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Flood modeling in Samsun Engiz Stream: Evaluation of the adequacy of river sections with HEC-RAS

Vahdettin Demir*[1], Nazire Göksu Soydan Oksal[2], Neslihan Beden[3]

[1] *KTO Karatay University, Faculty of Engineering and Natural Sciences, Department of Civil Engineering, Konya, Türkiye;* vahdettin.demir@karatay.edu.tr
[2] *Mersin University, Faculty of Engineering, Department of Civil Engineering, Mersin, Türkiye;* goksusoydan@mersin.edu.tr
[3] *Samsun University, Özdemir Bayraktar Faculty of Aeronautics and Astronautics, Department of Meteorological Engineering, Samsun, Türkiye;* neslihan.beden@samsun.edu.tr

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Abstract: Floods pose a significant threat to communities, particularly in Turkey's Central Black Sea Region, where they cause widespread economic, social, and environmental damage. The Ondokuzmayis district of Samsun has been especially vulnerable to recurrent flooding, emphasizing the need for precise risk assessments and effective flood management strategies. In this study, the flood modelling of Engiz Stream, located in the Ondokuzmayis district of Samsun, was conducted using one-dimensional modeling due to its speed, low computational cost and ease of implementation. Hydraulic modeling was performed in HEC-RAS using flow data from Ballıca Station on Engiz Stream and statistical distributions from the EasyFit software library. In the study, flow rates for 25, 50, 100, and 500-year flood return periods (Q25: 431 m^3/s, Q50: 479.87 m^3/s, Q100: 531.75 m^3/s, Q500: 665.37 m^3/s) were calculated, and the flow was modeled using a 5-meter resolution digital surface model. The modeling results indicated that while the cross-sections in urban areas were adequate, the river cross-sections in the agricultural areas where the river flows into the Black Sea were insufficient for the Q25 flow rate and beyond.

Keywords: Samsun; engiz stream; flood modeling; HEC-RAS

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1. Introduction

Floods are defined as natural events that cause water that cannot fit into its bed to overflow into surrounding areas, affecting life in this region materially and spiritually. The effects of this disaster can now be predicted with the help of information systems that use statistical approaches and location-based analyses. In this way, necessary precautions can be taken before the incident occurs and natural disasters can be managed without crisis management.

Hydro-meteorological events, especially rain and snowmelt, can cause significant damage to surrounding habitats by overflowing streams from their main beds. River floods can affect areas that operate primarily in the fields of agriculture, animal husbandry, transportation, social areas and industry, and can cause serious material and moral damage in these regions. In addition, floods damage the ecosystem by disrupting the natural structure of the land in the region where they occur. The irregularity of weather events in recent years and increasing climate change make it easier to predict when and how large hydrological disasters such as droughts, landslides and floods will occur (Eryürük & Eryürük, 2024). The unexpected and random nature of floods poses challenges for developing hazard-risk management and mitigation strategies. For this reason, the impact of uncertainties in weather events on the process of flood occurrence should be evaluated with various scientific models and based on these models, precautions to minimize flood risk should be taken in advance. Considering the magnitude of direct and indirect damage that a potential flood can cause, determining the flood hazard and planning the necessary precautions in a timely manner has become a critical requirement to prevent loss of life and property (Doğu, 2016).

In recent years, using HEC-RAS (Hydrologic Engineering Center's River Analysis System) integrated with Remote Sensing (RS) and Geographic Information Systems (GIS) has become popular for many rivers flood modeling in the literature. Uçar (2010), was created the terrain model of the Değirmendere basin in Trabzon using ArcGIS; the flow rates with different recurrence periods were determined using statistical methods, and hydraulic analyses and flood maps were produced using HEC-RAS in line with this data. Çitgez (2011), stated that the Black Sea Region is one of the most sensitive regions of Turkey in terms of floods, inundations and landslides. In the flood modeling carried out for Kaynaşlı District of Düzce Province, the rainfall-flow relationship and peak flows were obtained. He also calculated the maximum flow rate that the river section could carry. As a result of the study, it was stated that the flow that would occur from 100-year recurring rainfalls is a flow that the river section cannot carry. Geyikli (2015), obtained flood maps for Q_{10}, Q_{25}, Q_{50}, Q_{100}, Q_{500} recurrence flow rates in the hydraulic analysis that is performed with HEC-RAS and HEC-GeoRAS software in a section of Derme Stream in Malatya Province. Demir & Kisi (2016), prepared flood maps for the Mert River in Samsun using GIS and HEC-RAS. Doğu and Yıldız (2019), carried out one-dimensional flood modeling in Çoruhözü Creek, a tributary of the Kızılırmak River located in Kırıkkale, using HEC-RAS. In their study, where they calculated flood peak flows using synthetic unit hydrographs and precipitation data, they emphasized that the cross-sections for 500 and 1000-year peak flows were insufficient. Peker et al., (2024) carried out flood modeling for the Göksu River passing through the center of Mersin-Silifke in the HEC-RAS environment and produced flood hazard maps. Flood modeling was performed using GIS, HEC-RAS and HEC-HMS (Hydrologic Modeling System). In the hydraulic model, Manning roughness coefficients obtained from 2018 CORINE data and 25, 50, 100, 500-year recurrence flow rates obtained from HEC-HMS were used. In the study carried out on 5 m resolution DEM, it was stated that water depths reached 10 m and water velocities reached approximately 0.7 m/s. Bozdoğan & Canbolat (2024) determined the flood risk potential of the Delibekirli Stream Basin passing through Hatay Kırıkhan. In the research conducted based on the flood records of 2014 and 2015, various project flood recurrence flow rates (2-1000 years) were calculated with statistical and deterministic methods. Hydraulic modeling was performed under one-dimensional steady flow conditions using HEC-RAS software and it was determined that construction increases the flood risk by narrowing the stream bed.

HEC-RAS is software commonly used in one and two-dimensional hydraulic modeling and analysis of rivers, streams and other waterways. Two-dimensional modeling considers not only the direction of flow of water, but also its lateral (transverse) movement. This is used to more accurately model the behavior of water, particularly in areas with large floodplains, wetlands, deltas, and complex topography. One-dimensional (1D) modeling is used to assess flood risk in river and stream systems, predict water levels, and analyze water flow. It also contributes to the efficient management of water resources by examining the effects of structural elements such as bridges, culverts and dams on water. This modeling is especially important in water engineering projects and flood management studies (Demir, 2020).

In this study, one-dimensional flood modeling of Engiz Stream located in Ondokuzmayis district of Samsun province was carried out. In the study, flood recurrence flow rates were obtained in the EasyFit software environment using river flow data and statistical methods. These flows are modeled in 1D in HEC-RAS software, and it is aimed to determine how the river will behave in recurring flows, the adequacy of river sections, the risk status of bridges in case of possible recurrences, and the upstream and downstream water levels. One-dimensional modeling is the most practical application of flood modeling studies and was applied to investigate the adequacy of river sections and the water carrying capacity of bridges over the river against possible scenarios.

2. Materials and Methods

HEC-RAS is software by the US Army Corps of Engineers and is widely used in hydrodynamic simulations (USACE, 2023). Users can access the software free of charge at "https://www.hec.usace.army.mil/". In this study, flood modeling was carried out in one-dimensional (1D). HEC-RAS analyzes 1D flow in rivers using the Saint Venant equation. The hydraulic model calculates the boundary friction force with a semi-empirical formula that takes into account channel roughness, such as the Manning equation (USACE, 2024).

$$S = \frac{AR^{2/3}}{N} S_F^{1/2} \tag{1}$$

Here, S is the flow rate, A is the cross-sectional area, R is the hydraulic radius, N is the Manning roughness coefficient and SF is the slope. The momentum equation is obtained by including the non-dimensional friction slope (SF) as follows:

$$\frac{\partial Q}{\partial T} + \frac{\partial SV}{\partial X} + gQ\left(\frac{\partial z}{\partial X} + S_F\right) = 0 \tag{2}$$

The final form of SF in the Manning equation is as follows.

$$S_F = \frac{Q^2 N^2}{R^{4/3} A^2} \tag{3}$$

EasyFit software was used to calculate the recurrence flow rates. The software ranks the data according to several distributions, draws the probability density function and tests the distribution suitability (Farooq et. al., 2018; Ministry of Agriculture and Forestry, 2015). Kolmogorov-Smirnov (KS) test was used to determine the appropriate statistical distribution for this study. After determining the most appropriate distribution, flood flow rates were obtained for various return period probability values.

2.1. Study area

The Yeşilırmak Basin is located in the north of Anatolia and discharges its waters into the Black Sea via the Yeşilırmak river system. The basin, which is bordered by mountain peaks such as Canik, Giresun, Gümüşhane, Pulur, Çimen, Kızıldağ, is surrounded by the Black Sea and other basins. The basin, which has an area of approximately 39,628 km^2, constitutes 5% of Türkiye's surface area. Engiz Stream (Figure 1a) located on the border of Yeşilırmak and Kızılırmak Basins and included in the Yeşilırmak Basin management plan is a stream source that starts at an elevation of 1300 m in the Central Black Sea Region and flows into the Black Sea by passing through the Ondokuzmayis district of the central districts of Samsun province (Ministry of Agriculture and Forestry, 2015). The region receives high rainfall, especially in winter and spring, due to the Black Sea climate. Therefore, the region carries a flood risk due to sudden water rises. The study area is shown in Figures 1a, b and c.

In this study, Engiz stream Annual Instantaneous Maximum Flow (AMF) data (m^3/s) were used and the data were obtained from the 7th Regional Directorate of State Hydraulic Works (DSI). Data from the Ballıca station numbered D15A039 for the years 1964-2022 were used. Ballıca station is located 3 km ahead of the asphalt road that turns left from the Ondokuzmayis district on the 33rd km of the Samsun-Bafra Highway. The station is located at 36°4'3" East longitude and 41°29'11" North latitude. While the precipitation area is 151.40 km^2, the approximate elevation value is 15 meters (General Directorate of State Hydraulic Works -DSI, 2024). The change of data is given in Figure 2.

In Figure 2, the highest AMF value is 350 m^3/s and was observed in 1967. The average of the AMF data is 90.6 m^3/s and shows an increasing trend over the years.

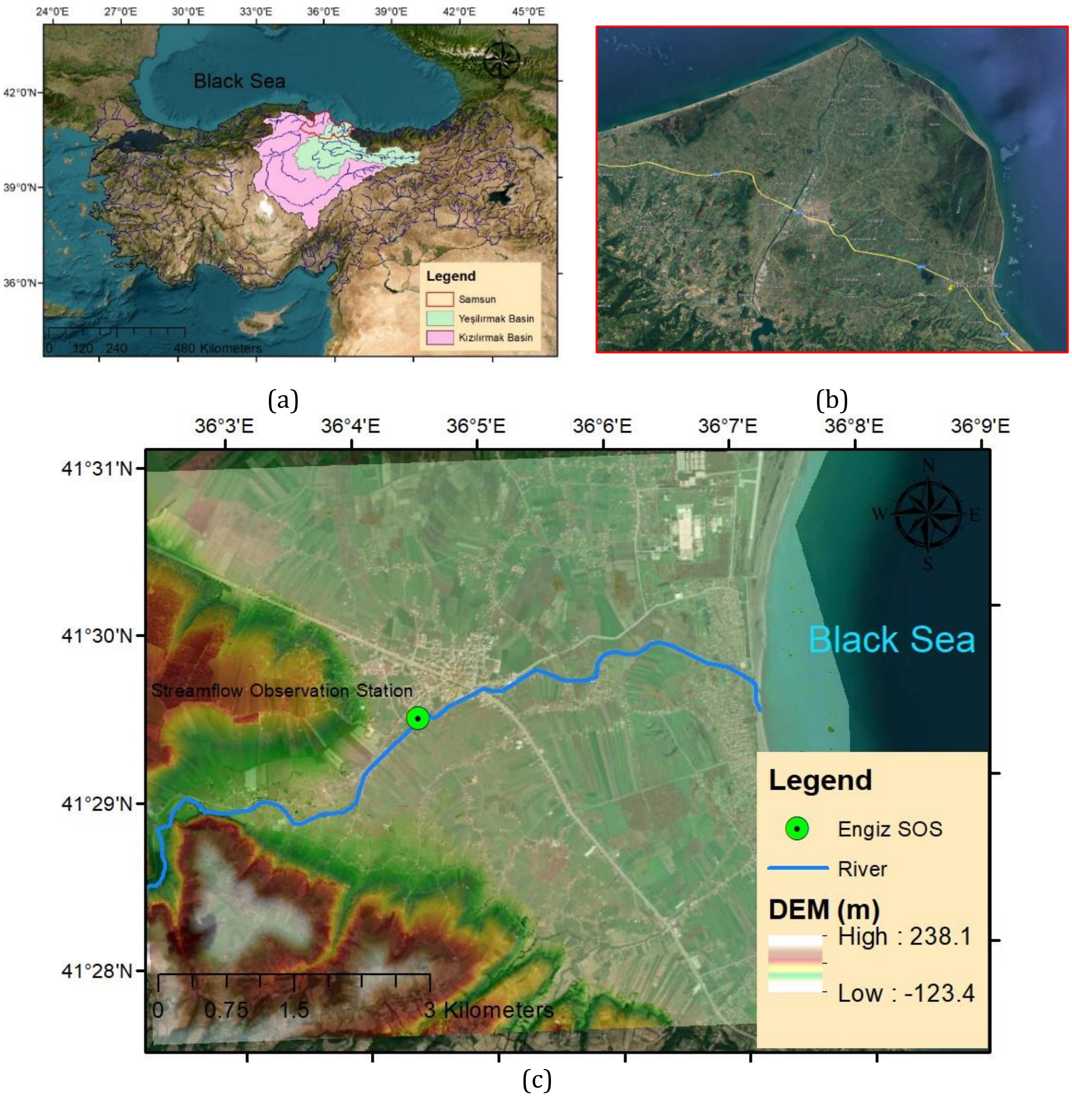

Figure 1. Study area: a) basin scale, b) region scale, c) HEC-RAS flood model area

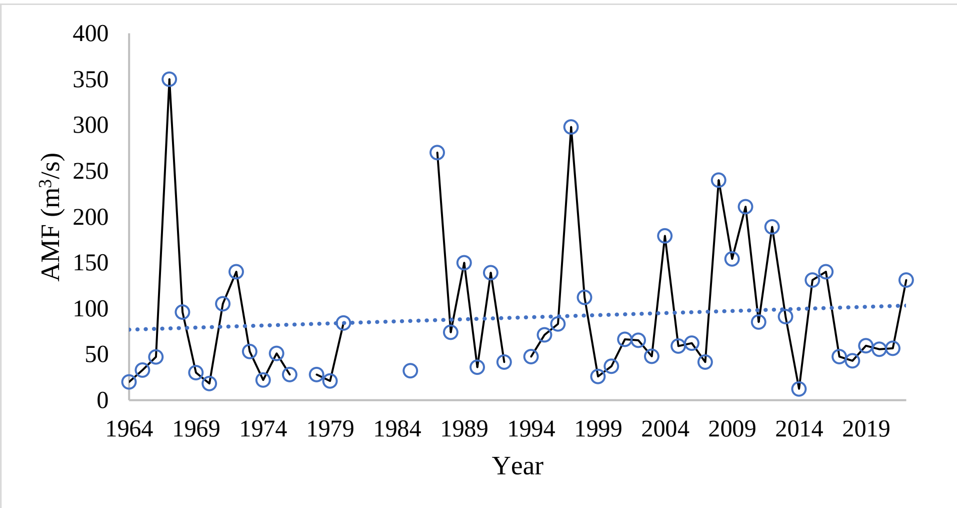

Figure 2. Annual change of AMF data

3. Results

In the study, it was determined that the best fit with the KS test was the "Wakeby" distribution. Other probability density curves examined are given in Figure 3.

Flood recurrence flow rates obtained with the probability value of the most appropriate distribution and recurrence periods are given in Table 1. In the study, hydraulic modeling was carried out for four different return periods (25, 50, 100 and 500 years) commonly used in literature.

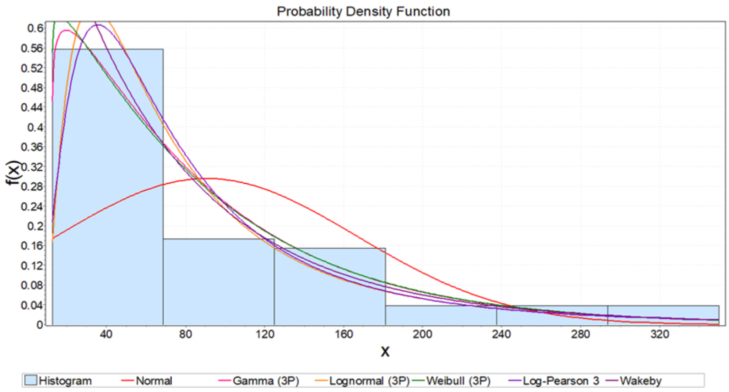

Figure 3. Probability density functions

Table 1. Return periods

Return Year	Q_{25}	Q_{50}	Q_{100}	Q_{500}
Flow Rate (m^3/s)	431	479.87	531.75	665.37

The flow value obtained in Table 1 was used as steady flow in HEC-RAS. The Digital Surface Model (DSM) used in the modeling has a resolution of 5 meters and was obtained from the General Directorate of Mapping. This data was obtained in 2018 using the image automatic matching method of stereo aerial photographs with 5 m grid spacing and 30 cm resolution and has UTM-WGS84 reference information (General Directorate of Mapping, 2024). The Manning value was assigned as a constant of 0.033 since only river sections were investigated (Demir & Keskin, 2019). After defining the river geometries, energy and momentum equations and coefficients depending on the bridge properties (Pier Shape Drag Coefficients=2; Pier Shape Yarnell K Coefficients=1.25) were determined via the Bridge Modeling Approach editor. For details, USGS (2010) can be examined. Then, steady flow modeling was performed at the critical depth boundary condition. River profiles obtained according to recurrence flow rates are given in Figure 4.

When Figure 4 is examined, it is determined that the first of the 4 bridges (the pedestrian bridge close to the source) defined on the DEM and the last bridge (before the Black Sea exit) are risky at the border position at Q_{25} flow rate, while they are insufficient at the following flow rates. Bridges within urban areas were determined to be sufficient in terms of cross-section and water flow. The areas where cross-section deficiencies are seen are shown in Figure 5 below.

When Figures 4 and 5 are examined, it is determined that the sections where the river sections are insufficient in the region are in the agricultural areas before the urban zone and in the area where the river exits the Black Sea after the urban zone. Although these results show that the river sections are insufficient, they also show that 2D modeling is needed in the region to determine whether the spread of water poses a risk.

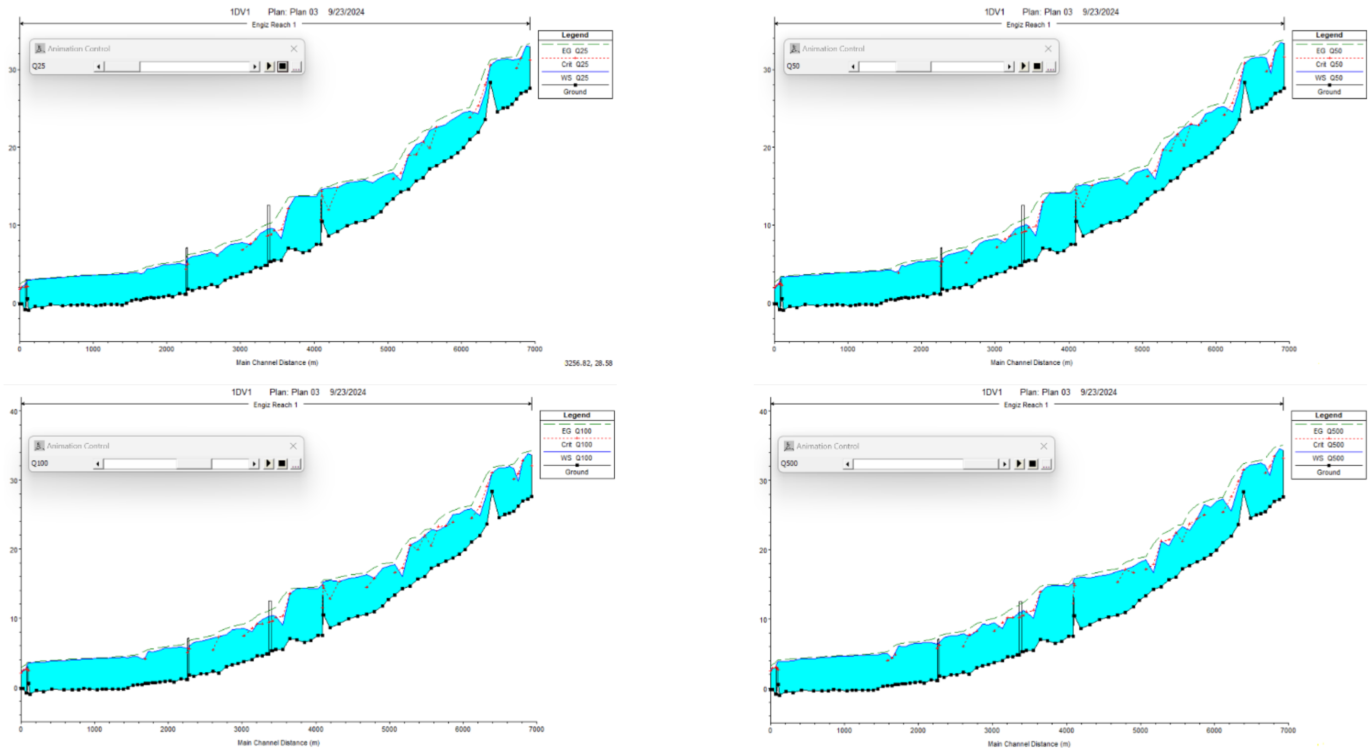

Figure 4. River profile for Q_{25}, Q_{50}, Q_{100} and Q_{500} flow rates

(**a**) (**b**)

Figure 5. (a) Downstream section, (b) Upstream section

4. Discussion

HEC-RAS is widely accepted as a reliable and widespread tool in 1D flood modeling. Its structure based on extensive engineering practice and solid theory enables the model to be used effectively in analyzing flow dynamics and flood risks. Its user-friendly interface allows easy modeling of different scenarios, while its extensive database and supporting documentation increases the flexibility of the model (USACE, 2024). However, the 1D modeling approach of HEC-RAS also has some limitations. Since the model is considered as one-dimensional (1D) flows, it may be insufficient to fully reflect complex geometric structures, side currents, and three-dimensional flow characteristics. Uncertainties may be present in the results of the model in areas where branches separate and merge. In this respect, the studied region was modeled on a single channel, and the inadequacy of the sections was resolved quickly and practically with one-dimensional modeling. To increase the accuracy of the model results, it is critical to calibrate HEC-RAS outputs with field data and/or remote observations and 1D and 2D hybrid modelling (Tektaş & Polat, 2021; Yiğit & Kaya, 2020). In this context, past flood images, especially water marks on buildings, are important in validating the model (Demir, 2020).

The calibration process increases the predictive power of the model, especially for extreme flood situations (Demir & Keskin, 2021). In this context, changing the manning values and verifying the flow observations with the model results are the most preferred calibration techniques. In this study, the manning definition was evaluated with a fixed value of 0.033 only for the middle river region and slopes, and since past flood images could not be accessed.

The results obtained in the study provide important findings regarding the flood risk around the Engiz Stream. It has been determined that the hydraulic infrastructure, especially pedestrian and road bridges, in the region where the river flows into the Black Sea cannot safely transfer flood flows. This situation shows that in addition to pre-flood non-structural measures, interventions aimed at infrastructure improvements are also critical. While it is a positive result that bridges in urban areas can pass Q_{25} to Q_{500} flow rates, the need for two-dimensional modeling in rural and agricultural areas indicates the need for more detailed studies for risk analysis (Demir et. al., 2021) Future two-dimensional modeling will enable the effects of floods to be evaluated from a broader perspective, contributing to the reduction of economic losses and sustainable disaster management.

5. Conclusions

Floods are defined as natural disasters that negatively affect the economic and social life of the people in the region where they occur. It is known that the risks of this disaster can be minimized by taking non-constructive measures, especially before the flood occurs. In this context, flood modeling is one of the most practical tools. In this study, 1D flood modeling of Samsun, Ondokuzmayis Engiz Creek, which was selected as the application area, was carried out using 5-meter DSM and AMF data with HEC-RAS and EasyFit software. As a result of the study, it was determined that the sections in the region where the river enters the urban area and then empties its waters into the Black Sea are inadequate, and the pedestrian and highway bridges in these regions are inadequate to pass water, but the bridges in the urban area can pass Q_{25} to Q_{500} flow rates. In addition, the findings showed that there was a need for two-dimensional modeling in the region due to insufficient cross-section in one dimension.

Successful applications of HEC-RAS provide effective results in case of using high resolution bases of the model and verified rainfall, flow and flood hydrographs. However, to eliminate the limitations encountered in the modeling process, it is suggested in the study to increase the data diversity and quality (e.g. integration of different Manning values, investigation of base flow and different flood discharges) and to support it with two-dimensional modeling. In future studies, the distribution of the flood, danger and risk status will be investigated with two-dimensional modeling, which is intended to be carried out. In addition, economic losses against possible flood scenarios will be examined with two-dimensional modeling.

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V. Demir: Conceptualization, Software, Writing—original draft preparation.
N. G. S. Oksal: Conceptualization, Visualization, Writing—reviewing and editing.
N. Beden: Conceptualization, Data curation, Writing—reviewing and editing.

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