12th World Congress on Water Resources and Environment (EWRA 2023)
"Managing Water-Energy-Land-Food under Climatic, Environmental and Social Instability"
Thessaloniki, Greece, 27 June - 1 July 2023

Outlining a master plan framework for the design and assessment of flood mitigation infrastructures across large-scale watersheds

P. Dimas[1*], G.K. Sakki[1], P. Kossieris[1], I. Tsoukalas[1], A. Efstratiadis[1], C. Makropoulos[1], N. Mamassis[1], K. Pipili[2]
[1] *Dept. of Water Resources and Environmental Engineering, School of Civil Engineering, NTUA, Athens, Greece*
[2] *ANODOS S.A., Athens, Greece*
* *e-mail: pdimas@mail.ntua.gr*

Introduction

On September 16, 2020, the Hellenic Ministry of Infrastructure assigned to the concessionaire of the Central Greece Motorway E65 the design and construction of supplemental works for the urgent flood protection of areas along the motorway alignment, including the Western Thessaly region (Greece). Considering the damages and losses induced by the Medicane Ianos over the greater Thessaly region the concessionaire, on its own initiative, proclaimed the need for developing a Master Plan for the West Thessaly flood protection. The final area of interest, herein referred to as Western Peneios watershed, occupies approximately 6400 km^2, thus constituting a mega-scale hydrological, hydraulic and water management study that poses multiple conceptual and computational challenges (Papaioannou et al. 2021). The overall question of the Master Plan is to provide a synthesis of already proposed as well as new projects (dams, embankments, ditches), and prioritize them under a multipurpose prism. The methodological framework is comprised of three axes: (i) a preliminary assessment of specific areas where high risk is expected due to flood phenomena, by utilizing a GIS-based multi-criteria decision analysis approach, (ii) a semi-distributed representation of the rainfall-runoff transformations and the flood routing processes across the entire watershed, and (iii) a coupled 1D/2D hydrodynamic simulation of the flood prone riverine system, also including a highly complex system of artificial channels. The final planning prioritizes the strengthening of flood protection in the study area through the combined influence of a set of large-scale projects, i.e., dikes, multi-purpose dams (permanent reservoirs) and retention basins of controlled inundation (temporary reservoirs). The objective is to sketch a framework for facing similar studies in a holistic manner, while maintaining a high level of computational efficiency and explainability.

Materials and methods

The first pillar of the methodology consists of an efficient way to make a preliminary assessment of the areas where a high flood risk is expected utilizing simple geospatial criteria, by following Allafta and Opp (2021). In this vein, we first compile eight thematic layers, i.e.: (i) mean annual rainfall, (ii) distance from river network, (iii) elevation, (iv) terrain slope, (v) land use/land cover, (vi) drainage network density, (vii) soil permeability, and (viii) hydrolithology. Based on experts' knowledge, the highly heterogeneous information of these layers (either quantitative or qualitative) is "translated" into flood susceptibility scores, from 1 (very low) to 5 (very high). Eventually, we produce an overall flood susceptibility map, as a weighted overlay of individual layers, which is the guide for employing the detailed hydrodynamic analysis. Characteristic snapshots are shown in Figure 1.

The hydrodynamic analysis across the flood prone areas is driven by design flood hydrographs that are produced through a hydrological simulation model (2nd methodological pillar) that runs over the entire watershed. The representation of the generation and routing mechanisms of flood flows is based on a semi-distributed discretization of the hydrological system, by formulating a network-type model consisting of nodes, stream/river branches, and sub-basins. The configuration of the complete rainfall-runoff system includes 212 nodes, 210 branches and 306 sub-basins, thus composing a mega-scale case study. The event-based approach, following the combined NRCS-CN and synthetic unit hydrograph methods is applied: the first implements the transformation of the design storm event over each sub-basin into flood runoff, while the second implements its routing to the corresponding outlet node. Next, the point hydrographs through all sub-basins are synthesized and propagated along the hydrographic network by applying a novel conceptual approach that allows assigning travel time parameters on the basis of macroscopic properties of the river system (Efstratiadis et al. 2022). The computational implementation is employed through HEC-HMS software, allowing the representation of major hydraulic structures (i.e., reservoirs, spillways, gates).

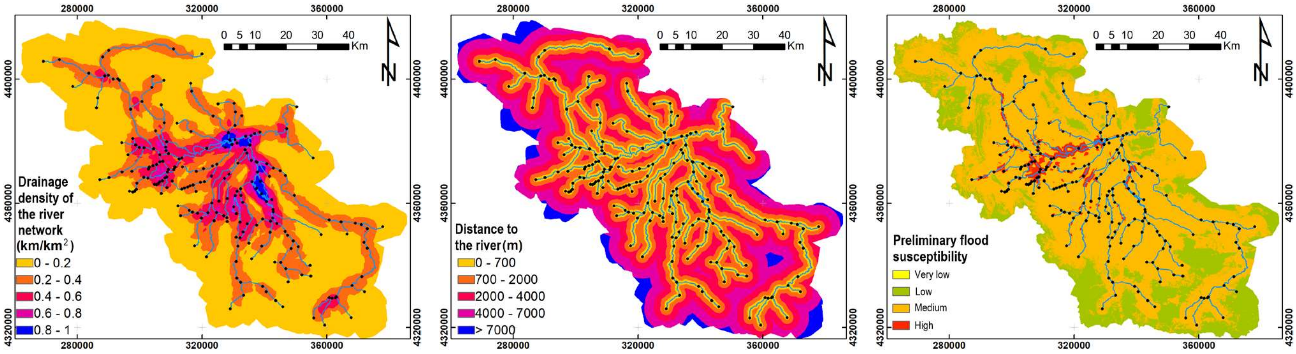

Figure 1. Two out of eight thematic layers used in assessing the flood prone areas in Western Thessaly (left: drainage density, middle: distance from river network) and final map of preliminary flood susceptibility (right).

The final pillar of the methodology aims at disclosing the inundation mechanisms in the areas of interest through hydrodynamic analysis. In this context, we use the HEC-RAS software, by performing coupled 1D-2D simulations (Brunner et al. 2015). Emphasis is given on representing the flow exchange mechanisms from the main river channels (within the banks and/or dikes) to the broader floodplains and vice versa. This is employed using lateral structures that control the overflow dynamics. Automated procedures and interfaces of HMS and RAS with the data processing system HEC-DSS are developed in R environment.

Results and concluding remarks

The simulations through the combined hydrological-hydrodynamic modelling scheme are performed by considering a set of storm events for a return period of 100 years. Initially, this scheme is used to represent the current status of the system. Next, we inspect several planning scenarios, involving the development of three types of flood mitigation works, namely: (a) dikes, along parts of the lower channel network, (b) six new multi-purpose reservoirs in the upstream, mountainous, parts of the watershed, and (c) nine retention basins in the middle and downstream parts, extending over 390 km^2 of agrarian land. Regarding the operation of reservoirs (existing and planned), a critical assumption is their storage conditions at the beginning of the flood event. In this vein, we examine two sub-scenarios, i.e., considering them full or assuming a buffer storage equal to 15% of their capacity.

Our analyses reveal the effectiveness of the combined scheme of the different flood mitigation works, and particularly the role of good management practices of reservoirs. The full development scenario ensures significant retention of the flood volumes and attenuation of flood peaks, as well. In particular, the reservoirs can store 65 out of 150 hm^3 produced in their upstream sub-basins, and the larger ones decrease flood peaks up to 75-95%. An important amount of about 56 hm^3 can also be temporarily retained in the closed basins, most of which is diverted from the adjacent channel network. Their performance may also be further improved by installing control structures along the dikes (e.g., lateral gates), to better manage the arriving flood flows.

References

Allafta, H. and Opp, C. (2021) 'GIS-based multi-criteria analysis for flood prone areas mapping in the trans-boundary Shatt Al-Arab basin, Iraq-Iran'. Geomatics, Natural Hazards and Risk 12(1):2087–2116

Brunner GW et al. (2015) Combined 1D and 2D Hydraulic Modeling within HEC-RAS. World Environmental and Water Resources Congress, May 17–21, 2015, Austin, TX, pp 1432–1443

Efstratiadis A et al. (2022) Revisiting Flood Hazard Assessment Practices under a Hybrid Stochastic Simulation Framework. Water 14(3):457

Papaioannou G et al. (2021) A Flood Inundation Modeling Approach for Urban and Rural Areas in Lake and Large-Scale River Basins. Water 13(9): 1264