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Flood Directive implementation in Greece: Experiences and future improvements

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Abstract: The implementation of the European Directive 2007/60 is a crucial step towards the development of a sophisticated flood management plan for the main River Basin Districts by including any necessary structural measures. For this reason, extensive hydrological and hydraulic analysis is needed under the ubiquitous uncertainty which cannot be eliminated by numerical models. In this study, we present our experience from the directive implementation and we discuss structural components of uncertainty in the flood modelling practice mostly related to the river network. We propose and review some of the most efficient engineering practices by examining issues like: (a) the consistency and accuracy of the required input data of the topography such as the Digital Elevation Model, cross-sectional measurements of the river and maps of land use; (b) the uncertainty components related to the hydrological SCS-CN framework and other hydrological methods for the determination of the input hydrograph; (c) the theoretical framework of each hydraulic model such as the scheme dimension (1d, 2d or coupled 1d/2d), the type of solution of the numerical scheme (explicit or implicit), the boundary conditions and the type of discretization (grid or section-based); (d) the uncertainty components related to the flood inundation modelling, such as the roughness coefficient at the river and floodplain; (e) the necessity of validation data such as the flow discharge, the flood inundation area, and the velocity measurements.

Key words: European Directive 2007/60; flood modelling, uncertainty, river geometry, roughness coefficient

1. INTRODUCTION

The optimum design of flood protection works has been the primary target in Europe due to the occurrence of extreme flood events in the last decades (Tsakiris et al. 2009). However, the large uncertainty in the prediction of flood inundation extending from the hydrological and hydraulic input (Efstratiadis et al., 2014) to the inundation algorithms (Dimitriadis et al., 2016) has shifted the primary target to flood risk management rather than protection as described in the EU Directive 2007/60 (Mostert and Junier, 2009). The Directive implementation highlights the need to quantify the uncertainty of the most important parameters included in the estimation of the flood risk and hazard maps, and by also offering the opportunity, through the experiences gained and identified difficulties, to suggest possible improvements. In this study, we present our experience from the directive implementation in a main River Basin District (Central Makedonia GR10). We present our methods used to construct the flood maps for high flood risk zones (Fig. 1) and how we tackle several practical issues mostly related to: (a) the consistency and accuracy of the required input data of the topography such as the Digital Elevation Model, cross-sectional measurements of the river and maps of land use (section 2.1); (b) the uncertainty components related to the hydrological SCS-CN framework and other hydrological methods for the determination of the input hydrograph (section 2.2); (c) the theoretical framework of the hydraulic models used, e.g., the 1d HEC-RAS or quasi-2d FLO-2d, such as the scheme dimension, the type of solution of the numerical scheme, i.e., implicit and explicit, respectively, the boundary conditions and the type of discretization, i.e., section-based and grid-based, respectively (section 2.3); (d) the uncertainty components related to the flood inundation modelling, such as the flow hydrograph (Di Baldassarre and Montanari, 2009) and roughness coefficient of the river and floodplain; (e) the necessity of validation data such as the flow discharge, the flood inundation area, and the velocity measurements, so as to be able to verify the model output but to also justify any adopted assumptions related to the input parameters and methods. Additionally, in section 3, we present two applications, one following the standard methodology for the construction of flood risk maps and one including a sensitivity analysis for the most uncertain river parameters, in case of limited or inadequate information of the river geometry and surface material, an common case in Greece as compared to other European countries. Finally, in section 4, we conclude our analysis and we discuss on the structural components of uncertainty in the flood modelling practice along with suggestions for a possible future improvement.

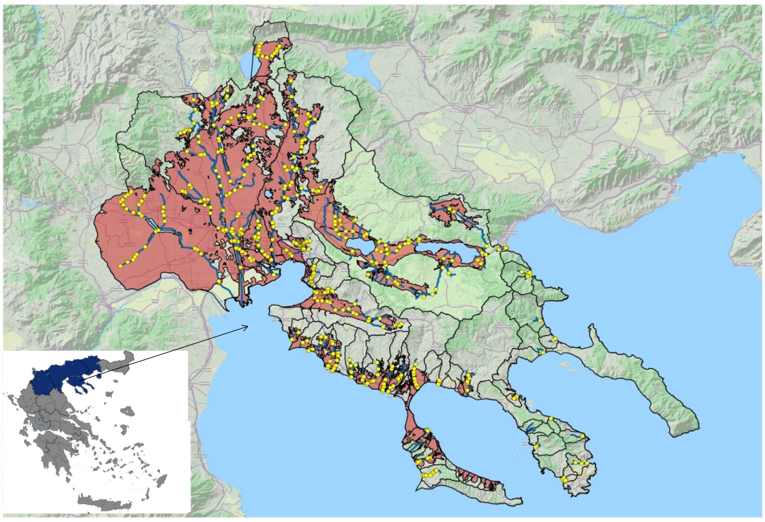

Figure 1. High risk flood zones (purple areas), technical works (yellow points) and river network (blue lines) of the GR10 basin located at central Makedonia, Greece.

2. EFFICIENT ENGINEERING PRACTICES

2.1 Topographical input data

Topographical data is one of the preliminary input data for the hydrological and hydraulic study of a river basin. It describes the morphology of the study area and therefore, all model output and plotted maps are highly dependent on the accuracy of the land survey. For a detailed analysis on the sensitivity of the spatial resolution and method to the flood inundation modelling can be seen in Papaioannou et al. (2016). Usually, for the floodplain area a coarse Digital Elevation Map (DEM) is used, whereas for the area along and at the banks of the river a more detailed survey is usually acquired. In the current study, the applied DEM is provided by the National Cadastre and Mapping Agency S.A., with a pixel size of 5x5m^2. An important feature is that the analysis of the DEM is more accurate near the coastline where there is a potentially higher flood risk. Particularly, in these areas a finer pixel size is often used, i.e., 1x1m^2.

In order to improve the uncertainty of the DEM, actual field topographical measurements are conducted, especially near the river network (i.e., cross-sections), at areas of environmental importance and interest, and near technical works (Fig. 1), such as bridges, levees, dams etc., that are of great importance for the flood risk management. Another way to improve the accuracy of the DEM would be to use satellite data extracted from satellite images of larger discreet ability by assigning the pixel size of the imagery, however this method is very expensive since high cost equipment is required. Therefore, the applied DEM in the hydrological and hydraulic analysis is usually reconstructed based on some field measurements obtained from Survey Engineers. Afterwards, the pixel is resized according to the needs of the flood propagation model for the conduction of the hydrological and hydraulic analysis of the river basin. This process is aimed to keep both the stability of the used model and the sufficient spatial resolution for the optimum simulation of the hydrological process and the spatiotemporal evolution of the flood inundation map.

2.2 Hydrological modelling

For obtaining the input flow hydrograph we follow the standard hydrological method of estimating the ombrian curves through the General Extreme Value distribution (e.g., following the methodology described in Koutsoyiannis et al., 1998):

$$i(d) = \frac{a(T)}{(d + 0.076)^{0.686}} \tag{1}$$

where i is the rainfall intensity (mm/hr), d is the rainfall duration (hr), T is the return period (years) and a is a function of T , usually of the form $a_1(T^{a_2}$-$a_3)$, with a_1, a_2 and a_3 parameters determined by the historical rainfall data of the area of interest and the isohyetal map (spatial distribution of rainfall).

Additionally, we estimate the hyetograph through the alternative block method for the return periods of 50 and 100 years (best and moderate case scenarios) and through the worst profile method for the 1000 years return period (worst case scenario). These three scenarios are further processed for the evaluation of the input flow hydrogrpah by a rainfall-runoff model, such as the SCS-CN one implemented through the HEC-HMS (www.hec.usace.army.mil/software/hec-hms/).

2.3 Hydraulic models for flood inundation

After the construction of the DEM and the flow hydrograph, we select the type of the hydraulic model for the flood inundation, i.e., one-dimensional (1d), two-dimensional (2d) or quasi-2d (a brief mathematical description of 1d, quasi-2d and 2d algorithms can be found in Tsakiris and Bellos, 2014). Particularly, in cases where the flooded volume is propagated mostly by the river and not by the floodplain, 1d models are applied (such as HEC-RAS 1d), following the standard procedure of model building, simulation and validation (e.g., Lazaridou et al., 2004). A detailed review on the hydrological Muskingum flood routing models can be found in Koussis (2009) and of the determinants of hydraulic modelling choices for free-surface flow that are based on the interplay between flow characteristics and cross-scale and scale-independent views can be found in Cheviron and Moussa (2016).

In cases where the lateral momentum of the flow is no longer negligible compared to the longitudinal one, a 2d model should be applied. However, since 2d hydraulic models (or of higher dimensions) usually have a larger numerical burden and, as a consequence, are more time-consuming, quasi-2d (or else coupled 1d/2d) models are often preferred (Bates and Roo, 2000; Papaioannou et al., 2016).

After selecting the type of model, the type of discretization (i.e., cross-sectional based or grid-based models), the nature of the numerical scheme (i.e., explicit or implicit or mixed), the boundary conditions (e.g., with the preservation of depth or velocity etc. at the various boundaries; cf. Domeneghetti et al., 2013) as well as various model parameters (with some being physical-based while others behaved as black-boxed) still need to be determined depending on the information we have on the area and on the behaviour of the selected model. All the aforementioned choices will have an effect on the flood inundation output and therefore, on the flood risk management.

2.4 River parameters

An additional advantage of the aforementioned quasi-2d models is that they enable the use of Monte-Carlo analysis, a necessity when the observed and measured data are limited or when the applied parameters, model algorithms and model boundary conditions are expected to be unknown or of high uncertainty. An interesting and unavoidable feature of all models is that they are prone to discretization errors and thus, even if the topography and all the hydrological and hydraulic parameters are well determined, still there would be a fraction of uncertainty related to the selected model algorithm. An illustration of this characteristic based on benchmark experiments (i.e., where the geometry and all parameters related are known in detail) can be found in Dimitriadis et al., (2016). Since the uncertainty components related to the flood inundation are numerous, and even a broad Monte-Carlo analysis could be impractical in terms of time cost, a decision needs to be taken towards the estimation and sensitivity analysis of the parameters with the larger weight of uncertainty at the model output. Such parameters (from the highest to the lowest standardized uncertainty) are the model algorithm, the river roughness coefficient and that of the floodplain (obtained from the land use as instructed by Corine, 2000; http://geodata.gov.gr/en/dataset/corine-2000), the input flow hydrograph, the longitudinal and transverse slope of the river and floodplain and the model resolution (Dimitriadis et al., 2016). Note that the former result is based on specific benchmark experiments, parameter range and model algorithms. Although the river parameters (i.e., roughness coefficient and geometry) seem to have a large effect on the flood inundation, it can sometimes be highly-expensive or even devious to measure them in field, especially in rough topographies of during severe flood events. This can be tackled by applying a sensitivity analysis, as in the case of the flow hydrograph.

2.5 Validation data

The data collection for validation purposes is an important task in flood modelling since, however sophisticated the analysis may be, limited validation could lead to unjustified actions such as model over-fitting, adoption of non-physically-based algorithms and unnecessary use of assumptions with only a minor contribution to the flood risk map. The validation data should include flow hydrographs that initiated particular flood events (e.g., obtained from operational gauging stations), flood inundation maps resulted from these events (e.g., using satellite images), and other important characteristics of the events such as velocity measurements (e.g., through installation of broad river network measuring devices) and roughness coefficients (e.g., from geological surveys). However, since recording in field can be sometimes impractical (or even impossible) during extreme (or even moderate) flood events, especially in rough topographies (and policies) as in Greece, the application of sensitivity analyses (e.g., Horritt and Bates, 2002; Dimitriadis et al., 2016) can be rather crucial.

3. APPLICATION

In this section, we present two applications, one following a standard practice for the assessment of flood risk maps and one including additional components of uncertainty particularly related to the river network.

3.1 Axios river basin with current practices

Following the processes described in previous sections for the Axios river (the longest river crossing the Makedonia basin GR-10), we construct the DEM following the methods explained in sect. 2.1 (e.g., by including information from studies of technical works in the area, land use maps and more detailed topographical surveillances), we estimate the flow hydrographs for return periods of 50, 100 and 1000 years and for a best, moderate and worst case scenario, as described in sect. 2.2. For this particular basin, since a quasi-2d model is required, we select the freeware FLO-2d (www.flo-2d.com/) raster-based model that has an explicit-central finite difference scheme and is more suitable for large grid cell size. In Fig. 2, we present the output flood hazard map for the moderate case scenario.

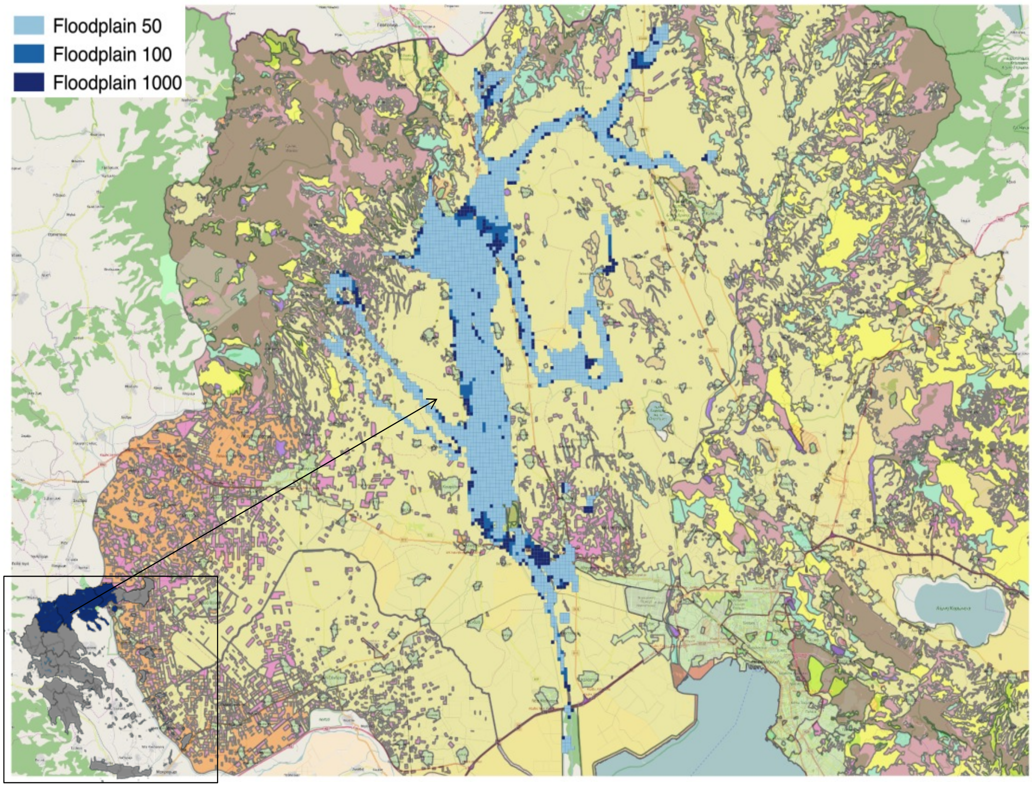

Figure 2. Flood inundation map for the Axios river basin for the moderate case scenario and for various return periods

3.2 Penios river basin with a proposed practice

The 40 km length of a fraction of the Penios river, located at Thessaly in Greece, extends from the Ali Efenti (upstream) to Amygdalia (downstream) gauging station (Fig. 3). In this application, we perform a Monte-Carlo analysis to account for the uncertainty of some additional components often met in ungauged basins and characterized by limited or inadequate information (Efstratiadis et al., 2014), such as the river width, depth and roughness coefficient. We apply the steady flow of 750 m^3/s determined from Oikonomou et al. (2013) as the best fit of an observed extreme flood inundation occurred in 28/1/2003. Thus, we generate 50 synthetic spatial timeseries for each river parameter following a log-normal distribution (Domeneghetti et al., 2013), with mean and standard deviation for the river width and depth as indicated by the DEM and by also preserving the correlation of the original data, and for the roughness coefficient within 0.025–0.03 and with a coefficient of variation 20–35% (Hydraulic Engineer Center, 1986). In Fig. 3, we illustrate how the model simulation can be improved by a sensitivity analysis of the river components. Particularly, the observed but not-simulated area (pink zone) as estimated from the original steady flow scenario can be somehow explained by the uncertainty of the river components (in Fig. 3, we only show the 50% water depth quartile by a brown zone).

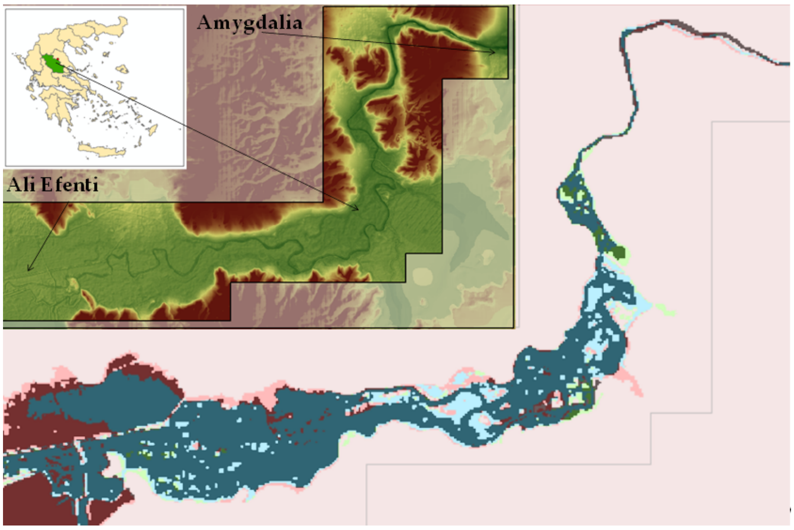

Figure 3. Location and topography of the study area, the best fitted simulated flood inundation for river geometry as estimated from the 5×5 DEM and for a constant 0.03 roughness coefficient (light blue zone is the observed and simulated by the model area, green zone is the non-observed but simulated area, pink zone is the observed but not-simulated area), the brown zone is the 50% water depth quartile, as estimated from the sensitivity analysis, and the dark blue is the mixture of light blue and brown colours.

4. CONCLUDING REMARKS

Some of the most uncertain parameters in flood inundation modelling that are often neglected or inadequately measured are the river geometry and roughness coefficient. While the former is usually obtained from a coarse DEM, the latter, in most cases, is considered as constant for the whole length of the river. In this study, we illustrate how the exerting uncertainty from these sources (along with additional hydrological and hydraulic sources such as input hydrograph and numerical schemes) can be quite large in cases of limited measurements or inadequate information on the river geometry and surface material. Therefore, a proposed engineering practice could be to always perform sensitivity analyses for all the parameters included in the flood risk framework but especially for the ones related to the river network (such as width, depth and roughness).

REFERENCES

Bates, P.D., and De Roo, A.P.J., 2000. A simple raster-based model for flood inundation simulation. J. Hydrol. 236(1), 54–77.

Cheviron, B., and Moussa, R., 2016. Determinants of modelling choices for 1-D free-surface flow and morphodynamics in hydrology and hydraulics: a review. Hydrol. Earth Syst. Sci., 20: 3799-3830.

Di Baldassarre, G., and Montanari, A., 2009. Uncertainty in river discharge observations: a quantitative analysis. Hydrol. Earth Syst. Sci., 13: 913–921.

Dimitriadis, P., Tegos, A., Oikonomou, A., Pagana, V., Koukouvinos, A., Mamassis, N., Koutsoyiannis, D., and Efstratiadis, A., 2016. Comparative evaluation of 1D and quasi-2D hydraulic models based on benchmark and real-world applications for uncertainty assessment in flood mapping. Journal of Hydrology, 534: 478–492.

Domeneghetti, A, Vorogushyn, S, Castellarin, A, Merz, B, Brath, A. 2013. Probabilistic flood hazard mapping: effects of uncertain boundary conditions. Hydrology and Earth System Sciences, 17: 3127–3140.

Efstratiadis, A., Koussis, A. D., Koutsoyiannis, D., Mamassis, N., 2014. Flood design recipes vs. reality: can predictions for ungauged basins be trusted? Nat. Hazards Earth Syst. Sci., 14: 1417–1428.

Horritt, M. S., & Bates, P. D., 2002. Evaluation of 1D and 2D numerical models for predicting river flood inundation. Journal of Hydrology, 268(1-4): 87-99.

Hydraulic Engineering Center, 1986. Accuracy of Computed Water Surface Profiles, U.S. Army Corps of Engineers, Davis, CA.

Koussis, A.D., 2009. Assessment and review of the hydraulics of storage flood routing 70 years after the presentation of the Muskingum method. Hydrological Sciences Journal 54(1): 43-61.

Koutsoyiannis, D., Kozonis, D., and Manetas, A., 1998. A mathematical framework for studying rainfall intensity-duration-frequency relationships, Journal of Hydrology, 206(1-2): 118–135.

Lazaridou, P. L., Daniil, E. I., Michas, S. N., Papanicolaou, P. N., Lazarides, L. S., 2004. Integrated environmental and hydraulic desigh of Xerias river, Corinthos, Greece, training works. Water, Air and Soil Pollution: Focus 4: 319–330.

Mostert, E., and Junier, S.J., 2009. The European flood risk directive: challenges for research. Hydrology and Earth System Sciences Discussions, 6(4): 4961-4988.

Oikonomou, A., Dimitriadis, P., Koukouvinos, A., Tegos, A., Pagana, V., Panagopoulos, P., Mamassis, N., and Koutsoyiannis, D., 2013. Floodplain mapping via 1D and quasi-2D numerical models in the valley of Thessaly, Greece, European Geosciences Union General Assembly 2013, Geophysical Research Abstracts, Vol. 15, Vienna, EGU2013-10366, doi:10.13140/RG.2.2.25165.03040.

Papaioannou, G., Loukas, A., Vasiliades, L., Aronica, G.T., 2016. Flood inundation mapping sensitivity to riverine spatial resolution and modelling approach, Natural Hazards, 83(1): 117–132.

Tsakiris, G., Bellos, V., 2014. A numerical model for two-dimensional flood routing in complex terrains. Water Resour. Manag. 28(5): 1277–1291.

Tsakiris, G., Nalbantis, I, Pistrika, A., 2009. Critical Technical issues on the EU flood directive. Eur. Water, 25-26: 39–51.