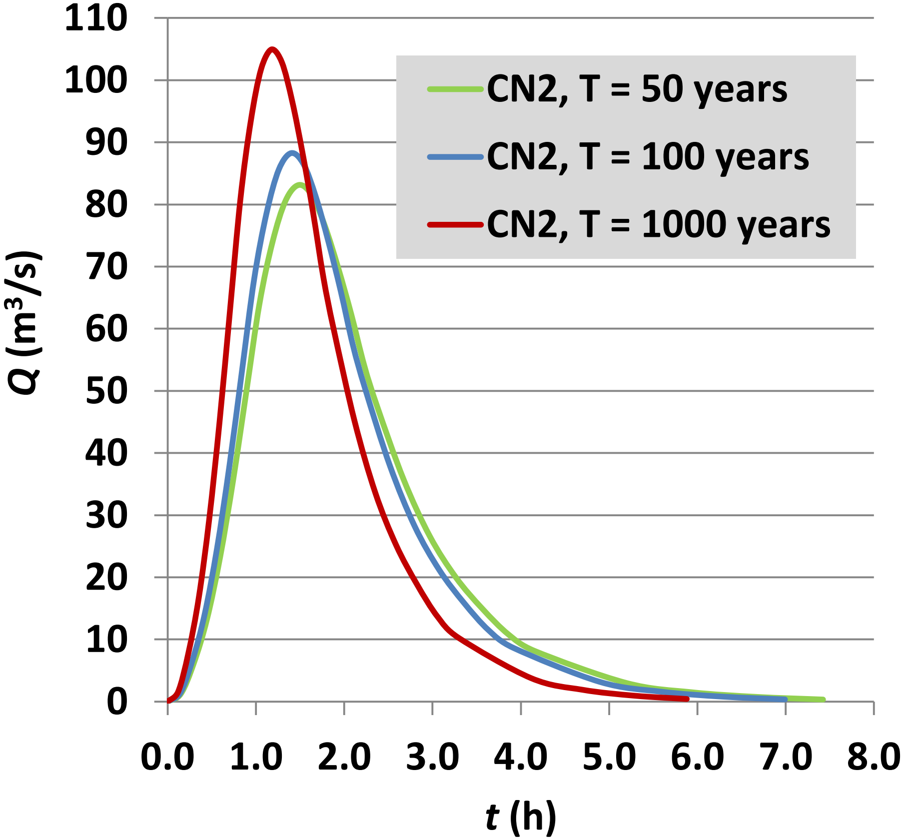


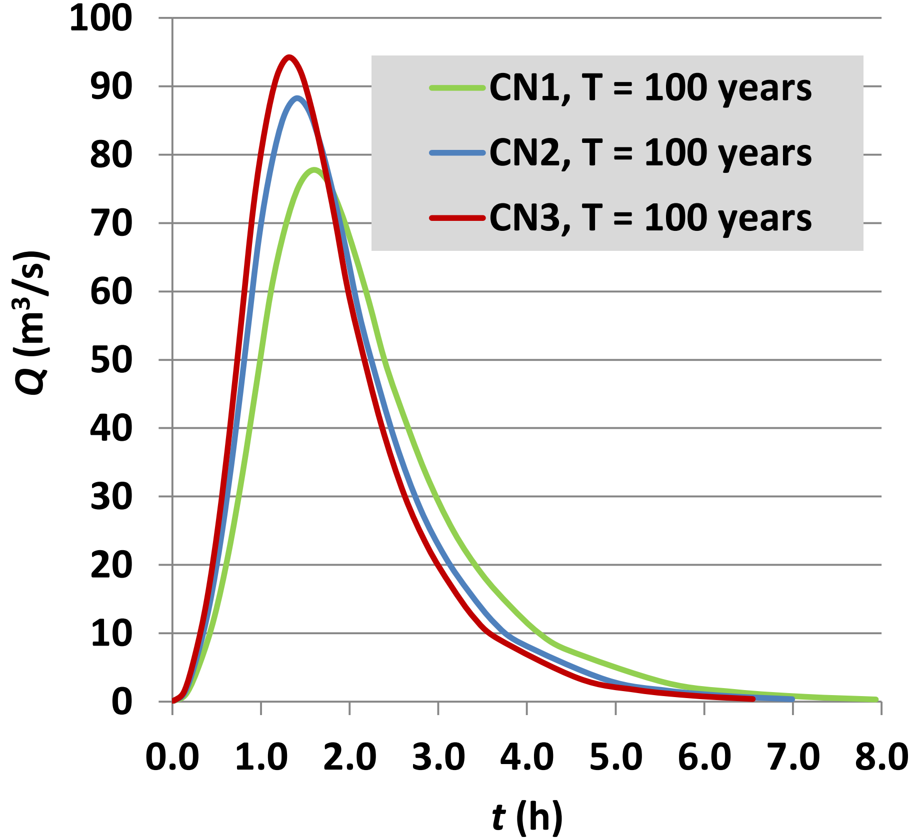
HYDROLOGICAL MODEL ASSUMPTIONS

- We used the **SCS-CN method** to estimate the **effective rainfall** at the sub-basin scale, considering **three hydrological scenarios** per **return period**. **Scenarios** are determined by combining **three** (i.e., dry, average, wet) antecedent soil moisture conditions (AMC), resulting to different CN values, and the rainfall intensities provided by the IDF relationship and its 80% confidence limits, which are measure of rainfall uncertainty.
  - The 20% lower rainfall estimation limit was assigned to CN1 and the 80% upper to CN3, thus representing the joint uncertainty associated with the rainfall parameters λ′ and ψ′, and the key hydrological parameter, CN, which is actually a random variable (Efstratiadis et al., 2014).
- Inflows to the river network are the hydrographs generated across the river basin, which are estimated by propagating the effective rainfall by each sub-basin to its outlet junction, via the unit hydrograph theory.
  - We applied the dimensionless synthetic unit hydrograph (SUH) by SCS, that uses as sole input the time of concentration, tc, of each sub-basin.
  - In order to account for the dependence of flow velocity to discharge, tc was considered decreasing function of rainfall

HYDROLOGICAL MODEL ASSUMPTIONS

Adjustment of unit hydrograph for different return periods (left) and different CN values, associated with different hydrological scenarios (right).



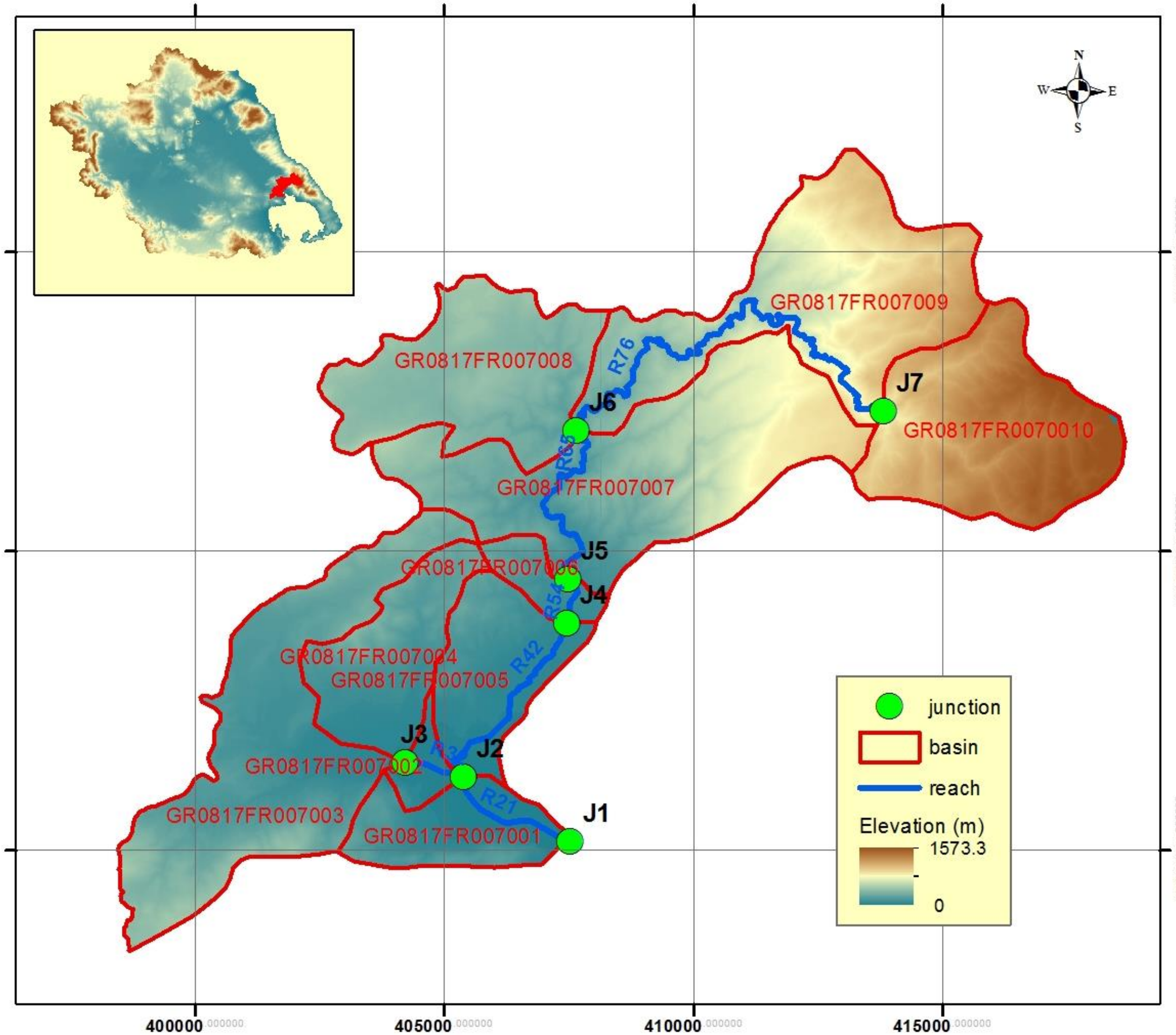


Semi-distributed hydrological modelling

- Xerias river basin of (116.8 km^2), which originates from Pelion and drains the southern part of the City of Volos, often causing severe floods.
  - The basin is divided into 10 sub-basins that exhibit significant heterogeneity, since their CN2 values (corresponding to AMC-II conditions) range from 50 to 82, while their 24-h rainfall depths for T = 100 years range from 198 to 253 mm.
  - The river network is represented by means of 7 junctions and 6 reaches, with average slopes ranging from 5.0% (upper course) to 0.3% (lower course).
  - In order to provide realistic estimations of the timing of hydrograph arrivals across the river network, which are inputs to the hydraulic simulation model, we employed simplified hydrological routing approaches, particularly the lag routing method, for relatively steep slopes (>1%), and the Muskingum method, for milder slopes.

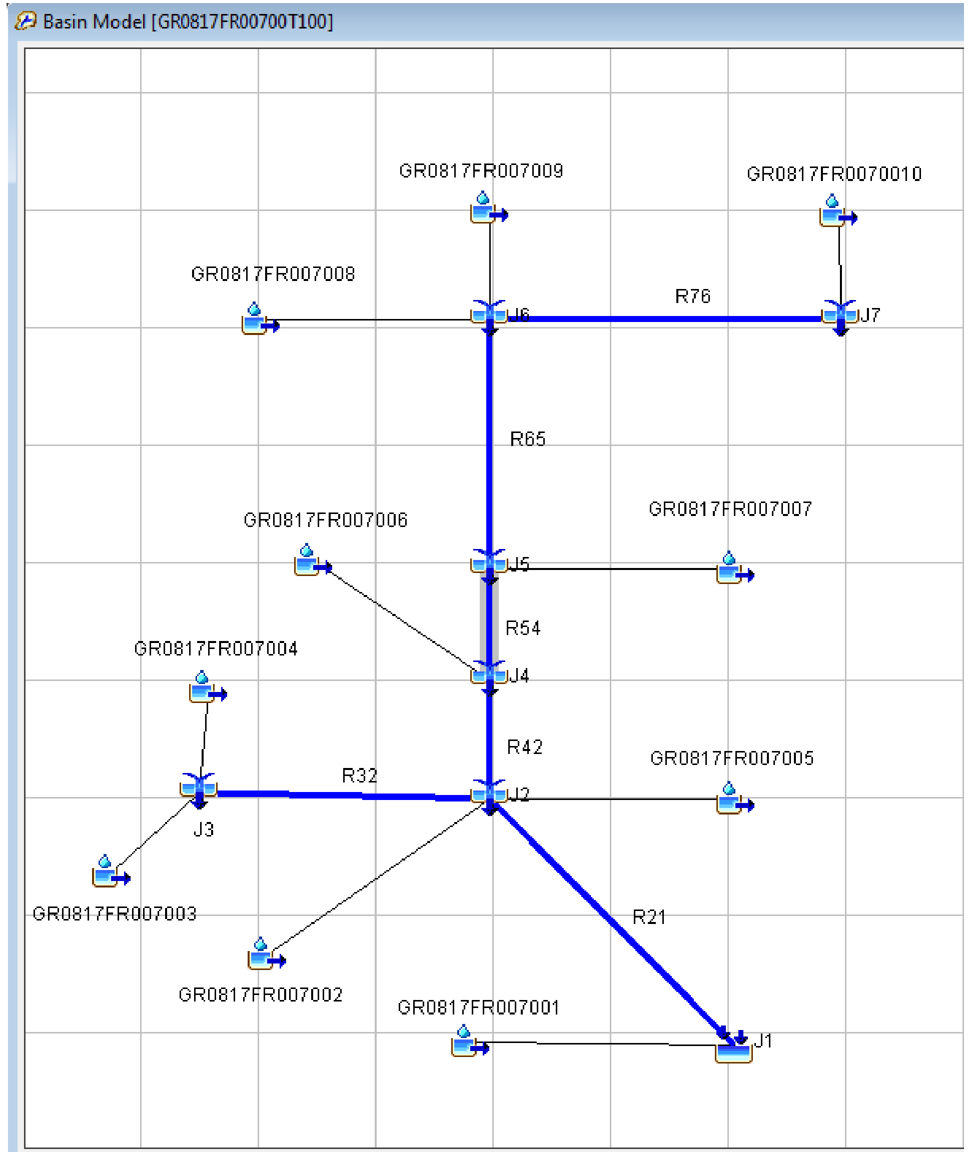
Semi-distributed hydrological modelling

Elevation map of Xerias river basin and modelling components (sub-basins, junctions, reaches).



Semi-distributed hydrological modelling

Representation of modeling components of Xerias river basin in the HEC-HMS environment



Semi-distributed hydrological modelling

Synoptic results at Xerias basin scale for the 3×3 = 9 scenarios, highlighting the uncertainty associated with rainfall-runoff modelling

Return period (years)	Lower rainfall scenario & dry AMC (CN1)	Normal rainfall scenario & average AMC (CN2)	Upper rainfall scenario & wet AMC (CN3)
		Total rainfall depth (mm)	
T = 50	162.6	189.3	213.1
T = 100	177.9	215.5	251.7
T = 1000	222.9	315.2	431.3
		Total flood depth (mm)	
T = 50	20.7	79.7	146.9
T = 100	26.3	99.4	182.9
T = 1000	45.9	181.0	355.8
		Runoff coefficient of flood event	
T = 50	0.127	0.421	0.689
T = 100	0.148	0.461	0.727
T = 1000	0.206	0.574	0.825
		Peak discharge (m^3/s)	
T = 50	81.8	414.2	820.4
T = 100	108.4	543.1	1063.6
T = 1000	357.4	1265.9	2287.9
		Flood runoff volume (hm^3)	
T = 50	3.859	10.744	18.602
T = 100	4.663	13.199	22.958
T = 1000	7.479	23.270	43.681

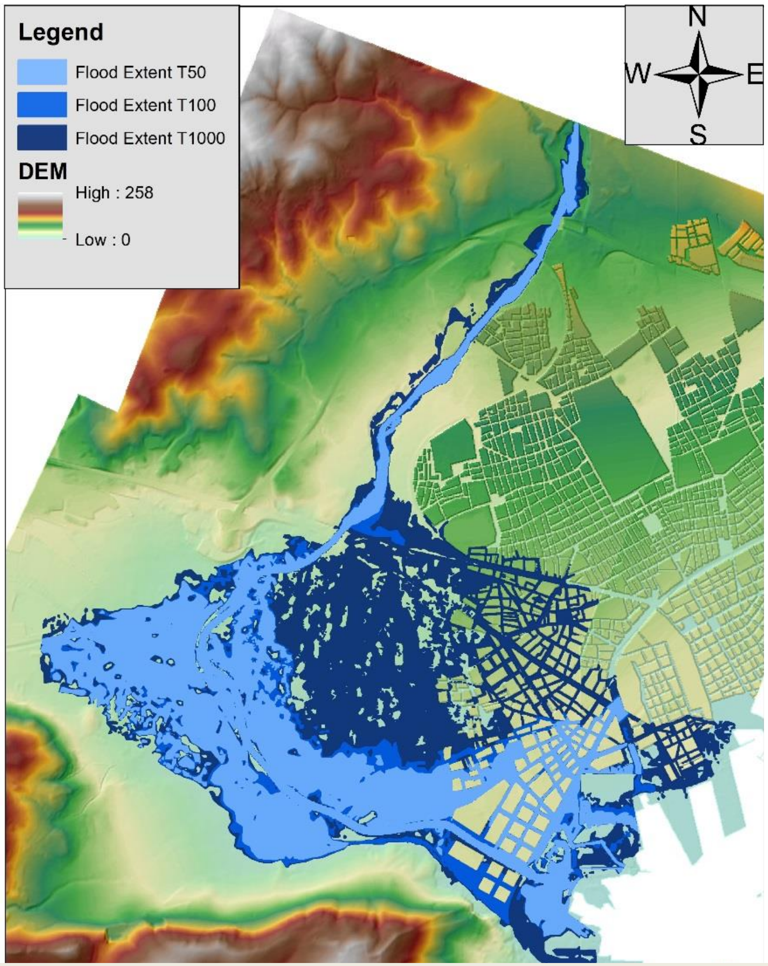
Hydraulic modelling of Xerias river basin

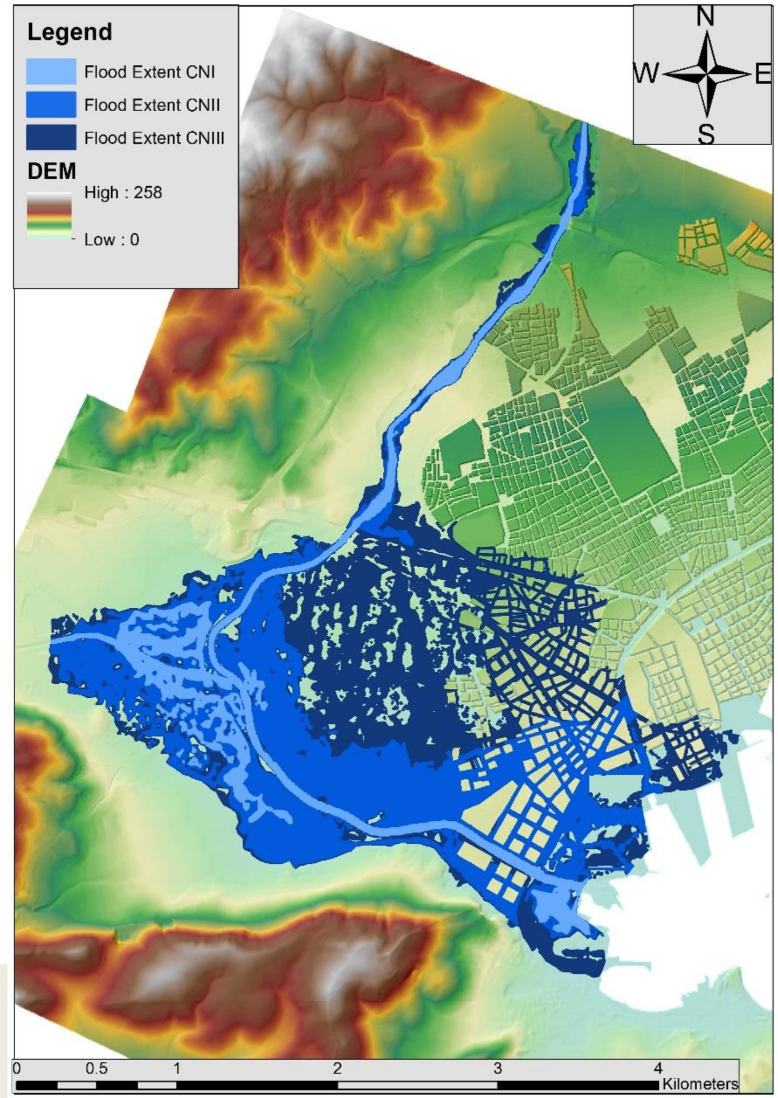
- The model domain extends downstream of junction J4, and involves three reaches (R42, R32, R21), crossing **urban areas** of Volos.
- **Historical flood inundation data** were used for validation of the methodology (Papaioannou et al., 2015) and evaluation of alternative hydraulic modelling approaches (Dimitriadis et al., 2016; Papaioannou et al., 2016). We used the HEC-RAS 2D model with:
  - Flexible mesh size (average 14 m)
  - 2D diffusion wave solution
  - Computation interval 2 s
- The input DEM was created by employing aerial imagery techniques with 5 m cell size, while buildings over urban areas were represented via the elevation rise method.
- Flood mitigation works have been merged with DEM, and the rest technical infrastructures (bridges, etc.) have been processed through specific modules that are available in the HEC-RAS platform.

Hydraulic modelling of Xerias river basin

- Inputs of hydraulic modeling were hydrographs provided by average hydrological simulation scenarios, using "average" roughness coefficients that were estimated according to CORINE 2000 land use classes.
- For all return periods, apart from the hydrographs provided by the lower and upper scenarios, we also perturbed the roughness values by -50% and +50%, respectively, to obtain overall uncertainty bounds of inundated areas and associated hydraulic quantities, i.e. water depths and velocities.

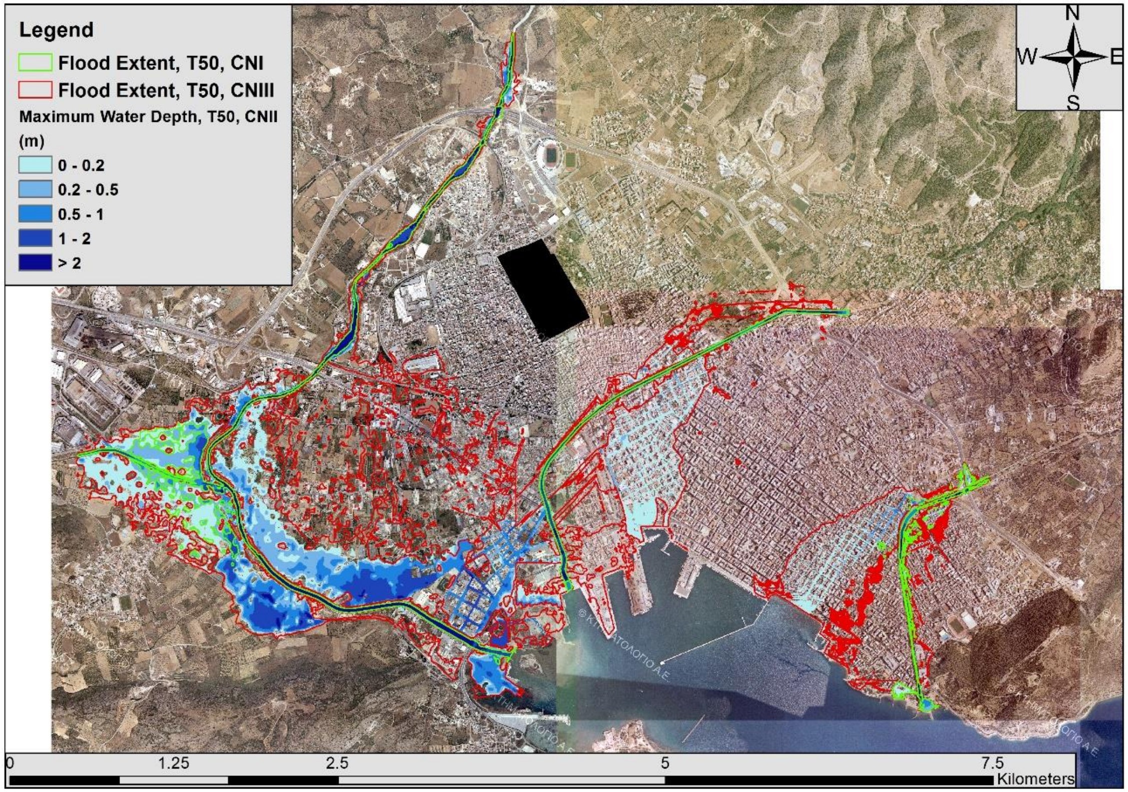
Hydraulic modelling of Xerias river basin



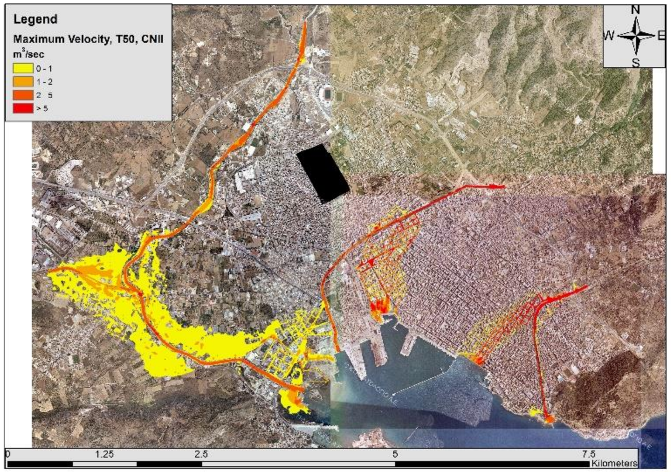


Flood extent of all return periods (T = 50, 100 and 1000 years), by employing the average hydrological scenario with average roughness coefficients (left), and overall uncertainty bounds of flood extent for T = 100 years, considering the most favorable and unfavorable combinations of input rainfall, soil moisture conditions and roughness coefficients (right)

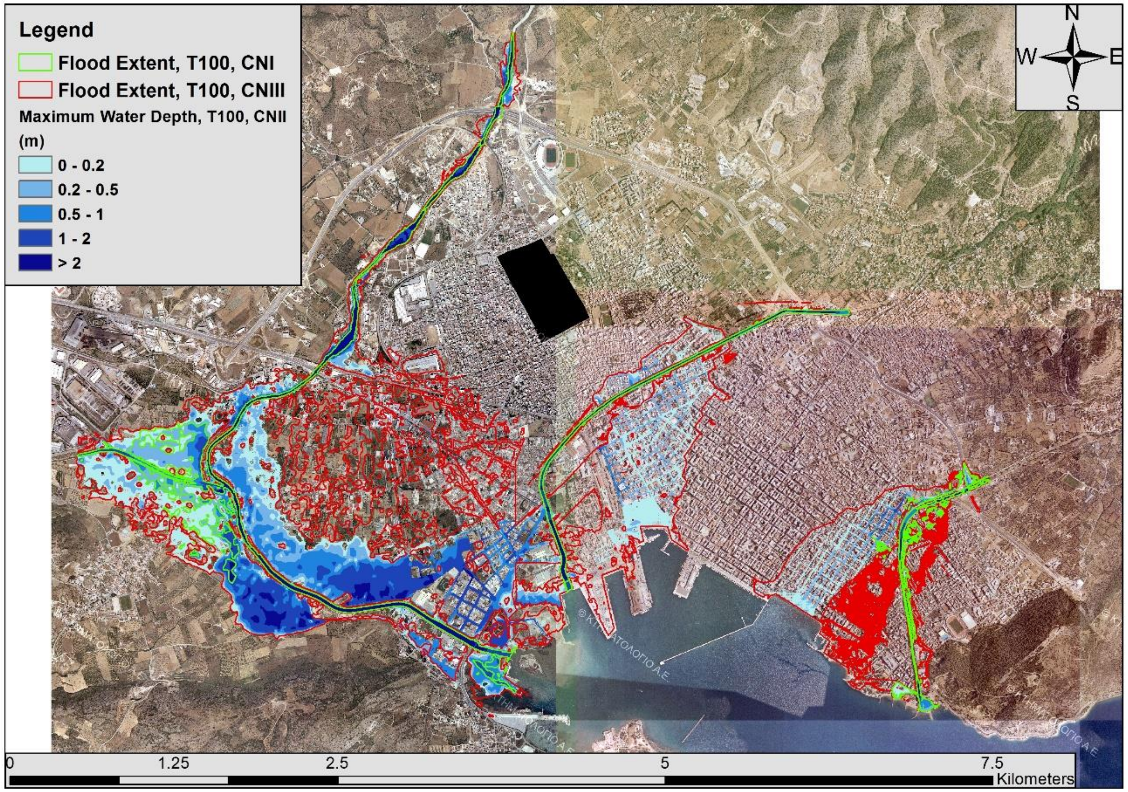
Volos City: Hydraulic modelling results



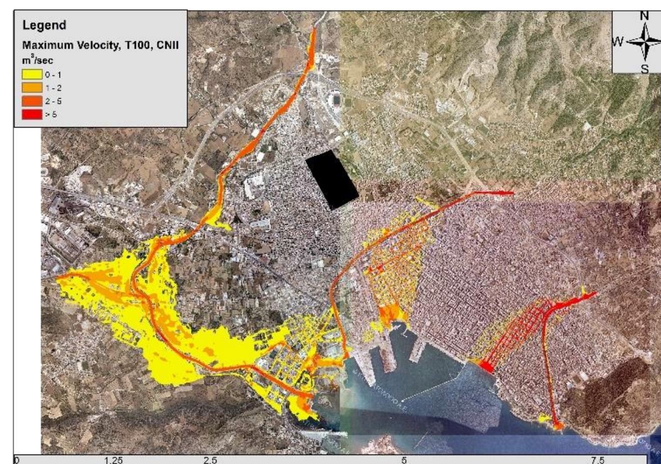
Flood extent and water depths of return period T = 50 years for all configurations of input rainfall, soil moisture conditions and roughness coefficients (up) and simulated velocities (down) only for average moisture conditions (CNII)



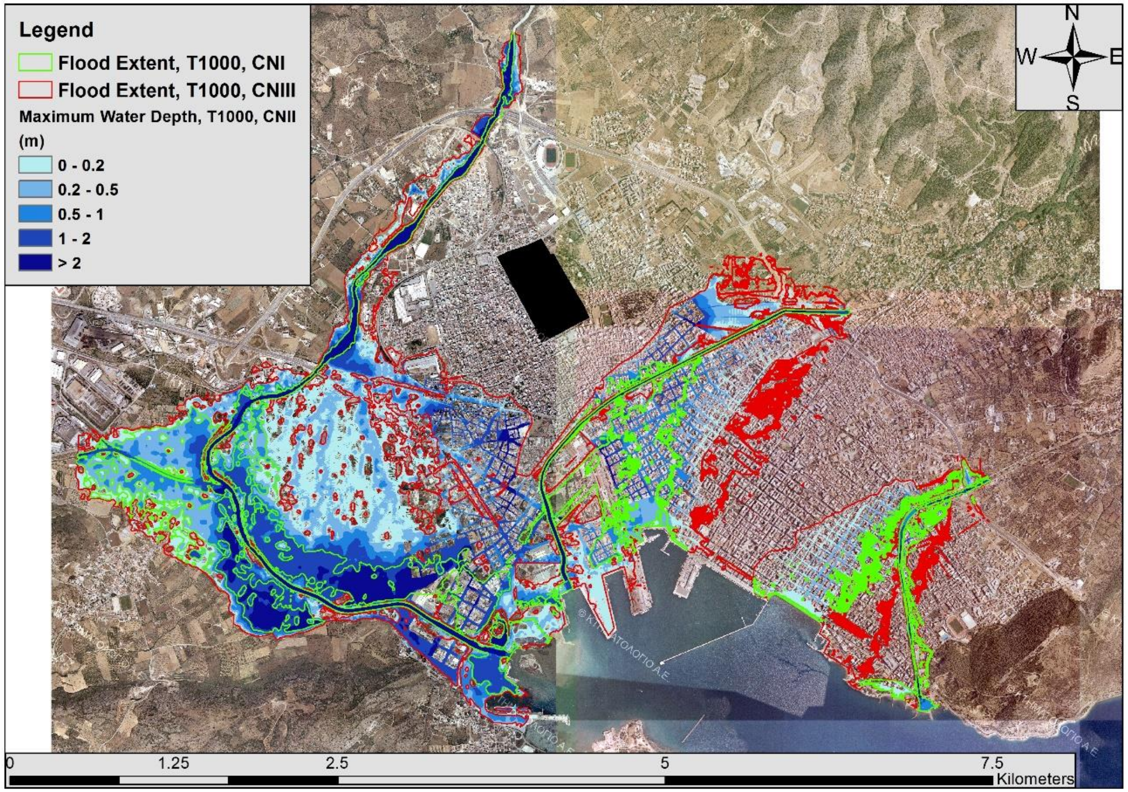
Volos City: Hydraulic modelling results

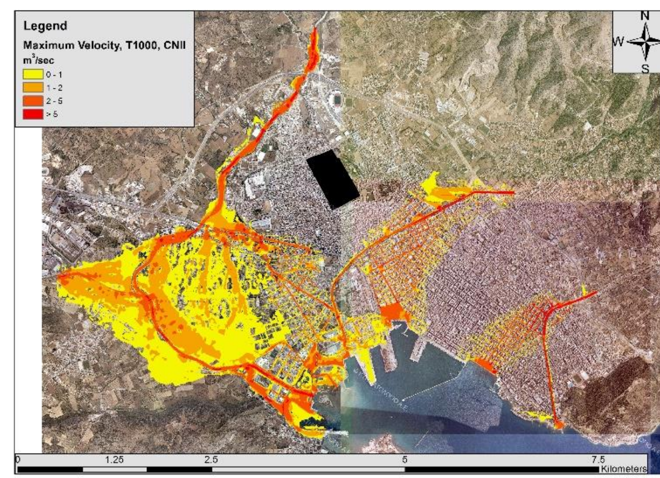


Flood extent and water depths of return period T = 100 years for all configurations of input rainfall, soil moisture conditions and roughness coefficients (up) and simulated velocities (down) only for average moisture conditions (CNII)



Volos City: Hydraulic modelling results





Flood extent and water depths of return period T = 1000 years for all configurations of input rainfall, soil moisture conditions and roughness coefficients (up) and simulated velocities (down) only for average moisture conditions (CNII)

Volos City: Hydraulic modelling results

Flooded areas (km^2) per river reach and total flooded extent of Volos city for all examined hydrologic and hydraulic scenarios at the selected return periods

Code	River Name	Conditions	T=50 years	T=100 years	T=1000 years
GR0817FR00700	Xerias	Dry (CNI)	0.42	0.49	1.79
		Average (CNII)	2.15	2.63	4.84
		Wet (CNIII)	3.69	4.49	6.33
GR0817FR00800	Krafsidonas	Dry (CNI)	0.085	0.087	0.75
		Average (CNII)	0.34	0.45	0.99
		Wet (CNIII)	0.93	1.34	2.91
GR0817FR00900	Anavros	Dry (CNI)	0.068	0.081	0.21
		Average (CNII)	0.21	0.25	0.33
		Wet (CNIII)	0.77	0.82	1.2
Entire Volos city	**Xerias & Krafsidonas & Anavros**	**Dry (CNI)**	**0.57**	**0.66**	**2.76**
		Average (CNII)	**2.68**	**3.32**	**6.01**
		Wet (CNIII)	**5.3**	**6.34**	**9.7**

CONCUDING REMARKS

- A **methodological approach** based on the implementation of the EU Floods Directive in Greece is developed for flood risk management of urban areas.
- **Spatially-distributed design hyetographs** are applied for **2D modelling** of **floods** taking into account **hydrologic** and **hydraulic model uncertainty**. (Spatially-distributed design hyetographs are applied for hydrologic and hydraulic 2D modelling of floods taking into account parametric and structural uncertainty).
- The results indicate the **uncertainty introduced** on **flood risk management** in **urban areas** using **typical engineering practices**.

References

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THANK YOU FOR YOUR ATTENTION!