Deciphering the Floodplain Inundation Maps in Greece

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Abstract: Floodplain inundation is caused by heavy rainfall, while its evolution depends mainly on land cover and geomorphologic characteristics of the river basins. The aim of this work is to decipher the similarities and differences of flood inundation maps that have been produced for various areas in Greece in the framework of the European Floods Directive (2007/60/EC). The adopted mapping methodology was accomplished through the use of the HEC-HMS software, which simulates the hydrologic processes of river basins and determines the design flood hydrographs for given return periods, as well as the HEC-RAS software, which simulates the hydraulics of open channel flow (computation of energy gradients and piezometric heads). Both packages are compatible with ArcGIS, which can be used for further data processing and visualization for cartographical purposes. The outcome of floodplain inundation mapping is anticipated to help in planning and prioritizing environmental and flood protection actions in a pre-disaster stage. The mentioned multi-methodology has been implemented to a great number of flood prone river basins in Greece. Flood maps, which can depict a variety of parameters, such as flood extent, water depths and piezometric heads for various return periods, were deciphered taking into account the specific characteristics of each area. The values of the aforementioned parameters are dependent on the (a) intense rainfall regime of the area (IDF curves), (b) geometrical characteristics of the river channel (cross sections areas, roughness, slope) and (c) geomorphologic, geological and soil characteristics of the flood plain (land cover, land use, elevations, slopes, soil permeability, hydraulic conductivity etc).

Key words: Flood inundation maps, European Floods Directive, HEC-RAS software, hydrology, hydraulics, geographical information systems.

1. INTRODUCTION

Floods are usually caused by extreme hydro-meteorological processes while their evolution depend mainly on geomorphologic factors, such as soil stability and permeability, vegetation cover, and the geometric characteristics of the river basins. River floods are considered one of the most important natural disasters supporting transition from traditional flood defense strategies to flood risk management approaches at basin scale. The necessity to move towards a risk based approach has also been recognized by the European Parliament, which adopted the new Flood Directive (2007/60/EC) on 23 October 2007. The objective of the directive is to establish a framework for the assessment and management of flood risk in Europe, focusing both on the frequency and magnitude of a flood as well as on the potential adverse effects **(**H**.** de Moel et al., 2009). The main tool for the implementation of this purpose is the production of flood maps, which cover not only the watercourse extent, but also all the inundated areas outside of it. Flood hazard estimation can be done using methods of varying complexity depending on data, resources, and time availability. While there are different approaches, the conceptual framework for flood hazards estimation is quite general and consists broadly of three stages **(**H**.** de Moel et al., 2009).The first stage deals with the discharges' calculation for specific return periods. The second stage (towards developing a flood hazard map) deals with the "translation" of discharges into water levels, something that can usually be done using rating curves or hydrodynamic models. In the final stage, the flooded area is determined by combining the raster of calculated water levels with the corresponding digital elevation model in the study area.

Along these lines, the aim of this work is to develop, in an advanced mode, a multiple framework of disciplines on hydrology, hydraulics and geomatics for creating flood maps for normal and extreme return-periods, always at the river basin scale. In specific, the work presents - step by step - a standardized methodology for the production of flood maps, through the use of open source software, which enables the user to determine the geo-morphological and hydrological features of the river basin, to calculate the design hydrograph for different return periods, to simulate the river systems within the river basin, and finally to estimate and illustrate the floodplain inundation according to Figure 1 (Panagoulia et al. 2012).

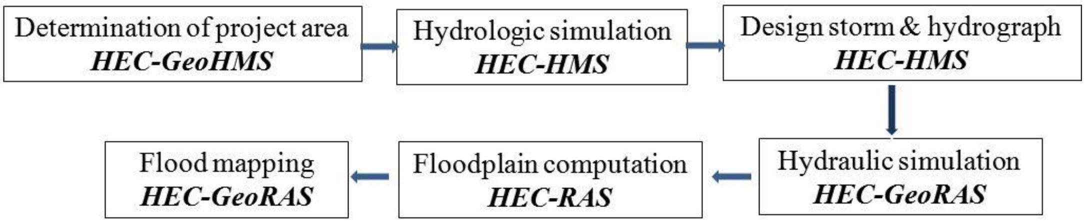

Figure 1. Flowchart for floodplain inundation mapping in HEC-HMS software package (Gkiokas, A., 2009)

In the following sections, this methodology is presented in more details, while in the section of case studies there is a robust compilation of results from model applications within several river basins in Greece.

2. METHODOLOGICAL FRAMEWORK

The whole methodology (Figure 2) is structured upon the basic principles of hydrology and hydraulics, as it involves simulation of watersheds and open channel systems. Hence, two major implementation issues are studied. The first one is the analysis of the river basin in terms of geomorphology and hydrology in order to compute the hydrologic discharge for different return periods and the second one is the detailed hydraulic investigation of the basin streams, which route these discharges. It is clear that the final product (flood maps) is highly dependent on the accuracy of computations which are involved in the above mentioned steps.

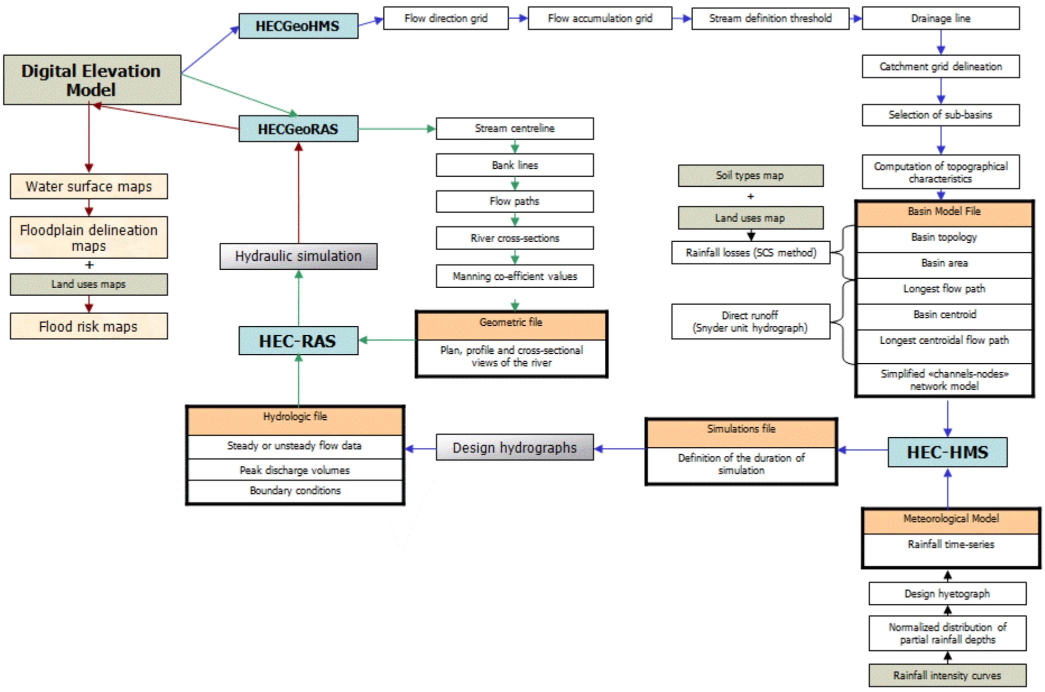

Figure 2. Interactive geomorphologic, hydrological and hydraulic processes in floodplain inundation design (Gkiokas, A., 2009)

Geomorphology and hydrology of river basins

The analysis of a river basin in terms of geomorphology and hydrology aims to determine the design hydrograph for different return periods. For this purpose, a significant range of data should be collected in order to ensure that the simulation of the hydrologic regime is enough precise.

First and foremost, a digital elevation model (DEM) for the study area should be obtained. It is clear that an adequate resolution of DEM (pixel size) can lead to a better cell-by-cell analysis of geomorphologic and hydro-geological characteristics. It can be considered that the DEM cell size derived from the digitization of the official state 1:5000 topographic maps in Greece (provided by the Military Geographical Service) is sufficient for obtaining a reliable "translation" of precipitation (water input) to runoff discharge (output). However, a smaller pixel size would be more appropriate not so much for the estimation of river banks and discharges, but for the simulation of the flood-routing procedures that take place.

The processing of the digital elevation model can be implemented through the use of specialized GIS software (e.g. HEC-GeoHMS) that can visualize spatial information and produce the required outputs for the hydrologic analysis. Hence, the outcome of this process is the delineation of the watersheds and sub basins as well as the combined characteristics of land cover and geological formations in order to estimate the water losses (e.g. SCS method).

Moreover, the digital elevation model is used to determine the stream network and the longest flow pathways within the river basin. In this respect, HEC-GeoHMS provides users with several programs (tools) for the determination of topology. These tools simulate the watershed as a network model of sub-basins, nodes and links with different features. Each link corresponds to the representative stream pathway and each node corresponds to the control points of the river basin (e.g. discharge inflow, river confluents, reservoirs, dams, outlets, etc). Sub-basins are parts of the whole watershed, which have similar characteristics in terms of geology, land cover, land uses and slopes. By combining these characteristics in the SCS method the water losses are computed (aggregated CN curve number per sub-basin).

The geomorphologic analysis of the river basin is a supportive issue for the hydrologic study intending to the calculation of the river basin discharge and the design hydrograph. An extensive time-series of rainfall data from different neighbor stations should be obtained and processed in order to determine the Rainfall Intensity-Duration-Frequency Curves for several return periods. Because such detailed data do not exist, correlations with other similar river basins often can be made in order to simulate the hydrologic regime of the study area in the best possible solution.

The rainfall can be used in HEC-HMS along with other inputs describing water losses and direct runoff processes. The final output is the design hydrograph of the river basin for several return periods. Such a hydrograph for 50-years return period is presented for the Alfeios River Basin in Greece in the section of case studies.

Hydraulic Simulation

The objective of the hydrologic analysis is to compute the basin discharge and its routing through the flow pathways (hydrograph). On the other hand, the hydraulic simulation aims to determine in detail the discharge routing in specific streams and the areas that might be affected by a possible flood episode.

On this subject, there are several open source computer programs (tools) like HEC-GeoRAS and HEC-RAS that define the river geometry and simulate the hydraulic open channel flow. More specifically, these tools define the river banks and pathways, select representative cross sections in quite dense intervals (e.g. per 200m) and finally perform the required hydraulic calculation making appropriate assumptions concerning the flow regime (e.g. steady or unsteady flow. uniform or non-uniform, 1-D or 2-D etc). The conveyance calculations are based on the energy balance among consecutive cross-sections and result in the determination of energy losses and piezometric heads along the river. It is clear that the availability of precise elevation and land cover data is of great importance either for the determination of the river geometry or the selection of the appropriate roughness coefficients along the watercourse and banks.

The final outcome of this analysis can be a complete map of piezometric heads along the whole length of the river. This information can be further processed and combined with the digital elevation model in order to create the flood hazard maps, which provide specific picture on the water depths, the flood extent and the areas that are affected by a possible flood event.

3. CASE STUDIES

Greece has suffered some severe floods either in the form of localized flash floods or over whole basin extent that have produced from floods of major river systems. Nevertheless, there is no particular and integrated attempt yet in Greece to produce maps of accurate flood hazard and flood risk, even though this is a required deliverable of the EC directive 2007/60/EC for flood risk management.

In this direction, the National Technical University of Athens has conducted wide research including five interesting applications on flood mapping. The case studies concern medium to large river systems within basins with totally different characteristics. The following map (Figure 3) shows the location of these river systems within the Hellenic Territory, while Table 1 shows the main features of each case study.

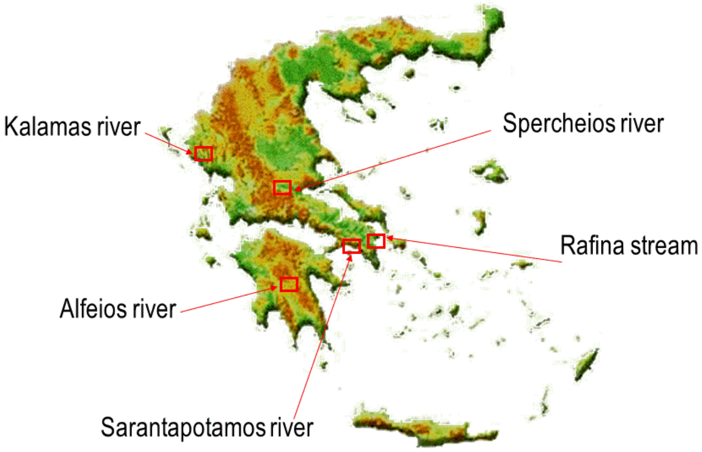

Figure 3. Location of river case studies in Greece

Table 1: Main features of case studies

S/N	Case study	Basin Area in km^2 (Hydrologic simulation)	River Length in km (Hydraulic simulation)
1.	Sarantapotamos River	200	20
2.	Spercheios River	1129	88
3.	Rafina Stream	126	12
4.	Alfeios River	165	20
5.	Kalamas River	795	15

The studies were all based on the methodology which was described in the previous section of this article. In the following lines, the most interesting points for these studies are presented.

The first step was to formulate the hydrological model for the computation of the design hydrograph per river basin for several return periods (T=20, 50, 100, 1000 years). For this purpose the already available digital elevation model was further processed and combined with soil type and land cover data in order to define the geomorphologic basin characteristics. The representation of the watershed hydrologic processes was based in the selection of methods for the computation of rainfall losses and direct runoff, which do not require extensive data availability. The SCS method was applied for the computation of rainfall losses, while the Snyder unit hydrograph was applied for the calculation of the direct runoff (Toutziari, 2012).

For each case, a design hyetograph was computed based on the processing of the available IDF curves and rainfall data from existing measurement stations. Hence, a Snyder unit design hydrograph was obtained for each case. It should be noted that further sensitivity analysis was undertaken for the calibration of the hydrograph to existing discharge measurements. The parameters that were analyzed in terms of sensitivity concerned the estimation of the CN curve number (SCS groups) and the flood routing coefficients.

In the Figure 4a selected hydrographs - before and after the calibration of the hydrologic model - are presented for the Rafina Stream case study (Pagana,V., 2012).

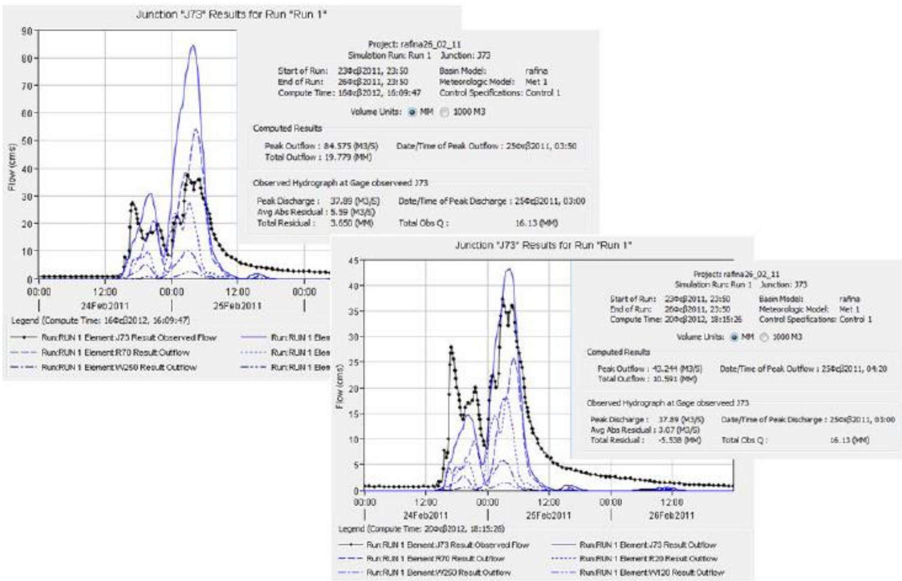

Figure 4. Calibration of the design hydrograph for the case of Rafina Stream (Pagana, V., 2012)

The next step of the analysis was the hydraulic simulation of each river system. This part of the study is highly depended on the quality of the elevation data that radically affect the geometrical "encoding" of the river cross sections. For this purpose additional topographical surveys were undertaken in order to achieve a better quality of the elevation model in correlation to the existing conditions. In addition, manning roughness coefficients were assigned to each cross section based on data concerning the river bed material which were obtained through the in-situ investigation as well as the available aerial maps (see Figure 5).

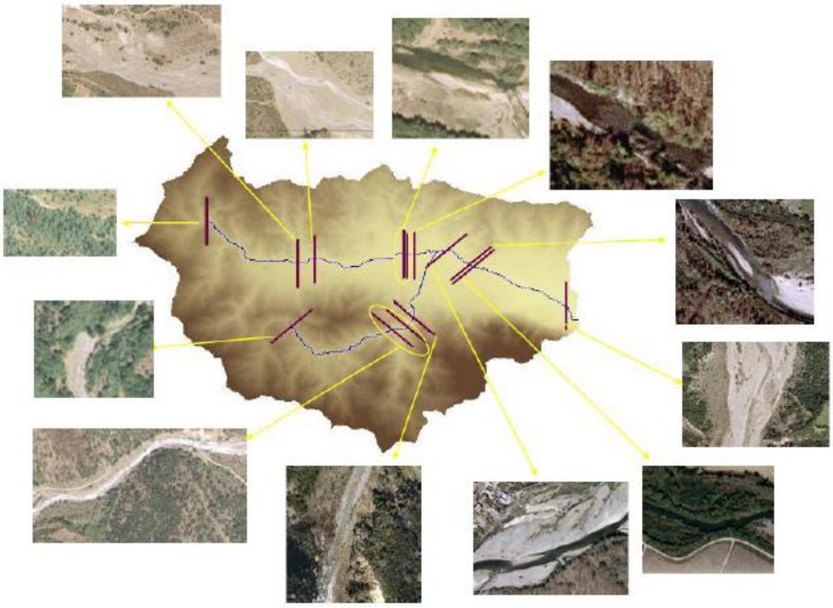

Figure 5. Aerial maps of the Spercheios River (Sotiropoulou,K., 2012)

The hydraulic simulation of each river system was performed with the use of the open source software HEC-RAS, which simulates the hydraulic routing of open channel systems for steady or unsteady flow conditions. The output of the hydraulic simulations was the calculation of hydraulic features (velocity, Froude number, critical depth, water depth, energy gradients, etc) per selected cross section. Based on the results of the above analysis a significant cartographical work was undertaken in order to depict the flood inundation polygons, to calculate the inundated areas and to estimate possible damages in financial terms. In the following figures, some representative cartographical products are presented. In Figure 6 the inundated areas for different return periods (2, 100 and 1000) are presented for Alfeios river basin.

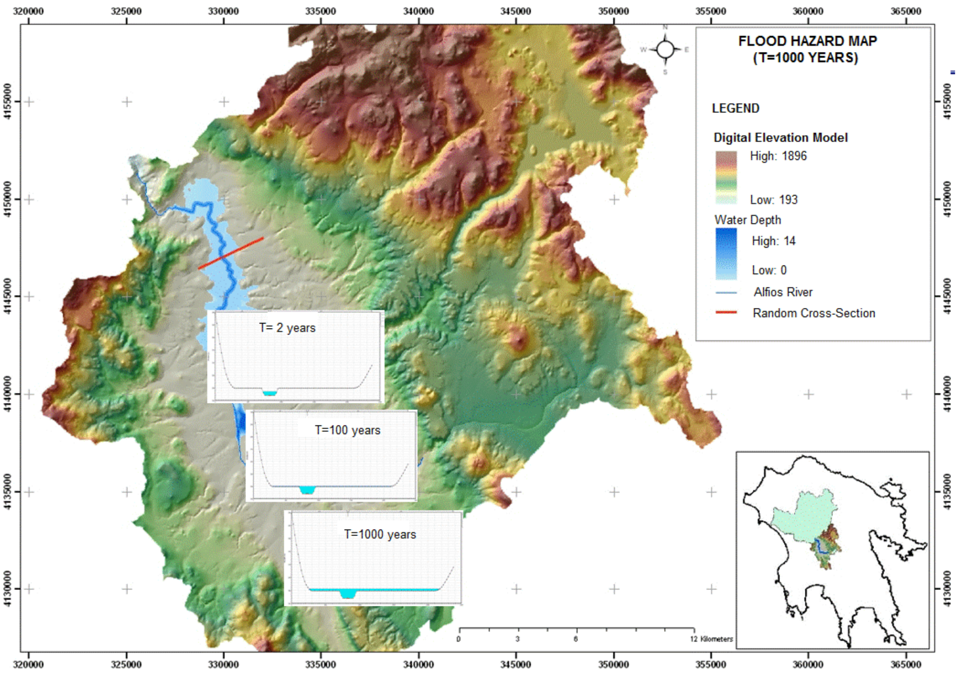

Figure 6: Water depths (floods) for different return periods of Alfeios River in Arcadia (Gkiokas,A., 2009)

Also in Figure 7 the flood hazard and risk maps for Kalamas river basin are presented. The maps were developed according to the EU Directive 2007/60, but they were adapted to the Greek standards and terminology (Theoulakis, 2010).

Figure 7a: Flood hazard map (water depths) for the case of Kalamas River (Theoulakis, K., 2010)

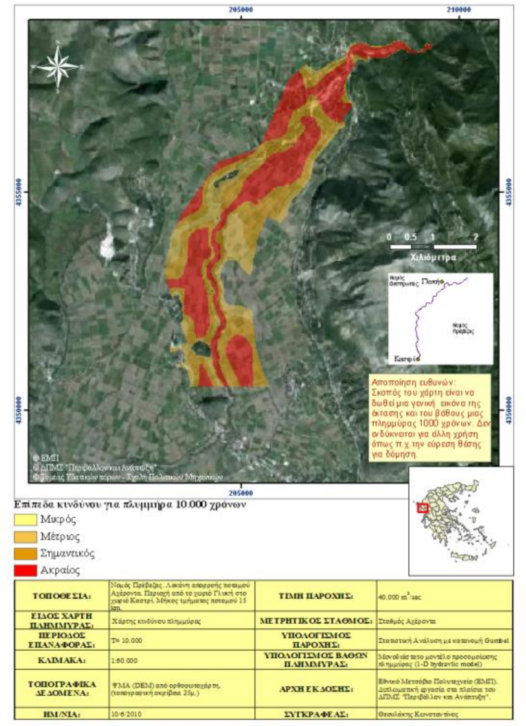

Figure7b: Flood risk map (inundated land-qualitative) for the case of Kalamas River (Theoulakis, K., 2010)

4. CONCLUSIONS

Even though there is a common conceptual methodology to create flood hazard maps the presented integrated framework involves the dynamics of coupled approaches to create flood maps in a variety of parameters, such as extent, depths, and piezometric heads for various return periods.

The values of the aforementioned parameters decipher dependence on the specific area regimes concerning the IDF curves, the geometrical characteristics of the river channel (cross sections areas, roughness, slope) and the geomorphologic, geological and soil characteristics of the flood plain (land cover, land use, elevations, slopes, soil permeability, hydraulic conductivity etc).

However the extent of inundated area is slightly varied along the increase of return periods from 20 to 1000 years.

All the already available or projects running flood maps in Greece partly comply with the EU Flood Directive (2007/60/EC) whereas the further step from hazard to risk map has not been yet completed. In addition, the protective effect of flood defenses has to be incorporated in the mapping methodology.

The process of creating flood inundation maps is affected by uncertainties in data, modeling approaches, parameters, and geo-processing tools. Popular techniques such as the generalized likelihood uncertainty estimation (Jung and Merwade, 2012), bootstrapping methods, and others have to be included to quantify uncertainty in flood inundation mapping.

The outcome of the study including the surrounding uncertainties in flood inundation mapping could be a powerful decision-making computational tool that would help in planning and prioritizing environmental actions in a pre-disaster stage. Such a tool would be widely applicable by agencies and decision makers and would efficiently support planning and management of operations that are critical for human, reservoirs, river channels, water conveyance systems and environmental sustainability.

REFERENCES

Gkiokas, A, Elaboration of a standardized methodological framework for the creation of flood hazard maps, MSc thesis, National Technical University of Athens, 2009

H. de Moel, J. van Alphen, and J. C. J. H. Aerts, Flood maps in Europe – methods, availability and use, Nat. Hazards Earth Syst. Sci., 9, 289–301, 2009

Jung, Y. and Merwade, V.”Uncertainty Quantification in Flood Inundation Mapping Using Generalized Likelihood Uncertainty Estimate and Sensitivity Analysis.” J. Hydrol. Eng., 17(4), 507–520, 2012

Pagana, V., Elaboration of flood inundation maps in Rafina basin, MSc thesis, 2012

Panagoulia D., N. Mamassis, and A. Giokas, An integrated methodological framework for floodplain inundation mapping for long return periods of flood events. Symposium in Deciphering River Flood Changes, Vienna, Austria, 03-05 September 2012

Sotiropoulou, K., Development of Flood maps under Directive 2001/60/EU. Application to Spercheios basin, Postgraduate Thesis, National Technical University of Athens, 2012

Theoulakis, K., Production of flood hazard and flood risk maps based on the EU Directive 2007/60, Postgraduate Thesis, 154 pages, Athens, 2010

Toutziari, M., Implementation of a methodological framework for creating flood risk maps in Sarantapotamos river basin, MSc thesis, 2012