Hydrologic issues in demarcation studies of watercourses in Greece

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Abstract

In this work various hydrologic issues related to demarcation studies of watercourses in Greece, currently conducted according to law 4258/2014, are discussed. Detailed specifications were published in February 2017. The demarcation lines have to surround the flooding area, the existing banks and any technical works associated with the watercourse. According to the new law, demarcation lines have to be defined for conditions with and without regulation works. This presents particular problems in inhabited areas and relates also to the flood risk assessment required by the 2007/60/EU Floods Directive. The Special Secretariat for Water, Ministry of the Environment and Energy, is responsible for the implementation of the Floods Directive. Within this framework the Secretariat published (2016) idf relations for all areas of Greece, a significant step for hydrology studies. Determining peak flows for ungaged areas is difficult and involves high uncertainty. Although, advanced computer capabilities are used for detailed hydrologic modeling, a substantial revision of flood engineering procedures is required, as many of the empirical relations used are based on limited field data developed decades ago. Additional guidelines and specifications for hydraulic computations, especially for the case "without works" and legal framework are also needed.

Keywords: demarcation, flood, ungaged areas, flood directive, Greece

1. Introduction

Demarcation studies of watercourses (excluding navigable streams) in Greece are carried out according to Law 4258/2014, amending laws 3010/2002, 880/1979 and 2052/1992. Detailed specifications were published in Feb. 2017 (FEK428B/2017). Demarcation lines ideally serve the dual purpose of protecting the watercourse environment and determining safe zones for building and other uses, associated also with setting flood insurance rates. For this purpose to be achieved a legal supporting framework is also needed. Demarcation studies are required for the environmental licensing of technical works. Exception is provided for the cases of maintenance of flood protection works, dam construction, culverts or bridges not affecting the flow of the watercourse -after hydraulic study determining the corresponding flood lines-, and "small" watercourse (A>0.5 or 1 km^2 within or out of city plan limits respectively). In many cases streams of ephemeral flow are involved, in which case no measured stage-discharge data exist and one has to rely on predictive methods for the determination of flood discharge. The studies require extensive review of environmental and hydraulic aspects of the existing and projected conditions of the watercourse and its watershed. Regardless of the length of the watercourse under study, hydraulic and environmental conditions of the whole watershed have to be assessed and presented. Hydraulic design is understood as flood protection design, which is understandably the dominant criterion especially in urban areas. However, in areas designated as agricultural lands, occasional flooding could even be desirable according to environmental criteria, and provisions are set by the law for reimbursements of farmers in the cases of damages. Stakeholders' participation is not always easy as the whole procedure is very time consuming and many agencies are involved. Complications also arise from legal or illegal land use changes when the agricultural land gets inhabited and the expropriation costs get high, prohibiting the materialization of demarcation. Regarding building close to watercourses: old building regulations (1979) set specific distances from the banks depending on whether regulation works needed were constructed, the new regulations (Law 4067/2012) provide for guidelines to be set by presidential decree, as proposed by the Minister of Environment, Energy and Climatic Change. In Flood Directive 2007/60/EC on the assessment and management of flood risks it is stated:

(2) Floods are natural phenomena which cannot be prevented. However, some human activities and climate change contribute to an increase in the likelihood and adverse impacts of flood events.

(3) It is feasible and desirable to reduce the risk of adverse consequences, especially for human health and life, the environment, cultural heritage, economic activity and infrastructure associated with floods...

(12) ..., it is necessary to provide for the establishing of flood hazard maps and flood risk maps...

(18) Member States should base their assessments, maps and plans on appropriate "best practice" and "best available technologies" <u>not entailing excessive costs</u> in the field of flood risk management.

In Greece the Special Secretariat for Water, Ministry of the

Environment and Energy, is responsible for the required flood risk assessment and the implementation of the Floods Directive. Many cities have developed around rivers. Especially in the case of rivers with ephemeral flow, the river course is often severely restricted. Rapid urbanization, combined with largely unregulated development has a profound impact on watercourses. It increases the runoff volume and the peak discharge, because of the increased impervious cover provided by streets, parking lots etc, and changes in hydraulic efficiency associated with artificial channels and storm drainage collection systems. This has to be accounted for in the design and makes calibration difficult, even in the case where discharge data are available. Consequently even for cases where measured hydrographs are available the effect of predicted changes has to be evaluated based on new estimated values of the coefficients. Wigmosta and Burges (2001) note that considerable basic and applied research focuses on understanding and evaluating the influence of land use changes, such as urbanization or forest management on watershed hydrology and geomorphology. The motivation for the research is to develop land use policies that minimize adverse impacts and maintain biodiversity and sustainability of human influence ecosystems. Detailed and reliable hydrologic and hydraulic computations are critical for the demarcation of watercourses which is closely related to the assessment and management of floods.

2. Hydrologic issues

Design for a given return period is not uniquely defined and may vary considerably depending on the selection of the parameters and methodologies involved: choice of appropriate idf curve, rainfall distribution, rainfall height and duration, unit hydrograph type. Transformation of rainfall to runoff requires determination of an appropriate design hydrograph. In ungaged basins this becomes almost an art and depends largely on the experience of the design engineer. It involves choices of many interrelated parameters. Singh and Woolhiser (2002) in the 150-yr anniversary hydrology paper discuss many aspects of mathematical modeling in watershed hydrology, illustrating the complexity of the problems involved. Even though advanced computation capabilities facilitate computations, the original data for the empirical equations used are quite old and there are questions on the appropriate resolution to be used and the resolutions effects on the modeling of hydrologic parameters (Moglen & Hartman, 2001, Hill and Neary, 2005, Daniil and Michas, 2006).

2.1 Return period

The return period is set by the specifications to 50yrs, unless otherwise specified by the responsible agency. In recent implementation of the Flood Directive for flood risk assessment in Greece the following were adopted: T=50 high probability with alternating blocks distribution, T=100 average probability with alternating blocks distribution and T=1000 low probability with worst profile distribution. The X-year peak discharge in lack of data is assumed to be the one resulting from the X-year precipitation. Graeler *et al* (2013) present an overview of the state of the art for estimating multivariate design events and compare different approaches. The construction of multivariate distribution functions is done through the use of copulas. A synthetic case study is used to generate a large data set of simulated discharges that is used for illustrating the effect of different modelling choices on the design events. Based on different uni- and multi-variate approaches, the design hydrograph characteristics of a 3-D phenomenon composed of annual maximum peak discharge, its volume, and duration are derived. They also present an ensemble-based approach. For a given design return period, the approach chosen clearly affects the calculated design event, and much attention should be given to the choice of the approach used as this depends on the real-world problem at hand. As Efstratiadis *et al* (2014) note, the different aspects of uncertainty in flood modeling are only partially represented by the return period of the design rainfall. A more consistent approach would require integrating the uncertainties of all associated components, including model input, model parameters and initial conditions. Such an option can be offered by stochastic simulation, which is the most effective and powerful technique for analyzing systems of high complexity and uncertainty. In particular, the model parameters, many of which are in fact variable, reflect the high complexity of the flood system. In the context of stochastic simulation, these should be treated as random variables, to which are assigned proper statistical distributions. The benefits of stochastic simulation also include the generation of synthetic storm data. In most routine flood studies employing event-based models, the shape of the design hyetograph is very simple. Typically, a single-pulse storm event is considered with a single rainfall peak, which generates infiltration patterns that lead to a single flood peak. However, if a Monte Carlo approach is adopted, using ensembles of synthetic storm events provided by stochastic models, the latter will have arbitrary temporal distributions, comprising both single and multiple pulses within the same storm event.

2.2 Effective rainfall - Design hyetograph - rainfall distribution

Within the framework of the implementation of the Floods Directive the Secretariat published (2016) intensity - duration – frequency (idf) relations for all areas of Greece, a significant step for hydrology studies. According to specifications these idf curves should be used with appropriate adjustments for elevation and spatial integration. Effective rainfall and rainfall time distribution should also be determined. Design storm duration is also an associated parameter when hydrographs are used, relating to the time of concentration/lag as well. Whereas with the rational method a peak runoff coefficient (for the time of concentration) should be determined, in more sophisticated methods using hydrographs other simulations, like CN numbers or Green-Ampt should be used. CN numbers affect the lag time computations in the SCS method and depend also on the antecedent moisture conditions. Often CNI is related to favorable conditions, CNII with average conditions and CNIII to adverse conditions. In the recent research project DEUCALION it s proposed that a probable scenario is obtained by weighing according to the local anticipated moisture conditions. Initial conditions are known to be of crucial importance for hydrological models. Berthet *et al*. (2009) compared different initialization strategies of the soil moisture component of a rainfall-runoff forecasting model. The continuous mode was compared to several event-based approaches for the same model. The main conclusion is that the best results were obtained when the model was run in a continuous mode, that corroborates the results of previous studies. However, they showed that one of the tested event-based initialization strategies could lead to performances rather close to what is obtained with the continuous approach, provided that the model can be run on a short pre-forecast period. It is concluded that the loss in performance when running the model using event-based strategies is not substantial. If an efficient assimilation of the last observed streamflow is possible, event-based strategies can be efficiently used for operational purposes when and where it is impossible to run a model continuously.

2.3 Discharge Determination

In Greece according to national guidelines relating to stormwater projects (PD696/74) the methods to be used include the rational method, the Fuller formula and hydrograph development in cases of large basins that should be divided into subbasins. Drainage area is the most important parameter in determining runoff peaks, however the relation is not linear and geologic and morphologic parameters are also important. Complex hydrologic systems should be analyzed using hydrographs and not simply the rational method. Thus, the time and spatial variability of watershed response can be better assessed. Comparisons of the rational method, the Fuller equation, and hydrologic modeling with HECHMS using SCS hydrographs has been presented for case studies in Greece (Daniil and Michas, 2009). Area specific fitted equations relating the drainage area to the peak flows can be developed and used in adjacent regions. The Fuller equation, a usual choice for the determination of design discharges in highway or railway projects, in many cases overestimates the discharge. The use of SCS hydrographs is preferred (Daniil *et al*., 2010). In the third edition of Design of Small Dams (US Dept. of the Interior, Bureau of Reclamation,1987) six types of dimensionless hydrographs are presented based on 162 reconstructed flood hydrographs. The Sierra Nevada type and the Rocky Mountain Thunderstorms seem applicable to some Greek mountainous basins and have been used by the authors in recent studies. These hydrographs involve choice of a parameter Kn which can be interpreted as a Manning coefficient of the whole basin which varies with the return period, with higher values associated with lower return periods. The quest for the appropriate unit hydrograph continues (Grimaldi *et al*. 2011, 2013). Uncertainty analysis is very difficult to be implemented in hydrograph estimation and the confidence limits are unavoidably very large. The demarcation specifications limit the use of the rational method to catchment areas 0.5~5 km^2 within the city plan limit or 1~10km^2 out of it, only in the case of a single well defined watercourse in the catchment. As Efstratiadis *et al*. (2014) note that regarding predictions in ungauged basins with modeling tools that use regionalized parameters cannot be trusted before validation at a local setting. This is of key importance in the case of small and semi-arid Mediterranean basins. Yet, conceptual models are not easily applied to ungauged basins, since their parameters cannot be derived through regional approaches but must be estimated via calibration. It is proposed that more attention should be paid to conceptual flood modeling, which can ensure both physical consistency and parsimony. This also involves the formulation of synthetic unit hydrographs that ensure a realistic representation of the time–area transformations.

2.4 Hydraulic computations with/ without works

As the main channel of ephemeral watercourses is formed to accommodate ‘common’ floods, appearing a few times a year, floods of high return period most often are associated with inundation of overbank areas and shallow water flow, around obstruction (buildings etc) in many cases. This type of flow cannot be represented adequately with one dimensional flow models. 2D or 3D analyses require more detailed input data and computation time, but provide definitely more appropriate simulation results. Comparison of 2D and 3D analyses show that as the effect of the vertical component is limited, 2D analysis can be sufficient at a lower cost. However, in order to get high resolution results, detailed topographical data are needed. The issue gets more perplexed with the definition of "existing conditions". In the past the flood lines without works were interpreted as in the case of the natural morphology only (without any buildings or technical works). Related issues is the presence of insufficient technical works and also the projection of future land development. Additional guidelines and specifications should be set towards this direction.

3. Examples from case studies

3.1 Demarcation studies by Hydroexigiantiki

Some examples of case studies are presented in the following table. The studies were conducted prior to the new law. In most cases discharge determination from previous studies was used for the demarcation. An example of a methodology developed by a county in the U.S. adapted to the specific conditions of the area, approved for use from the Federal Emergency Management Agency (FEMA) for the creation of the revised maps for the area, is given.

3.2 The DuPage County, Illinois, U.S. example

The county's rapid urbanization, combined with largely unregulated development during the 1980s, had a profound impact on many streams and rivers. Prompted in part by the extreme 1987 flood event, DuPage County established the County Stormwater Management (DPCSM) program to mitigate future flood damages along the county’s waterways. DPCSM also assumed responsibility for managing and maintaining the floodplain models and maps of all regulated stream reaches throughout the county that were developed by FEMA in the late 1970s. These flood insurance rate maps depicted the 100-year floodplains. With the rapid urbanization these maps quickly became outdated and inaccurate. Accurate maps are important because property owners, regulators and developers use them to reduce and prevent future flood damages. As a result, DPCSM undertook the task of creating new maps to reflect changes. The new floodplain maps were developed using the county’s watershed planning models rather than traditional techniques used by FEMA, because of problems stemming from the technique’s assumptions that

Table 1. Recent demarcation studies by Hydroexigiantiki

Watercourse/ Location	Demarcation cause - special conditions	Watershed area A(km2)	Reach length (km)	Return period T(yrs)	Discharge method	Discharge (m3/s)	Remarks
Meganitis/ Peloponnese	licensing of aggregate extraction area	61.0	2.1	100	rational	300	~6 km from the sea
Selinountas/ Peloponnese	licensing of aggregate extraction area	330.2	0.59 + 0.56	100	rational	625	~7 km from the sea
Anapodaris/ Crete	downstream of dam	78.5/ 87.4	3.85	50	hydrograph +routing	106.7	downstream of dam
Pyrna/ Attica	Licensing for expansion of wastewater facilities	11.1/ 15.85	1.06	50	isochrones rational hydrographs	120*	Watercourse of special environmental interest/ existing closed culvert
Vrysaki, Ag. Stefanos/ Attica	city planning	2.65 4.87	1.12 0.98	50	rational	47.9 79.5	runoff to Marathon lake, part of Athens water supply system

* design discharge of the existing culvert. In the flood risk assessment study the adverse condition discharge was 117, while the favorable condition was only 12.3m3/s.

there are no significant changes in a watershed affecting its hydrology over the period of analysis, that control structures do not regulate or modify flows, and that a consistent climatic record exists. Contrary to this, the rapid urbanization of DuPage County’s extremely flat topography severely affected the hydrology for the period of analysis. In addition, there are a number of control structures on the streams, which cause many backwater situations and severe flow regulation. The County’s methodology allows for the use of continuous simulation data. Because flow information could be extracted for every cross-section throughout the county for the past 60 years, DPCSM could develop accurate recurrence intervals for each of the cross-sections in the model. This improved continuity lead to a more accurate floodplain map. After a comparison analysis between the traditional method and the method used by DuPage County, completed in 1996, it was confirmed that the county’s procedures produced reasonable results and could manage situations that other techniques traditionally had difficulty handling. Due to DPCSM’s past successes, DuPage County received funding from FEMA to support activities aiming to provide a more accurate study of current floodplains. Ultimately, DPCSM will determine new floodplain elevations and create revised floodplain maps countywide.

(http://www.estormwater.com/lines-demarcation)

4. Implementation of demarcation lines

Many times in the past validated demarcation lines have been annulled, as based on insufficient topographical data, and in other cases set marks on the ground have been removed. Additionally it is not clear how land ownership within the demarcation lines area is handled. It is often assumed that the area should be expropriated. The new law provides for the operation of a data base of proposed and approved demarcation lines, connected also to the National Cadastre & Mapping Agency data base and maps. This provision will prove extremely helpful for planning and information of land owners in the future.

5. Specifications' improvements needed

- Specification of scale of maps to be used in order of results to be comparable
- Determination of design return period in relation to land use of the area
- Detailed specification of methods and conditions for the determination of flood lines in the case "without works", especially in densely inhabited areas
- Legal framework regarding handling of ownership and land uses within the demarcation area

6. Conclusions

Demarcation studies of watercourses (excluding navigable streams) in Greece are carried out according to Law 4258/2014, amending laws 3010/ 2002, 880/1979 and 2052/1992 and related technical specifications (FEK428B/2017). The studies require extensive review of environmental and hydraulic aspects of the existing and projected conditions of the watercourse and its watershed. Guidelines of Directive 2007/60/EC on the assessment and management of flood risks are gradually incorporated in the demarcation studies. Determining peak flows for ungaged areas is difficult and involves high uncertainty. The advanced computer capabilities should be used for better determination of the parameters involved. The demarcation lines have to surround the flooding area, the existing banks and any technical works associated with the watercourse, as paths or maintenance roads of regulation works. Additional guidelines and specifications should be set regarding the scale of maps to be used in order of results to be comparable, the determination of design return period in relation to land use of the area, detailed specification of methods and conditions for the determination of flood lines in the case "without works", especially in densely inhabited areas and future conditions, legal framework regarding handling of ownership and land uses within the demarcation area.

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