GEOFIZIKA VOL. 33 2016

DOI: 10.15233/gfz.2016.33.7
Original scientific paper
UDCs 551.577.37, 556.166

Generation of 2D flood inundation maps of Meriç and Tunca Rivers passing through Edirne city center

Uğur Akkaya [1, 2] *and Emrah Doğan* [3]

[1] Sakarya University, Institute of Natural Sciences, Sakarya, Turkey

[2] Abant Izzet Baysal University, Department of Architecture and Urban Planning, Bolu, Turkey

[3] Sakarya University, Department of Civil Engineering, Sakarya, Turkey

17 December 2015, in final form 12 April 2016

Natural disasters can be defined as hazardous and usually large scale natural incidents that may cause loss of lifes and property and that occur mainly or completely out of human control. Due to climatic changes draughts are being experienced in various parts of the world in the recent years. Floods are also observed to take place more frequently and severely in some regions. As it is reported by many scientific studies, flood modeling can only be possible through the designation of flood risk management strategies and the determination of the dynamic behaviors of rivers. In this context, the city of Edirne located downstream of Meriç River Basin, which runs through Turkish, Bulgarian and Greek soils, is frequently exposed to flooding. The majority of the currents that cause this take place within the Bulgarian borders, which covers 66% of the basin. This part of Meriç River Basin has a mountainous geography, it has a rather high average slope of 12.5% within Bulgarian lands, while in Edirne it is quite low with a bottom slope of 0,00036. In the present study, 2D flood modeling of the Meriç and Tunca Rivers that passes through Edirne city center were made and flood inundation maps were generated. With the analysis of the results obtained from flood inundation maps, a drainage channel capable of discharging flood rates that exceed the maximum rate Meriç River main bed can accommodate was designed, and the downstream conditions of the channel were evaluated.

Keywords: flood map, 2D model, MIKE 11 and MIKE 21, Meriç River, discharge channel

1. Introduction

Natural events are generally the natural consequences of the cycle intended to restore the inner balances of the nature. The cases where human communities suffer from this cycle are referred to as natural disasters (Kilicer, 2000). The increase of world population and climate change strengthen the pressures on the changes of the natural environment's inner balances, and causes natural disasters to be experienced more frequently and severely (Sönmez and Kesici, 2012). Throughout the world floods, overflows and drought are among the natural disasters that cause the highest loss of life and property after earthquakes. It is observed that floods that have been experienced more and more in the recent years causing significant hazards both in rural and urban areas. "These hazards causing loss of life and properties and give damages to the settlement, agricultural areas, transportation systems, environmental pollution and epidemics as well (Mason et al., 2010; Rozalis et al., 2010; Sönmez et al., 2013; Ceribasi et al., 2014; Kryzanowski et al., 2014; Söwmya et al., 2015).

According to the last report published by the United Nations, urban population is in the rise in comparison to the rural population. From 2011 to 2050 world population is expected to increase from 7 billion to 9.3 billion. Accordingly, urban population which was reported to be 3.6 billion in 2011 is expected to reach 6.3 billion by 2050 (Hammond et al., 2015). These data indicate that rapid urbanization is inevitable, and the natural consequences of rapid urbanization such as buildings, roads, bridges and streets render permeable surfaces impermeable or limit their permeability, which in turn increases surface flow rates and causes flash floods (Ceribasi et al., 2013; Semadeni et al., 2008; Konrad, 2014; Hénonin et al., 2015; Ceribasi and Doˇgan, 2016; Sönmez et al., 2016).

Flood modeling is the main instrument in the prevention of flood damages. As it is pointed out in many scientific studies, flood modeling can only be possible with the determination of flood risk management strategies and the dynamic behaviors of a given river (Bladé et al., 2012). Floods can be modeled by integrating 1D and/or 1D-2D (Horritt and Bates, 2002). Although being practical, 1D flood modeling only makes one-way calculation and therefore it may result in interruptions between the sections and in falls short in producing accurate results for complex flow systems and the areas where the topography changes frequently (Huthoff et al., 2015). On the other hand, recent studies show that taking into account the topographic and geometric properties of 1D models in 2D flood modeling produces quite successful results (Cook and Merwade, 2009). By means of 2D modeling the land can be represented more accurately with free surface currents and flexible mesh system and flood inundation maps can be seen continuously within the whole area. However, 2D modeling cannot represent the hydraulic elements in river beds (Frank at al., 2001; Sönmez, 2013). In order to reduce the time needed for calculation and to clearly represent hydraulic elements, it is considered suitable to use 1D modeling of river beds and 2D modeling of flood area. Thus, flood inundation maps can be generated by means coupling of the two models.

In the present study, 1D/2D coupled flood modeling of the Meriç and Tunca Rivers that passes through Edirne city center were made and flood inundation maps were generated. While the MIKE 11 software was used for modeling river beds, MIKE 21 was utilized for modeling the flood area. In order to coupling

MIKE 11 and MIKE 21, MIKE FLOOD software was used. As for topographic data, maps of 1:1.000 and 1:5.000 scaled maps were used and all structures that are estimated to remain in the current flood area were taken into consideration. Accordingly, the flood risk level of each structure was determined.

2. Study area and data set

2.1. Study area

The city of Edirne, at the western end of Turkey and shines with its natural beauties and historic structures that reach back to the 1400s B.C., is located within Meriç River Basin. Meriç River Basin, on the other hand, is located within Turkish, Bulgarian and Greek lands in the Eastern Balkans. As shown in Fig. 1, 65% of the total of 52600 km² area of Meriç River Basin is in Bulgaria, while 28% of it is in Turkey and 7% is in Greece (Orsam, 2011).

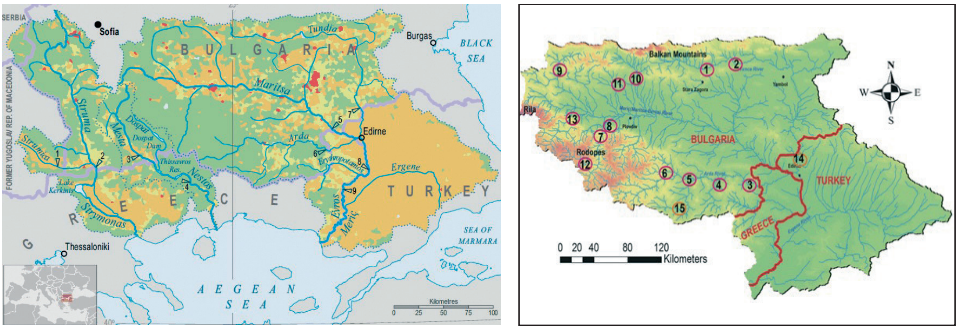

Figure 1. Meriç River Basin (Sezen et al., 2007).

Meriç River, as one of the large river systems in the region and as the subject of the study, passes through and also constitutes part of the borders between Bulgaria, Turkey and Greece. Meriç River originates from the Rila Mountain one of the Balkan Mountains at the western part of Bulgaria. Generally progressing eastwards, it enters Turkey about 15 km east of Sivilengard. After forming the Turkey-Greece border, it incorporates Arda branch coming from Greece around Arda bridge locality, and then continues to flow southwards by joining Tunca River coming from the left side of Edirne city center. Finally, it joins with Ergene River and disembogues into the Aegean Sea.

Due to the high basin slope at the upstream and the rather plain topographic structure of Edirne located at the downstream part, there have been many floods in the area. Floods cause significant financing and non-financing damages particularly in the settlement areas of Edirne. For instance, in the floods that took part between the dates of 17 February 2005 and 24 March 2005 shown in Fig. 2,

Figure 2. The flood of 2005 (Disaster and Emergency Management Agency (AFAD), 2005).

approximately 12 000 ha agricultural land was flooded and two bridges collapsed in Edirne. The consequential damage was determined to be approximately 50 million $ (DSI, 2005).

The reason of the frequent floods experienced in the area is related with the reservoir capacity and operation methods of the 16 dams located on Arda, Meriç and Tunca Rivers. While the total reservoir volume of the dams within Bulgarian borders is approximately 2.2 billion m³, that of those on the Arda River is approximately one billion m³ (Angelidis at al., 2010). These dams do not serve for a flood prevention purpose and are operated for energy generation. The dams in Bulgaria are mostly used for hydroelectric production. Concerning the effects of the dams on the discharge rates, Fig. 3 presents the maximum daily discharge values measured from 1985 to 2007 by the station on the Kuleliburgaz (Pythion)

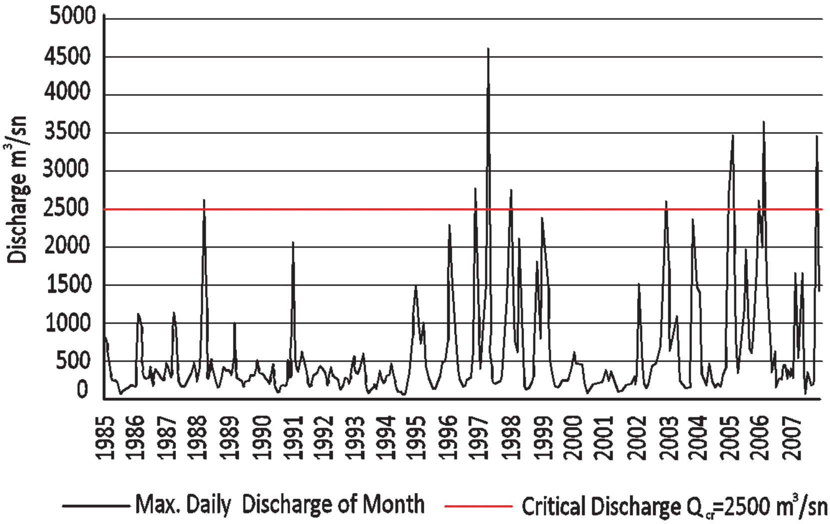

Figure 3. Maximum daily discharge rates of Meriç River from 1985 to 2007 (Angelidis et al., 2010).

Bridge located on Meriç River, approximately 40 km south of Edirne. Examining the daily maximum discharges for each month within the 23-year period in which measurements were carried out shows that within the 11-year period from 1985 to 1995 while the values exceeded 2500 m^3/s only once, in the following 12-year period from 1996 to 2007 this critical level was exceeded for a total of 7 times. Accordingly, while only one instance of flooding was experienced in the first period, in the second period one flooding was experienced in every two years (Knight and Staneva 1996; Kibaroğlu at al., 2005; Orsam, 2011).

2.2. Topography

The stream cross sections of Meriç and Tunca Rivers that cause floods in the study area were generated from bathymetric map. The part that is predicted to be exposed to flooding were obtained from maps of 1:5000 sensitivity and the winter and summer levees built in the past for flood-prevention were processed on the map at 50 cm sensitivity. With the obtained point data terrain model are generated by the software ARCGIS 10.2 as shown in Fig. 4.

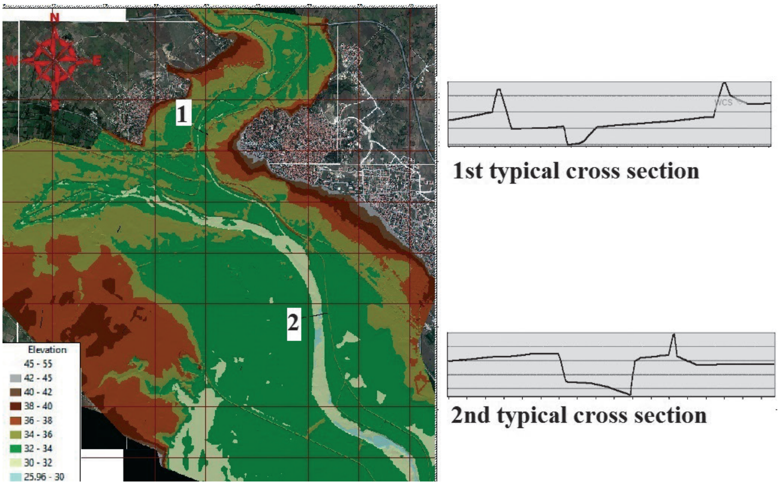

Figure 4. Study area topography and typical cross sections (*smaller figure*).

2.3. Hydrological data

The data observed from 1986 to 2014 by the DA01a003 numbered Kirishane current observation station located on Meriç and operated by the State Hydraulic Works were used for flood modeling. Also the data observed by the E01A013 numbered Suakacagi current observation station located on Tunca River from 1961 to 2014 were used. Flood recurrent interval were calculated by using the maximum currents reported by these stations.

In order to test the suitability of the flood rates calculated through statistical methods to the inundation function, Kolmogorov-Smirnov (K-S) probability line correlation test was used. By means of statistical methods, flood rates of Meriç River were determined to be fitting to Gumbell inundation. In consequence of the Kolmogorov-Smirnov (K-S) probability line correlation test, it was determined that Tunca River is suitable to Log-Pearson Type-3 inundation. The flood recurrent interval calculated with the data of both stations are presented in Tab. 1.

Table 1. Expected maximum discharge values for Meriç and Tunca rivers.

	Flood discharge							
Year	2	5	10	25	50	100	200	500
Tunca River	136.11	242.76	315.52	405.51	469.74	531.03	589.41	654.20
Meriç River	722.66	1 157.80	1 445.90	1 809.91	2 076.96	2 348.01	2 615.08	2 967.43

3. Hydrological modeling

In the present study MIKE 11 (1D) software was used for modeling the river bed. However, as from the part where the stream enters the settlement area MIKE 21 (2D) software and coupled 1D-2D MIKE FLOOD software were used to determine flood area.

3.1. 1D modeling

Running on finite differences-basis, the Hydrodynamic (HD) module of MIKE 11 software is capable to solve non-stationary current statuses in rivers and model both currents in river regimes and floods through digital methods adapted to local current conditions. Model solution system can be applied for both low slope and high slope rivers where vertical homogenous current conditions are available.

In 1D model calculations in MIKE 11 modeling system Saint-Venant equations based on the average of cross sections are taken as basis. In this way, water level (s), discharge (Q) or average rate of flow (U) can be identified. This can be set forth as a continuity equation as follows

$$\frac{\partial A}{\partial t}+\frac{\partial Q}{\partial x}=F_s \tag{1}$$

$$\frac{\partial Q}{\partial t}+\frac{\partial}{\partial x}\left(\frac{\alpha Q^2}{A}\right)+gA\frac{\partial h}{\partial x}+\frac{gQ|Q|}{C^2AR}=0 \tag{2}$$

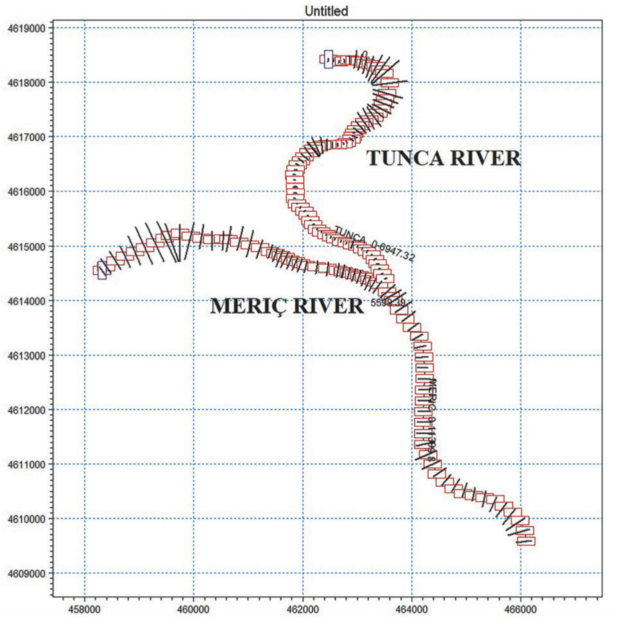

Figure 5. MIKE 11 stream network arranger.

where h is the water depth, Q is the discharge, α is the velocity distribution coefficient, x is the stream network piece (chainage), t is time, F_s is the source term, g is the acceleration of gravity, C is the Chezy coefficient, A is the wet section area, P is the wet perimeter, and R is the hydraulic radius.

The model calculates water heights at tributaries and flood beds by means of the sections obtained from the DEM (Digital Elevation Model). Afterwards, flood maps are generated with the use of MIKE 11 GIS, a GIS-based software written for MIKE 11 modeling system and runs by using MIKE 11 HD module results (Fig. 5). 1D flood modeling models Tunca River as 7.06 km, and Meriç River as 13.5 km. Cross sections are taken at 50 m intervals and more frequently at critical areas.

3.2. 2D modeling

MIKE 21 is capable of modeling 2D free surface through flexible mesh system. Within the MIKE 21 modeling system, 2D model calculations are solved through Saint-Venant equations based on average depth.

In this way, water level (s), Cartesian velocity components "U" and "V" can be identified. This situation can be written as a continuity equation as follows:

$$\frac{\partial s}{\partial t} + \frac{\partial}{\partial x} Uh + \frac{\partial}{\partial x} Vh = F_s \tag{3}$$

$$\frac{\partial s}{\partial t}+U\frac{\partial U}{\partial x}+V\frac{\partial U}{\partial y}+g\partial_x s+\frac{g}{C^2 d}U\sqrt{U^2+V^2}+\frac{\partial}{\partial x}\left(K_{xx}\frac{\partial U}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_{yy}\frac{\partial U}{\partial y}\right)=F_s \quad (4)$$

$$\frac{\partial s}{\partial t}+U\frac{\partial V}{\partial x}+V\frac{\partial V}{\partial y}+\frac{\partial s}{\partial x}+\frac{g}{C^2 d}V\sqrt{U^2+V^2}+\frac{\partial}{\partial x}\left(K_{xx}\frac{\partial V}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_{yy}\frac{\partial V}{\partial y}\right)=F_s V_s \quad (5)$$

where s is the height, h is the total water depth, U, V are the depth averaged Cartesian velocity components, C is the Chezy coefficient, K_{xx} and K_{yy} are the eddy viscosity, F_s is the source term, and U_s and V_s are the velocity components at the source.

Calculation mesh is generated in MIKE Zero environment. The most important advantage of the flexibility of the mesh is the ability to generate the mesh frequently at parts where sensitive calculation is needed and less frequently at other parts (Fig. 6). Accordingly, simulation duration and model stability can be adjusted in an optimum way.

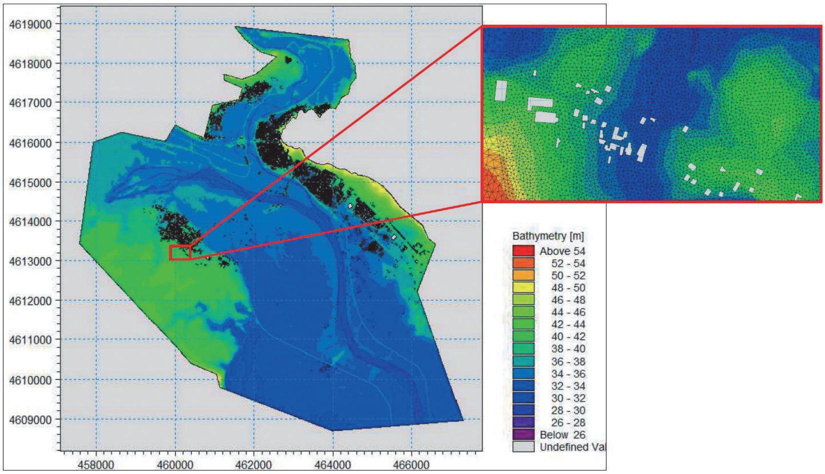

Figure 6. Mesh file and more sensitively generated flexible mesh at urban areas.

Also during the generation of flexible mesh system for Meriç and Tunca Rivers at places close to the rivers where structures are dense and in order to process the levees sensitively maximum mesh interval is selected as 10 m². In order to simulate the area between stream shorelines and the structures close to the stream, small mesh area needs to be selected at these areas. In other parts, mesh area is determined to be maximum 50 m². Afterwards, a triangulation was generated and in order to ensure homogeneity the operation “smooth” was carried out 50 iterations. This operation ensures the homogeneity of the triangle structure and affects stability. During mesh generation the buildings predicted to be exposed to flooding are removed from the calculation mesh. Thereby it is possible to observe which existing building is under what level of risk in case of a probable flood.

3.3. Model parameters

3.3.1. Friction parameters

Manning "*n*" was used as the friction parameter. In terms of land use types, other than the river bed settlement area: 0.020, forest, green fields etc.: 0.035 and in terms of material in stream channel concrete: 0.017, natural structure: 0.035

3.3.2. Time and distance parameters

3.3.2.1. MIKE 11 maximum dx and dt

Distance (dx) time (dt) and parameters are essentially related with stability. These values need to be determined independently for each incident. In order to achieve stability, the role of these parameters in meeting the Courant condition were taken into consideration. In MIKE 11 stage Meriç River dx was determined to be 100 m, while for Tunca River dx and dt were determined to be 100 m and 1 second.

3.3.2.2. MIKE 21 time, distance and Courant condition parameters

In cases where finite difference equations are used for the solution, Courant number should be used to achieve model stability. In order to achieve model stability Courant number needs to be less than or equal to 1.

This number can be determined by means of the following formula

$$Cr = \left(\sqrt{g \cdot D} + v\right) \cdot \frac{\Delta t}{\Delta x} \tag{6}$$

where Cr is the Courant number, Δt is time interval, Δx is distance interval, $\sqrt{g \cdot D}$ is wave velocity and v is velocity.

Performance of a stable simulation of the shallow water equation depends to time, distance and Courant condition (CFL) also in MIKE 21 environment. In the selection of these values experience and trials gain prominence. At MIKE 21 stage for Meriç and Tunca Rivers dx is read from the domain (min: 1 m, max: 30 m), dt is determined to be minimum 0.0001 second and maximum 0.5 second and the critical CFL number is determined to be < 0.8.

3.3.3. Hydrodynamic parameters

3.3.3.1. Wave approx

This is an important parameter for stability. In flood simulations "High Order Fully Dynamic" wave approach was preferred. Especially in simulations where water mass inertia is significant on basis of time and distance (such as flood) it is chosen as a stability-improving factor. Also in the flood simulation study of Meriç and Tunca Rivers this choice was chosen in line with DHI's suggestion (DHI, 2014)

3.3.3.2. Default values

Default values of the hydrodynamic parameters were used as they are, except for the "δ" value. The δ value was increased from "0.5", the default value in flood simulation studies, to "0.85". Because the coefficient "δ" expresses a time-centered gravity acceleration in momentum equation and is a stability factor.

4. Result and discussion

In consequence of 2D numerical modeling works, flood maps of Q2, Q25, Q50, Q100 and Q500 year recurrent intervals were generated. Model calibration was made with the scenario that took place in 2006 and that corresponds to the 25-year flood rate. Since flood inundation could not be photographed from the air in 2006, calibration was made on the basis of the current observation station water level. Examining the flood inundation maps shows that the Meriç River can safely accommodate 770 m^3/s flow rate. Any flow rate exceeding 770 m^3/s causes flooding in Meriç River. In consequence of 2D modeling Q25, Q50, Q100 and Q500 flood rates were observed to be the levees made between 1955 and 1975, shown in Figure 7. However, during flooding underground waters also rise and leakages occur behind the levees as also shown in Fig. 7. This, in turn, affects the settlements behind the levees negatively.

Figure 7. Levee in the 2015 flood and the current levee line (Akkaya et al., 2015).

Flood maps were classified and colored at 50 cm sensitivity and presented in Fig. 8. Examining the flood maps shows that Q25 and Q500 flood rates resulted

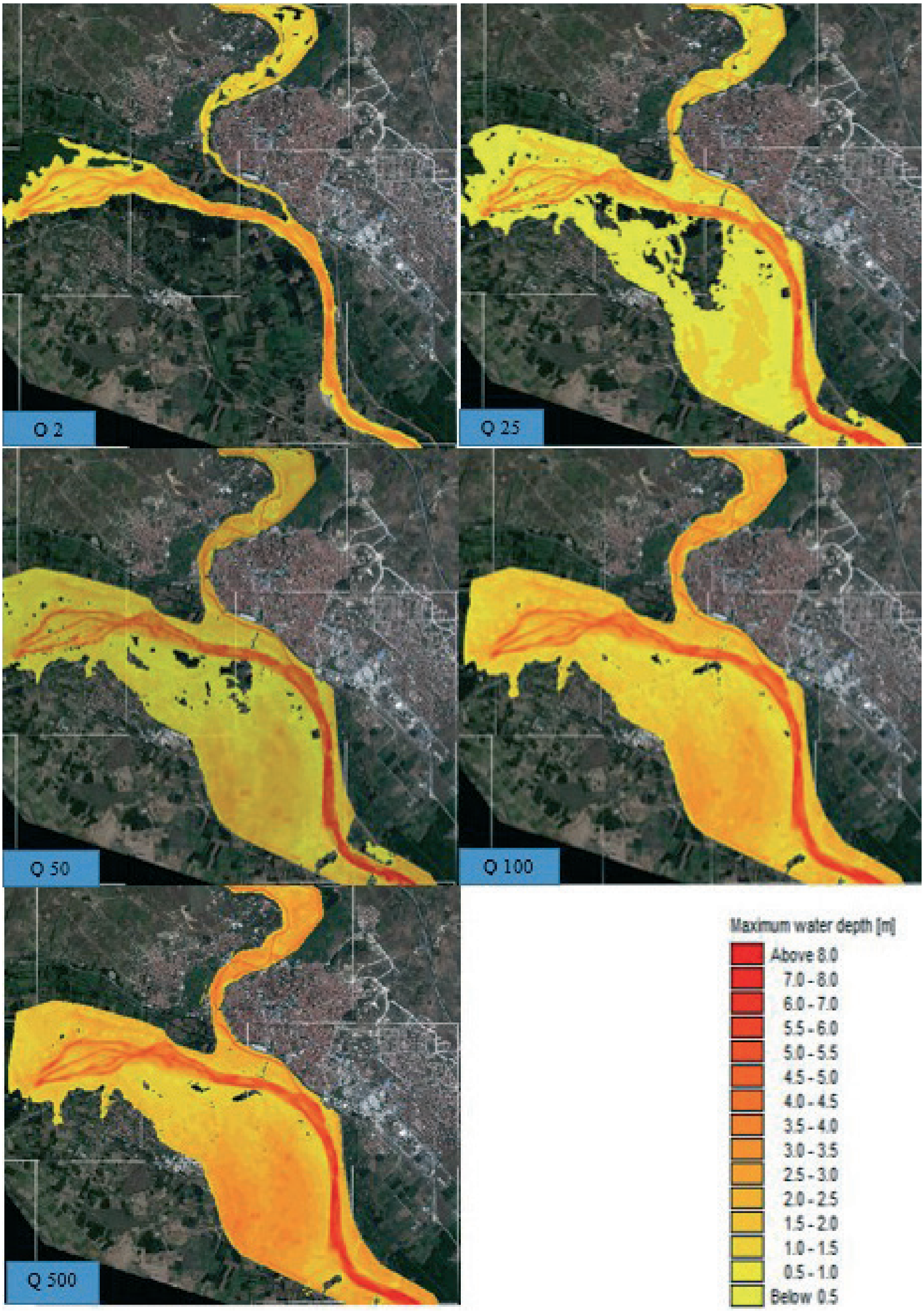

Figure 8. Q2, Q25, Q50, Q100, Q500 flood inundation maps.

in the same water inundation due to the levee, yet their water depths were different. Floods mostly affect Karaagac neighborhood, Bosna village and the summer houses, restaurants, historic structures close to the river and the building of the provincial department of environment. Due to the roads between the levees being plain and the inadequacy of the existing drainage channels, in case of a flood the waters remain for long periods and affect transportation negatively. For instance, in the flood occurred in 1984 transportation was not possible for a whole two days, for anything other than special terrain vehicles. Edirne also is a touristic center due to its long lasting history. The shorelines of Meriç and Tunca Rivers are used for social activities and recreation by the local population. Since these areas are located between levees, cleaning the deposit accumulation that occurs after every flood causes both financing and non-financing damages. Also the 2 300 ha agricultural land located between the existing levees submerge in consequence of the floods.

Despite the fact that presently the floods remain between the levees, local population are still affected negatively from the floods. This indicates that the criteria considered during the planning and construction of these structures are no longer valid today and that new solutions are required to be found for protection from floods. Also, due to the damages the levees suffer both from the floods and the population, occasionally flood waters break the levees as shown in Fig. 9.

Figure 9. Levee break in the flood of 2006 (Malkarali at al., 2008).

Although it can be considered to extend or clear the river bed in order to prevent floods, such precautions are not deemed suitable due to the existing living areas near the river and the fact that the narrowest part of the river bed is 200 m wide. It is also believed that such a solution would harm the historic silhouette of the city, particularly during the dry seasons.

In the light of the existing data, the most suitable solution is considered to use a drainage channel. The drainage channel will be able to transfer any flow rate above the safe 770 m^3/s to the downstream part of the city. Although Meriç constitutes the border between Turkey and Greece, its flood area passes from the Turkish land, about 4 km from the border. The fact that the area between the Greek border and the river is mostly used as agricultural lands indicates that land conditions are suitable for building the channel.

The primary criteria in the determination of drainage channel route are the elevation difference between the starting and ending point of the channel, optimization of the splitting and fill amounts that would be generated due to cross section, suitability of the areas to be expropriated depending on the width of the channel to be built, and finally the distance to settlement areas. With the consideration of the expropriation alternatives and the zoning status of the city, two different routes as shown in Fig. 10 were determined.

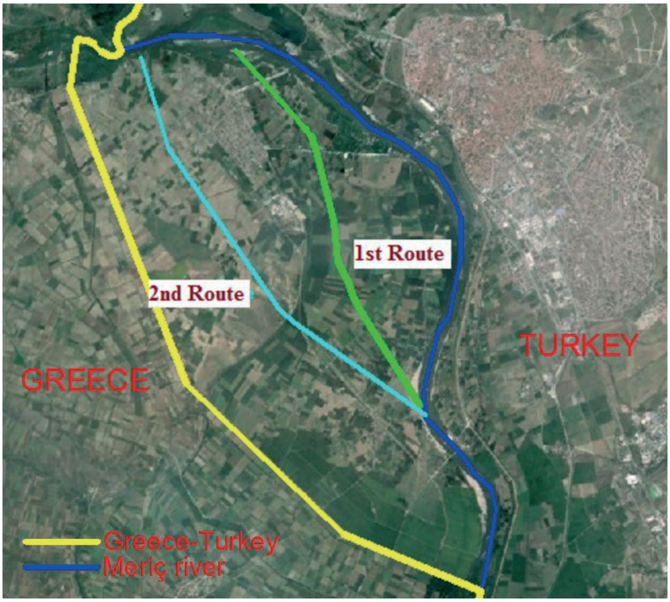

Figure 10. The 1st and the 2nd channel routes.

The drainage channel was designed to accommodate Q500 year flood rate. It was taken into consideration that Meriç is capable of transmitting flow rates of 770 m^3/s and any rate above this will be transferred into the channel by means of a controlled drain structure. As it can be seen in Fig. 11, the channel was designed in a leveed trapeze section and calculated with Manning formula. With the consideration of the sediment that may accumulate, the channel was designed to safely accumulate flow rates up to 2 300 m³/s.

$$Q = \frac{1}{n} \cdot \sqrt[3]{R^2} \cdot \sqrt{S} \cdot A \tag{7}$$

where: Q is flow quantity, n manning, R hydraulic radius, S slope and A channel section area.

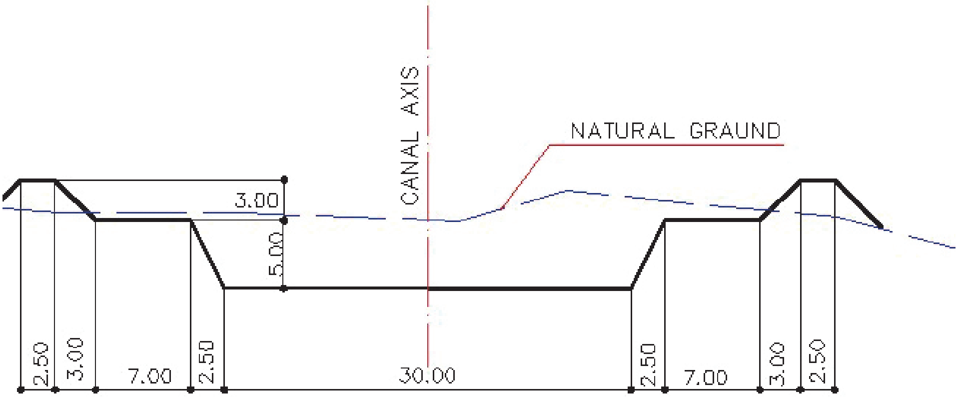

Figure 11. Canal typical cross section.

Drainage channel routes were separately processed on the terrain model. In 2D modeling maximum mesh interval for channel routes, river bed and levees was selected as 10 m². Since flooding is not expected for other areas sensitivity was reduced in order to shorten simulation time.

The 1st route for the drainage channel was planned to pass between Meriç River and Karaagac neighborhood. It starts with the coordinates x = 459 700, y = 4 614 707, z = 34 m and ends with the coordinates x = 464 089, y = 4 610 984 and z = 30 m. The 6 000 m long channel merges with Meriç River with an angle of 12°. In the determination of the route factors such as the availability of another drainage channel, the current expropriated status of the area from which the route will pass and the fact that the route remains in between of levees were considered as essential reasons. It can be seen from Fig. 12 that, in consequence of the 2D modeling the channel will be capable of safely accommodate Q500 flow rate and flood areas are not affected. Despite of its advantages such as ease of construction and low cost, in case the channel is implemented with this route there would be a need for building a bridge for the Karaagac neighborhood settlement area. This, in turn, will render the roads connecting to Edirne unusable and it is considered that it would eventually be inconvenient for the local population.

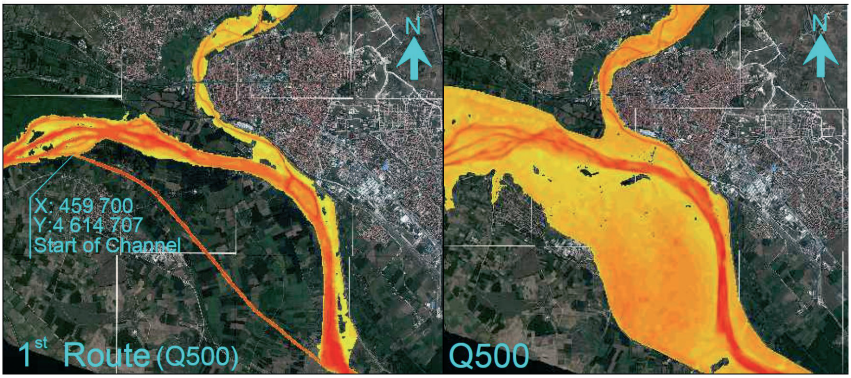

Figure 12. The 1st route 2D model.

The 2nd route planned for the drainage channel is shown in Fig. 13. It passes through the area between the Greece border and Karaagac neighborhood. It starts at the coordinates x = 458 138, y = 4 614 302 and ends at x = 464 089, y = 4 610 984. Channel length is 7060 m. In the determination of the route it was aimed to remove floods completely from Edirne's settlement areas. There is no settlement area between the channel and the Greek border. With this route, there will be no need to build new roads for transportation. The route joins Meriç River with an angle of 20°, from behind of Karaagac neighborhood. In consequence of 2D modeling, it is determined that the channel will be able to safely accommodate Q500 flow rate. It is observed that at the current status Edirne city center is not affected from flooding.

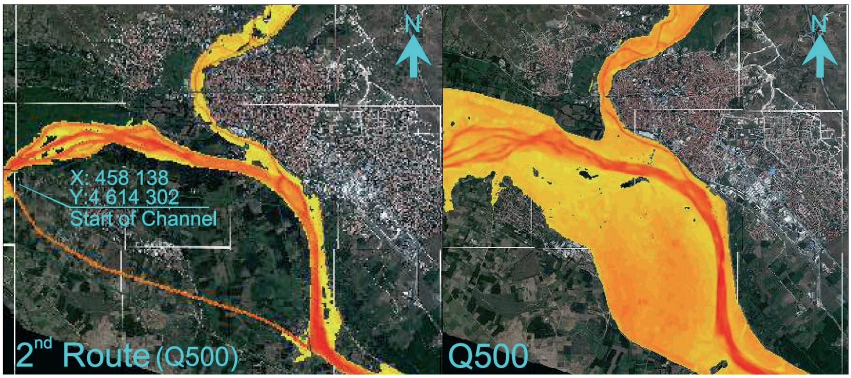

Figure 13. The 2nd route 2D model.

The downstream conditions of the drainage channel are important in terms of determining whether the solution proposal is appropriate. Three kilometers after the drainage channel joins Meriç River, the river forms the border

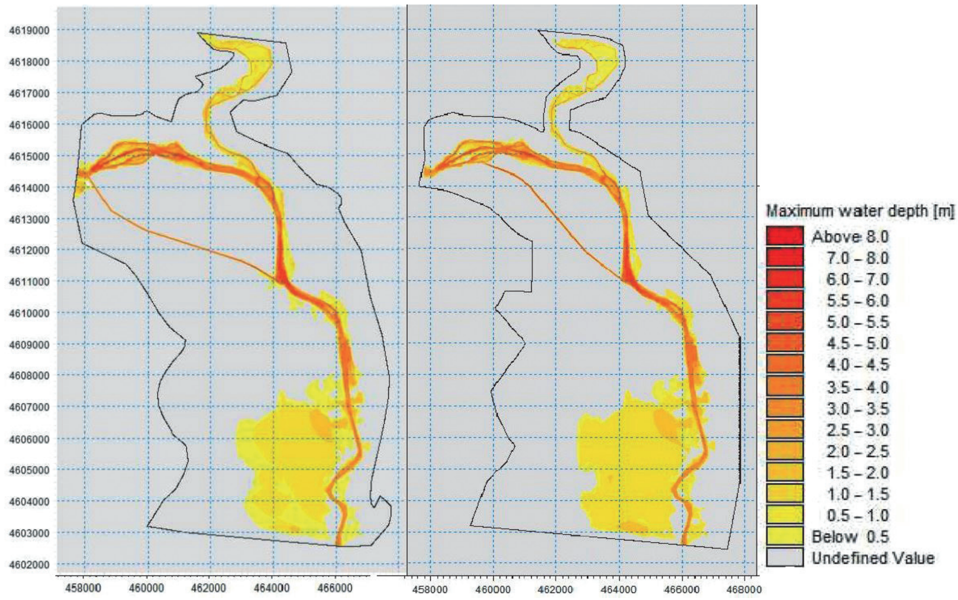

Figure 14. The 1st and the 2nd route 2D model downstream conditions.

between Turkey and Greece. With the conducted 2D modeling, downstream conditions of both routes are presented in Fig. 14. Examining the outcome of the model shows that due to the higher elevation on the Turkish side of Meriç River, it spreads to Greek agricultural lands. At downstream part there is no settlement area under risk. Both of the modeled routes are capable of safely accommodating floods. The choice between the two alternative routes can be made with the consideration of ease of construction and city zoning structure.

5. Conclusion

In consequence of the 2D flood simulations conducted on Meriç River, it was determined that the river bed is capable of safely accommodating a flow rate of 770 m^3/s, and that any flow rate above this causes flooding. It was also observed as a result of the modeling that the floods remain between the winter levees constructed between the years of 1955 and 1975. However currently there are settlement and social activity, recreation areas in these parts that are known to be flood areas. Floods mostly affect Karaagac neighborhood, Bosna village and the summer houses, restaurants, historic structures close to the river and the building of the provincial department of environment. During the floods transportation roads between Edirne and Karaagac Neighborhood and Alibeykoy, Umurca and Nasuhbey Villages become unusable and due to the flat geography of the terrain, waters usually cannot be drained quickly.

The current flood area is a large plain and with the protection of this area from floods a total of 2 300 ha area will be available for agriculture. Currently annual grain cultivation in the area is at a rather low level due to the risk of being exposed to flooding. Due to the floods that usually occur in February and March and the inadequate drainage between the levees flood water usually remain for a long period in the area and cause bottom fertilizer applied in autumn to be washed away. Also, the silt-sand layer brought along with flood waters further prevents plant development. Currently the area is mostly used for cultivating sunflower, corn and particularly paddy. With the prevention of the floods products that bring higher income such as vegetables, corn and beans can be cultivated, orchards could be an option to practicing.

Flood waters can break the levees built for flood-protection as it was the case in the 2006 flood, and thus floods can be effective also behind the levees. With the rise of the underground water level, leakages up to 50 cm depth can also occur behind the levees. It is understood that the criteria used for planning the levees in 1955 are no longer valid for today's conditions.

Within the scope of our study, a new solution was proposed with the consideration of the 2D modeling results and the measures taken until today for flood-prevention. Due to the flat structure of the terrain, the best solution to prevent floods is considered to be the construction of a drainage channel. The fact that both shores of the river is in Turkish s at the place it passes through Edirne makes the implementation of this solution possible. In order to ensure the sustainability of the solution downstream conditions at the point where the channel will join the river need to be well analyzed. At the point where the channel and Meriç River will join, the river bends left at an angle of 12°, and therefore the two alternative channels will join the river at 12° or 20° angle, and therefore would not cause gullying at the left shore of the river. Conducted modeling showed that Meriç River and the proposed channel would remove Q500 flow rate away from Edirne without causing any flood. After the point the channel joins Meriç River continues 3 km more within Turkish borders, and no flood water inundation takes place due to the high elevation on both sides of the river. However, after the point where Meriç draws the Turkish Greek border, flood waters may penetrate Greek soils on the right shore. The closest Greek settlement area here is Nea Yeyssa. In case of Q500 flow rate, flood waters would approach this settlement about 250 m. This distance allows the river bed to be cleared and extended. Thus, flood waters can be moved away towards Meriç downstream area which is already considered to be flood area.

Due to the high solid material content carried along with the floods it is considered that the capacity of the channel may be filled with such materials. In order to prevent this, solid material clearance operations need to be carried out during dry seasons. In this way, the channel will be a sustainable solution and Edirne can be protected from floods.

References

Akkaya, U., Doğan, E. and Ozcan, Z. (2015): Flood assessment of occurring Edirne in February 2015, in: *3rd International Symposium on Innovative Technologies in Engineering and Science*. Universidad Politecnica de Valencia, 2078–2087.

Angelidis, P., Kotsikas, M. and Kotsovinos, N. (2010): Management of upstream dams and flood protection of the transboundary river Evros/Maritza, *Water Resour. Manag.*, **24**, 2467–2484, DOI: 10.1007/s11269-009-9563-6.

Bladé, E., Gómez-Valentín, M., Dolz, J., Aragón-Hernández, J. L., Corestein, G. and Sánchez-Juny, M. (2012): Integration of 1D and 2D finite volume schemes for computations of water flow in natural channels, *Adv. Water Resour.*, **42**, 17–29, DOI: 10.1016/j.advwatres.2012.03.021.

Ceribasi, G. and Doğan, E. (2016): Application of trend analysis method on rainfall-stream flow-suspended load datas of West and East Black Sea basins and Sakarya Basin, *Fresen. Environ. Bull.*, **25**, 300–306.

Ceribasi, G., Doğan, E. and Sönmez, O. (2013): Evaluation of Sakarya River streamflow and sediment transport with rainfall using trend analysis, *Fresen. Environ. Bull.*, **22**, 846–852.

Ceribasi, G., Doğan, E. and Sönmez, O. (2014): Evaluation of meteorological and hydrological data of Sapanca Basin by trend analysis method, *J. Environ.Prot. Ecol.*, **15**, 705–714.

Cook, A. and Merwade, V. (2009): Effect of topographic data, geometric configuration and modeling approach on flood inundation mapping, *J. Hydrol.*, **377**, 131–142, DOI: 10.1016/j.jhydrol.2009.08.015.

DHI (2014): *MIKE 21 Reference Manual*. MIKE by DHI, available at https://www.mikepoweredbydhi.com/products/mike-21

Frank, E. A., Ostan, A., Coccato, M. and Stelling, G. S. (2001): Use of an integrated one-dimensional two-dimensional hydraulic modeling approach for flood hazard and risk mapping, in: *River Basin Management*, edited by Falconer, R. A. and Blain, W., WIT Press, Massachusetts, 99–108.

Hammond, M. J., Chen, A. S., Djordjević, S., Butler, D. and Mark, O. (2015): Urban flood impact assessment: A state-of-the-art review, *Urban Water J.*, **12**, 14–29, DOI: 10.1080/1573062X.2013.857421.

Hénonin, J., Hongtao, M. A., Zheng-Yu, Y., Hartnack, J., Havnø, K., Philipp, B., Gourbesville, P. and Mark, O. (2015): Citywide multi-grid urban flood modelling: The July 2012 flood in Beijing, *Urban Water J.*, **121**, 52–66, DOI: 10.1080/1573062X.2013.851710.

Horritt, M. S. and Bates P. D. (2002): Evaluation of 1D and 2D numerical models for predicting river flood inundation, *J. Hydrol.*, **268**, 87–99, DOI: 10.1016/S0022-1694(02)00121-X.

Huthoff, F., Remo, J. W. F. and Pinter, N. (2015): Improving flood preparedness using hydrodynamic levee-breach and inundation modelling: Middle Mississippi River, USA, *Journal of Flood Risk Management*, **8**, 2–18, DOI: 10.1111/jfr3.12066.

Kibaroğlu, A., Klaphake, A., Kramer, A., Scheumann, W. and Carius A. (2005): *Cooperation's on Turkey's transboundary waters: F+E, Project No: 903 19 226*. Federal Ministry for Environment - Nature Conversation and Nuclear Safety, Berlin, 167 pp.

Kılıçer, U. (2000): The Subcommittee report of natural disasters based on meteorological, Ankara, Turkey.

Knight, G. and Staneva, M. (1996): The water resources of Bulgaria: An overview, *GeoJournal*, **40**, 347–362, available at http://www.jstor.org/stable/41147007

Konrad C. P. (2014): Effects of urban development on floods, *U. S. Geologıcal Survey*, Fact Sheet 076–03.

Kryžanowski, A., Brilly, M., Rusjan, S. and Schnabl, S. (2014): Review article: Structural flood-protection measures referring to several European case studies, *Nat. Hazards Earth Syst. Sci.*, **14**, 135–142, DIO: 10.5194/nhess-14-135-2014.

Malkaralı, S., Korkmaz, M. S. and Sezen, N. (2008): International projects developed by related to floods and Maritsa River flood. Flood Conference. State Hydraulic Works, Edirne, **292**, 12–37.

Mason, D. C., Guy, J. and Schumann, P. (2010): Flood detection in urban areas using TerraSAR-X, *IEEE T. Geosci. Remote*, **48**, 882–894, DOI: 10.1109/TGRS.2009.2029236.

Orsam - Water Research Programme (2011): *The obligation of international cooperation in Meriç (Maritza-Evros) Basin water management.* Report No 4, 13–24.

Rozalis, S., Morin, E., Yair, Y. and Price, C., (2010): Flash flood prediction using an uncalibrated hydrological model and radar rainfall data in a Mediterranean watershed under changing hydrological conditions, *J. Hydrol.*, **394**, 245–255, DOI: 10.1016/j.jhydrol.2010.03.021.

Semadeni-Davies, A., Hernebring, C., Svensson, G. and Gustafsson, L. (2008): The impacts of climate change and urbanization on drenage in Helsingborg, Sweden: Suburban storm water, *J. Hydrol.*, **350**, 114–125, DOI: 10.1016/j.jhydrol.2007.11.006.

Sezen N. (2007): *River basin flood management: Meric River floods and Turkish-Bulgarian cooperation's*, DSI, 648.

Sönmez, M. F. and Kesici, O. (2012): The flood events in Kilis City depending on climate change and unplanned urbanization, *Eastern Geographical Review*, **28**, 57–77.

Sönmez, O. (2013): 2 Dimensional food models and creating flood inundation maps in rivers, Sakarya University, Ph.D. Thesis, 35–60.

Sönmez, O., Ceribasi, G. and Doğan, E. (2016): Short and long term streamflow prediction by different neural network approaches and trend analysis methods: Case study of Sakarya River, Turkey, *Fresen. Environ. Bull.*, **25**, 565–579.

Sönmez, O., Doğan, E., Ceribasi, G. and Demir, S. (2013): Impact of climate change on the daily water level fluctuation of Lake Sapanca, *Fresen. Environ. Bull.*, **22**, 1895–1903.

Sowmya, K., John, C. M. and Shrivasthava, N. K. (2015): Urban flood vulnerability zoning of Cochin City, southwest coast of India, using remote sensing and GIS, *Nat. Hazards*, **75**, 1271–1286, DOI: 10.1007/s11069-014-1372-4.

State Hydraulic Works (DSI) (2005): Press Release.

SAŽETAK

Generiranje 2-D karata poplave rijeka Meriç i Tunca koje prolaze kroz središte Edirnea

Uğur Akkaya i Emrah Doğan

Prirodne katastrofe možemo definirati kao opasne prirodne događaje, najčešće velikih razmjera, koji uzrokuju gubitke života i imovinsku štetu, a događaju se velikim dijelom ili potpuno izvan ljudske kontrole. Zbog klimatskih promjena posljednjih godina u različitim dijelovima svijeta događaju se jake suše. U nekim područjima je također uočen i porast učestalosti i jačine poplava. Kao što to navode mnoge znanstvene studije, za modeliranje poplava potrebno je izraditi strategiju upravljanja rizikom od poplava te poznavati dinamičko ponašanje rijeka. U tom kontekstu grad Edirne, koji se nalazi nizvodno od bazena rijeke Meriç, koja protječe kroz Tursku, Bugarsku i Grčku, često je izložen poplavama. Većina voda koje uzrokuju poplave akumulira se još u Bugarskoj, u kojoj se nalazi 66% riječnog bazena. Taj dio bazena je u planinskom području, čiji je prosječni nagib terena velik - 12.5%, dok je nagib terena u Erdineu malen - 0,036 %. Ova studija prikazuje 2-D modeliranje poplava rijeka Meriç i Tunca, koje prolaze kroz središte Erdinea te generiranje karata poplave. Analizom rezultata dobivenih pomoću karata poplave, dizajniran je drenažni kanal. Kapacitet drenažnog kanala dovoljan je za prihvat viška vode koju korito rijeke Meriç ne može prihvatiti. Također su procijenjeni i uvjeti nizvodno od kanala.

Ključne riječi: karta poplave, 2D model, MIKE 11 i MIKE 21, rijeka Meriç, odvodni kanal

Corresponding author's address: Uğur Akkaya, Sakarya University, Department of Civil Engineering, Esentepe Campus, 54187 Sakarya, Turkey; tel: +90 532 3610 736; e-mails: ugurakkaya@ibu.edu.tr, ugrakkaya@gmail.com