Flood Risk Assessment and Management Under Directive 2007/60/EU: Geodetic Approaches and Digital Technologies for Effective Prevention

Ani Stefanova
Department of Applied Geodesy Faculty of Geodesy
University of Architecture, Civil Engineering and Geodesy
Sofia, Bulgaria
stefanova_fgs@uacg.bg

***Abstract*-This article analyses the application of Directive 2007/60/EU on flood risk assessment and management, mainly focusing on the preliminary risk assessment and the methods for identifying and classifying areas with significant potential flood risk. It examines also various criteria and techniques for designing flood threat and risk maps as well as flood risk management plans. Special attention is directed at geodetic activities in the stage of preliminary studies in flood prevention, including digital terrain model of river valleys and creation of cross sections for hydraulic studies. It emphasizes the importance of the accuracy of digital topographic models and cross sections for successful flood management. The article proposes a systematic approach to effective flood risk management using geodetic and digital technologies in compliance with the European standards and Regulations.**

Keywords- cross sections, digital terrain model, European Directive, flood prevention, geodetic works.

I. INTRODUCTION

One of the main factors for floods (Fig. 1) in a certain territory is the inability to process unusually large amounts of water ("high tides") due to intense rainfall, melting snow, destruction of embankments, break of a dam wall or human activity through certain "critical" places of water currents.

Flood prevention includes measures such as research, design, construction works and constant monitoring of the relevant territory.

In the middle of the previous decade, the applied flood prevention measures were established as not sufficient and it was necessary to redirect to comprehensive flood risk management in the conditions of "coexistence" with floods. This is a serious problem that needs a solution.

Fig. 1. Flooded Vidin, Bulgaria - 1942

The main goal and task are to reduce future risk through research, assessment and impact on all factors influencing the flood occurrence and the significance of their consequences to human health, economic activity and environment.

As a solution to the identified problem, a comprehensive approach to flood risk management is introduced with Directive 2007/60/EU [1] – the European Floods Directive.

II. MATERIALS AND METHODS

The flood risk assessment for Bulgaria follows Directive 2007/60/EU, using a unified methodology under the Water Act. It includes geodetic surveys, hydraulic modeling with Chézy and Manning formulas, and digital terrain models from photogrammetry and laser scanning. One-dimensional (1D) and two-dimensional (2D) models estimate flood depths and velocities, while GIS and AutoCAD data ensure accuracy. These methods support precise flood hazard mapping and risk management planning.

A. Directive 2007/60/EU for flood risk assessmentand management

Flood risk assessment and management for the Republic of Bulgaria is subject to the European Floods Directive [1] which has been in force since 26.11.2007 and was transposed into the national legislation with the Amendment of the Water Act in August 2010.

The Directive [1] requires member states to implement a long-term planning approach to flood risk reduction in three stages:

- Preliminary flood risk assessment;

- Flood hazard and risk maps;

- Flood risk management plans.

a)   Preliminary flood risk assessment

The main task of the preliminary flood risk assessment is to assess the potential future flood risk in the basin management area in terms of human health, economic activity, environment and cultural and historical heritage.

The ultimate goal is to identify areas with a significant potential flood risk or significant likelihood of potential flood risk, based on the preliminary assessment.

According to the Water Act, the preliminary flood risk assessment in Bulgaria is done using a unified methodology [1].

Methodological guidelines have been developed with a detailed description of the necessary work stages and recommendations for their implementation.

The methodological instructions are structured in three separate parts:

- Part A – Preparation for development of methodological guidelines.

- Part B – Methodological guidelines for preliminary flood risk assessment.

- Part C – Methodological guidelines for development of flood hazard and risk maps.

The criteria and methods for determining and classifying risk and identifying areas with significant potential flood risk [1] are listed and described below.
- Horizontal distance criterion (Fig. 2) – the horizontal distance between a site and a nearby river can be used to approximate the flood threat.
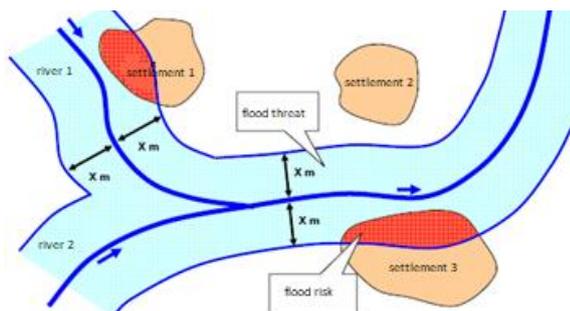

Fig. 2. Schematic draft of horizontal distance criterion

- Criterion for vertical distance (Fig. 3) – it is assumed that there is a constant depth of flooding starting from the lowest point of the river valley.
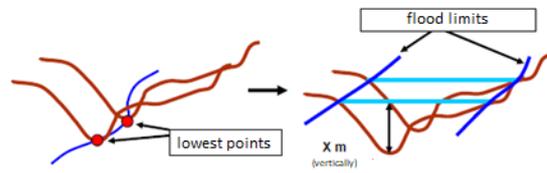

Fig. 3. Approach in applying vertical distance criterion.

- Method for calculating the normal depth – when both hydrology and the influence of topography on flood runoff conditions must be taken into account simultaneously, a simplified hydraulic approximation of the flooded depths calculated for steady movement/steady current conditions can be used. When calculating the normal depth, the Chézy formula (2) and the Manning formula (3) are applied to calculate the Chézy coefficient:

$$Q = V_m A \qquad (1)$$

$$V_m = C\sqrt{RI} \qquad (2)$$

$$C = \frac{1}{n} R^{1/6} \qquad (3)$$

Gauckler-Manning formula:

$$v_m = \frac{1}{n} R^{2/3} I^{1/2} \qquad (4)$$

$$R = A/U \qquad (5)$$

where: Q – runoff [m³/s]; v_m – average current velocity [m/s]; A – cross section area [m²]; C – speed coefficient [m^{1/2}s]; R – hydraulic radius [m]; I – water surface slope; n – Manning's roughness coefficient; U – wet perimeter.

- Method of using 1D model for calculating river sections – first, cross sections profiles must be extracted from the digital terrain model (Fig. 4). Based on them, the hydraulic 1D model is created which helps for assessment of depths and water levels in the studied area with set water quantities/runoff values.
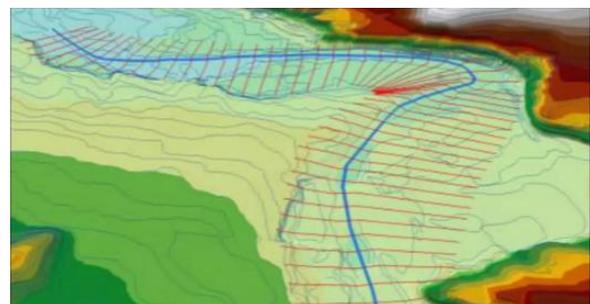

Fig. 4. Determination/extraction of cross section profiles for hydraulic calculations from a digital terrain model

- Method of using 2D - river models - when complex current conditions are present.

- Method of using a hydrological model based on a calculated Raster network for 2D – calculation of the surface runoff.

b) Preparation of flood hazard and risk maps [1]
Map making activities include:

- Geodetic measurements;

- Hydrological and hydraulic calculations and flood threat assessment;

- Processing and analysis of data for potentially affected sites and flood risk assessment;

- Creation of databases with intermediate and final results;

- Preparation of digital maps.

Flood hazard maps (Fig. 5) are for low, medium and high probability of flood occurrence. The Directive regulates the average probability of occurrence – 1%.
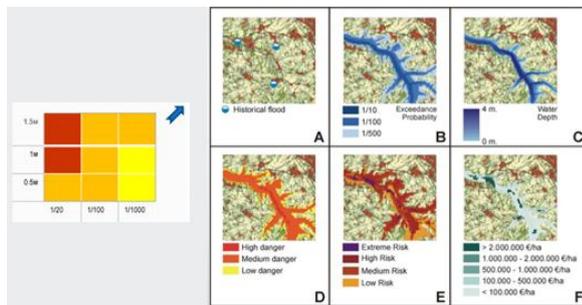

Fig. 5. Flood threat and risk maps: A – map of past floods; B, C – flood threat maps; E, D – flood risk maps; F – flood hazard map

c) Preparation of a flood risk management plans
The development of a flood risk management plan has been assigned to the Director of the Basin Directorate.

Flood risk management plans focus on:

- prevention

- protection

- preparedness

- forecasts and early warning system for flood risk.

B. Geodetic works in preliminary surveys for flood prevention

Geodetic works are part of complex activities related to flood prevention and damage assessment when high tides pass through potentially dangerous river valleys.

During the preliminary surveys, the following geodetic works [2] are carried out:

- Assessment (surveying) of the actual technical characteristics of artificial water sites – reservoirs, protective embankments, corrected spans, bridges, etc.;

- Defining the capabilities of existing reservoirs for high tides accumulation – updating "ponded volumes" curve, "flooded areas" curve, degree of reservoir filling with sediments;

- Geodetic surveying of riverbeds and protective facilities in the corrected river spans;

- Identifying "critical" points in past events;

- Creation of a digital topographic model of the river valley and its flooded areas.

C. Creation of cross-section profiles for hydraulic research

It is necessary that the cross-section profiles in the area of the facilities are representative of the river span with a density that allows for sufficient calculation of energy losses when the water current passes through the bright span of the facility.

The profiles are located in such a way that the energy gradient, the water surface slopes and the nature of the bottom in the inter-profile spaces are practically constant.

Cross-section profiles [2] are laid in:

- places with sharp changes in the river width;

- all major curves in the river bed;

- places where the current velocity changes abruptly, for example in the beginning and in the end of river rapids;

- the beginning and the end of river embankments (Fig. 6);

Fig. 6. Example of location of points for measuring a river profile [4]

- places or in proximity to existing permanent control cross section profiles;

- places of tributaries confluence which contribute to the main river runoff. Profiles are located (on the main current) immediately before and after the points of tributary confluence as well as along the tributary itself, immediately before the place of confluence;

- places before, after and in the span of bridge passages.

USACE (United State Army Corp of Engineers) recommends the following maximum distances between profiles [5]:

- 800m, for wide flooded areas and water surface slopes less than 0.38 ‰;

- 540m, for slopes less than 0.57 ‰;

- 360m, for slopes bigger than 0.57 ‰.

The location and range of the profiles are defined and marked in GIS format. The cross-section profiles are presented in AutoCAD format and the measured points are presented in ArcGIS database in horizontal coordinate system ATRS89 or WGS84. Also, the height data must be presented in the EVRS2007 height system and in the Baltic height system. The coordinates of the profile points are also presented in the 1970-year coordinate system.

D. Digital topographic model of a river valley

In the general case of computer modeling of river valleys aiming to determine the boundaries of flooded areas when passing high tides, the digital terrain model covers the watershed basin of the entire river system - the main river and all tributaries with significant contribution to the total river runoff [2].

The necessary information for creation of digital topographic model is obtained from:
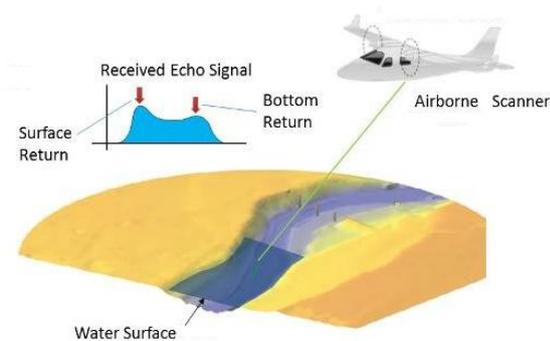
• Airborne laser scanning (Fig. 7);

Fig. 7. Laser scanning

• Geodetic surveying of hydrotechnical facilities;

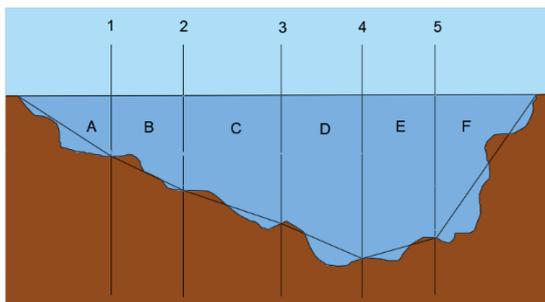• Cross section profiles of the river bed (Fig. 8);

Fig. 8. Scheme of cross section river profiles

• From existing or specially performed topographic, hydrographic, photogrammetric or other types of remote measurements.
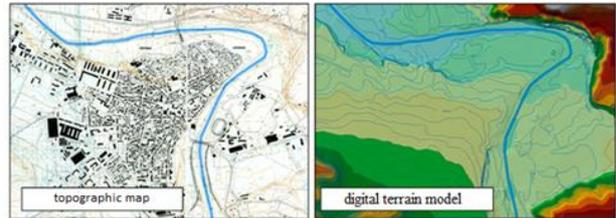
• Existing topographic maps (Fig. 9);

Fig. 9. Digital terrain model built on the basis of an existing topographic map [3]

E. Accuracy of cross section profiles and digital topografic models

In Bulgaria, there are no specific standards for the accuracy of geodetic works for the needs of hydraulic modeling. Only the Technical Specification of the Basin Directorate [6] mentions that the minimum horizontal accuracy of measuring points from cross section profiles is 25cm and the vertical accuracy is 10cm but these accuracies are not justified.

When performing such tasks, geodesists are guided by the specific technical specifications, the available source materials and tools as well as their own professional experience.

The following presentation shows the accuracy requirements determined in a study conducted in the 1990s by the Hydraulics Center of the US Army Corps of Engineers [5], supplemented with considerations regarding the possibility of their application in our country [2].

The main criterion for the impact of errors from the geometry profiles on hydraulic modeling was considered to be the corresponding error in the height of the high tide at a given span of the river valley with an appropriately selected velocity coefficient of the modeled water current.

Based on the research, the following conclusions were drawn:

• In areas where the velocity coefficient is determined with high reliability, the impact of errors in the heights of the cross-section profiles over the height of the model water surface is insignificant;

• The depths in the riverbeds along the profile line must be measured with an accuracy no less than 15 cm, i.e. directly using hydroacoustic equipment.

• Height errors when surveying profiles passing facilities (embankments, road, railway slopes, etc.) must not exceed 15cm. Profiles can be extracted directly from photogrammetric stereo models and in areas with dense vegetation by measuring via GPS in RTK mode or with a total station;

• With a given accuracy of the model high tide height – between 5 and 15cm with a sufficiently reliably

determined velocity coefficient, the allowable error in the heights of the cross-section profiles does not exceed 0.65m. With such accuracy, the profiles can be extracted directly from a stereophotogrammetric model prepared for topography mapping with 2m basic section. In relation to the conditions in Bulgaria, this means that for plain areas, digital terrain models, respectively profiles can be built using Large-scale Topographic Maps (LSTM) in scale 1:5000. In areas with hilly, semi-mountainous and mountainous topography where LSTM does not provide the necessary accuracy in depicting the area, it is necessary to conduct new photogrammetric or lidar measurements ensuring the specified accuracy.

The choice of 15 cm as the accuracy threshold in geodetic measurements for hydraulic modeling is based on both practical considerations and the findings from the Hydraulics Center of the US Army Corps of Engineers. Their study demonstrated that a 15 cm error margin in cross-section profile measurements does not significantly affect the accuracy of hydraulic modeling, particularly when the flow velocity coefficient is well-determined. This threshold aligns with the accuracy capabilities of commonly used surveying equipment, making it a practical standard in hydraulic modeling practices, ensuring sufficient precision without unnecessarily complicating the process.

III. Results and discussion

The flood risk assessment in Bulgaria, conducted under Directive 2007/60/EU, has enabled the identification of areas with significant flood risk through a structured methodology. The application of horizontal and vertical distance criteria, combined with hydraulic modeling, has provided reliable estimates of flood-prone areas. The use of 1D and 2D hydraulic models has improved accuracy in determining water depths and velocities, especially in complex terrain. Digital terrain models (DTMs) derived from geodetic surveys, airborne laser scanning, and photogrammetric data have enhanced the precision of flood hazard and risk maps. Despite the lack of specific national accuracy standards, the integration of USACE guidelines has ensured reliable data collection, particularly in geodetic measurements for hydraulic modeling. The results support

effective flood risk management by enabling targeted prevention, protection, and preparedness measures, though further refinement of accuracy standards and methodologies could enhance predictive capabilities.

IV. Conclusion

The implementation of Directive 2007/60/EU and the integration of geodetic works into the flood risk assessment and management process provides a comprehensive approach to protecting society and natural resources. This complex process requires cooperation between different institutions and specialists to ensure maximum efficacy and sustainability of flood prevention and management measures.

ACKNOWLEDGEMENTS

REFERENCES

[1] Directive 2007/60/EU on flood risk assessment and management, 2007.

[2] T. Kostadinov, D. Ognianov and R. Aneva, Geodetic works for flood protection in potentially dangerous river valleys, International Anniversary Scientific and Applied Conference, UACEG, 2012.

[3] Preliminary flood risk assessment in the main river basins of the Republic of Bulgaria - methodology for flood risk assessment according to the requirements of Directive 60/2007/EU, Part B, Methodological guidelines for preliminary flood risk assessment, Sofia, 2011.

[4] Report on the assessment of potential future floods in the Danube region and identification of indicative flood risk areas, Sofia, 2012.

[5] River Engineering Hydraulic and Channel Stabilization Survey. EM 1110-2-1003. Charter 17. United States Army Corp of Engineers. 2002.

[6] Technical specifications "Preparation of flood hazard maps and flood risk maps for the Danube River Basin Management Region". Programme "Environment" 2007-2013" 2014.