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Research Article

Flood Analysis with HEC-RAS: A Case Study of Tigris River

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Floods are seen in countries in tropical climatic zones, both in terms of quantity and harm. The non-tropical climate countries such as Turkey are also affected by the floods. The geographical structure of Turkey is extremely complex and varies even at short distance. Therefore, the shape and effects of the floods vary from region to region. Considering the peculiar state of nature, floods, which are the greatest disasters after the earthquake, are unlikely to occur. But floods are becoming more risky for human beings day by day because of the population growth, need of water and settlements, wrong zoning plan, and unplanned engineering practices. Regulation comes at the beginning of measures to be taken to minimize the damages that occur from the floods. To do these studies, it must be specified the changes which bridges on the rivers and hydraulics structures like regulator cause in cross sections and the effects of the changes to water surface profile due to the natural state of the land. In order to determine water surface profiles, many software packages have been developed for facilitating the analysis and calculation. HEC-RAS is one of them. In this study, the floodplain analysis was handled between Diyarbakır-Silvan Highway and historical Ten-Eyed Bridge. There are three bridges, and one of which are historical bridges, as well as fertile agricultural lands, facilities, and hospitals in the Dicle University campus, the Hevsel Gardens on the UNESCO World Cultural Heritage List, and some residential areas on the route under study. The aim of the study we have done in this much important route is to evaluate the flood areas and create a flood hazard map which can predict risky areas. And also contributing to the Tigris River Rehabilitation Project is one of the aims. About methodology, the 1/1000 maps of the study area were digitized using the AutoCAD Civil 3D program and cross sections were made by obtaining the digital elevation models of the region. The obtained cross sections were defined in the HEC-RAS software, and the hydraulic characteristics of the flood bed and the water surface profiles of the Q_{25}, Q_{50}, Q_{100}, and Q_{500} flood recurring and one-dimensional floodplain analysis of the Tigris River were determined.

1. Introduction

Flood can be defined as the flooding of areas that are not normally submerged as a result of higher current and level rise in a stream. Floods are among the main causes of natural disaster damage in many parts of the world, as well as can be determined by the causes affected environment. For this reason, the relationship between the flooded environment and flood characteristics should be investigated in detail [1]. River floods occur as a result of the sudden and heavy rainfall on the basin or the sudden melting of snow masses on the surface. Coastal floods occur on coasts because of solid movement due to fluctuations. Due to insufficient drainage systems, there are different types of floods, including floods caused by prolonged groundwater accumulation in sudden rainfall and storm conditions. In developed countries, the loss of life is reduced due to the development of flood detection services, while in less developed countries this problem is larger [2].

While most of the methods used for flood control and analysis were labor-free methods up to ten years ago, in recent years, ready-to-use package programs have been used [1]: HEC-RAS developed by the US Military Engineering Unit and MIKE 11-DHI developed by the Danish Hydrological Institute (DHI). These programs examine water surface profiles caused by hydraulic structures or changes in the route. In addition, these programs are used in the design of hydraulic structures by considering factors such as determination of flood levels.

Table 1: Tests of normality.

	Kolmogorov–Smirnov[a]			Shapiro–Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Daily maximum current	0.169	33	**0.018**	0.874	33	**0.001**

[a]Lilliefors significance correction.

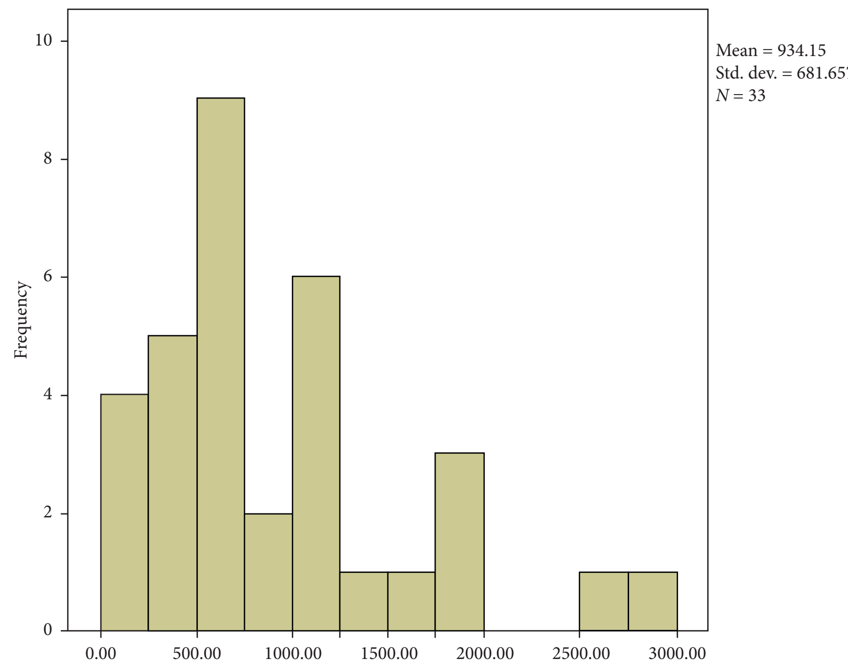

Figure 1: Daily maximum current (histogram).

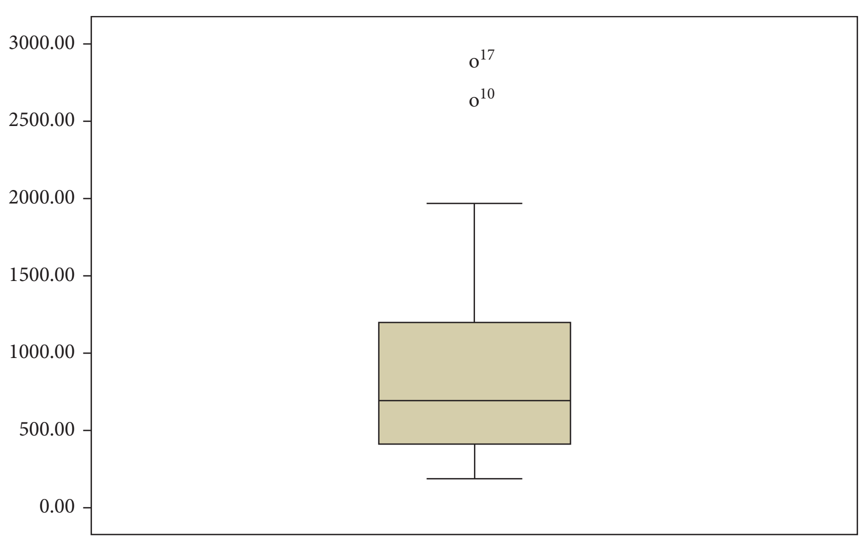

Figure 2: Daily maximum current (box plot).

Seckin [3] has determined that the results are approximated by applying the COH method to the experimental data for calculating the water profile and flow relationship. He used Energy Method, Momentum Method, Yarnell Method, WSPRO Method, HR Method, and USBPR Methods for one-dimensional flow analysis around bridge structure and tried to determine their reliability. He found that the results of outputs of energy equation were close to the experimental outputs, but in the others it was found to be different. Yurtal et al. [4] modeled the water surface profile calculations on the Seyhan River created by the regulator and the bridges in different sections by using the HEC-RAS program. Kara [5] has built

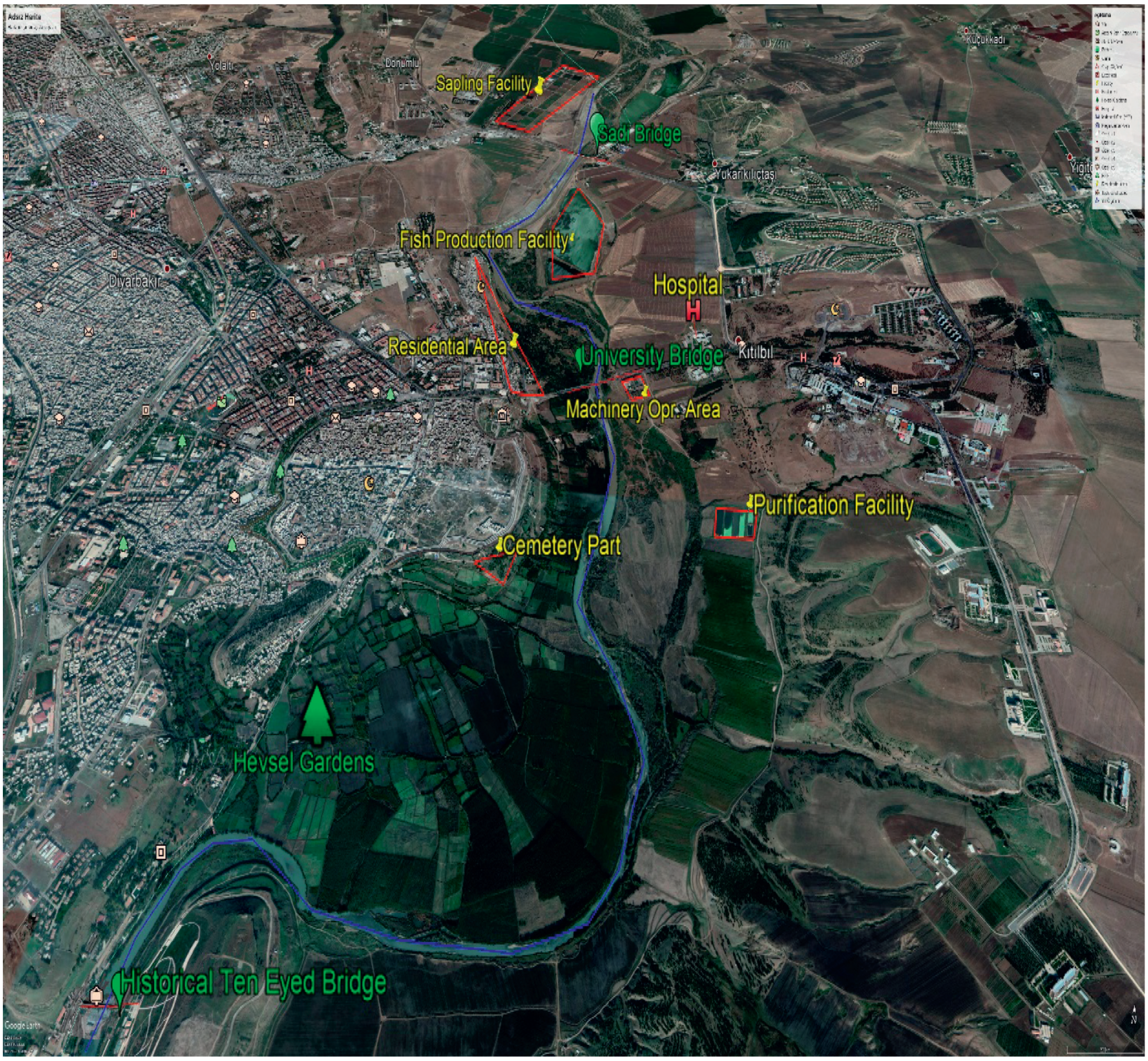

Figure 3: Tigris River studied route.

Table 2: Roughness coefficient calculation in different parts of the Tigris River.

Manning roughness coefficient	0 + 000.00~6 + 000.00 km (between historical bridge and University Bridge)	6 + 000.00~10 + 200.00 km (between University Bridge and Sadi Bridge)
n_0	0.028	0.028
n_1	0.005	0.020
n_2	0.000	0.005
n_3	0.000	0.000
n_4	0.040	0.045
m	1.150	1.150
$n = m(n_0+n_1+n_2+n_3+n_4)$	**0.08395**	**0.1127**

open-channel system and rectangular cross section models with different openings and sections on the system in the laboratory to determine water surface profiles. This created system was defined in the HEC-RAS program, at the same time; the results obtained in experimental studies are consistent with HEC-RAS results. Tuncer [6] examined the flood analysis of the Nakkaş Creek, causing loss of life in the floods in 2009, in the Kücükcekmece District of Istanbul using the HEC-RAS program. In this study, an Excel worksheet was prepared for the application of the Standard Step Method and Manning Formula. As with HEC-RAS, water levels were determined using Simplified Universal Method and Keulegan formula for

(a) (b) (c)

Figure 4: (a) Sadi Bridge, (b) University Bridge, and (c) Ten-Eyed Bridge views.

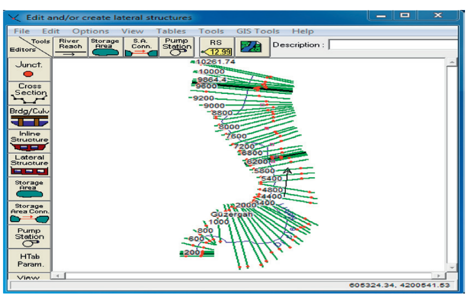

Figure 5: Cross sections of the route.

average flow rate using Standard Step Method. When the results of the study were compared with the HEC-RAS outputs, the water levels obtained from the Manning Formula were found to be lower than the Keulegan and Simplified Universal Methods. Deng and Li [7] applied the HEC-RAS model to the flood ground control evaluation of the Meg River Bridge and indicated that the model could be applied to the analysis of stagnant water elevation changes. Hameed and Ali [8] estimated Manning's roughness coefficient for Hilla River through calibration using the HEC-RAS model. Efe [9] studied on the Batman River which has a great flow and sometimes causes loss of life and property and concluded that Batman River regulation works carried out by DSI will be sufficient for the construction of the Batman River by using the HEC-RAS package program. Bagatur and Hamidi [10] evaluated stream characteristics of downstream flood problems after dam construction. Abdelbasset et al. [11] applied the HEC-RAS model to calculate the water surface profiles corresponding to the flood boundaries in the selected area below the Al Wahda Dam in the Sebou basin of northern Morocco. Khattak et al. [12] used HEC-RAS and ArcGIS to map a flood boundary of the Kabul River in Pakistan. Rajib et al. [13] evaluated the flood analysis of the Ohio River Basin in the US using a 1D/2D connected hydrodynamic model LISFLOOD-FP combined with hydrological model Soil and Water Assessment Tool (SWAT). According to the results of both studies, the hydrodynamic model could be used to evaluate the effects of climate change and land use changes on soil risks in river basins. Ullah et al. [14] used Pakistan remote control, geographic information system (GIS), HEC-RAS (1D), and HEC-Geo RAS combination to obtain flood prediction studies of Kalpani River. The results of the study showed that the results of the simulation showed a good performance in close match with the observed water surfaces. Yaylak [15], tried to determine the flood effect of Bitlis Stream, which can reach large flows from time to time and thus cause loss of life, by using HEC-RAS program and Geographical Information System (GIS), to the Bitlis Province with irregular urbanization. During this study, 1/5000 scaled current maps were digitized using ARGIS and height models were determined by using HEC-RAS software. The obtained water surface profiles were transferred to HEC-GEORAS software to obtain flood spread maps. Onen and Bagatur [16] have predicted flood frequency factor for Gumbel distribution with regression and GEP models. Bagatur and Onen [17] have presented the development of a predictive model for flood routing using genetic expression programming. Romali et al. [18] presented application of HEC-RAS and ARC GIS for floodplain mapping in Segamat town, Malaysia. Khalfallah and Saidi [19] have presented spatiotemporal floodplain mapping and prediction using HEC-RAS-GIS tools in the Mejerda River, Tunisia. Dysarz [20] has investigated application of Python scripting techniques for control and automation of HEC-RAS simulations. Baniya et al. [21] investigated hydraulic parameters for sediment transport and prediction of suspended sediment for Kali Gandaki River Basin, Himalaya, Nepal. Hırca and Sönmez [22] tried to determine flood inundation maps in Akyazi industrial zone.

In this study, the bridges over the Tigris River and the cross section changes caused by these hydraulic structures and also the current natural section changes were determined by the HEC-RAS program. As a result, the effects of flood spread maps on Dicle University hospitals, social and production (wood industry, fisheries, and fruit production) facilities, residential areas, historical Ten-Eyed Bridge, which

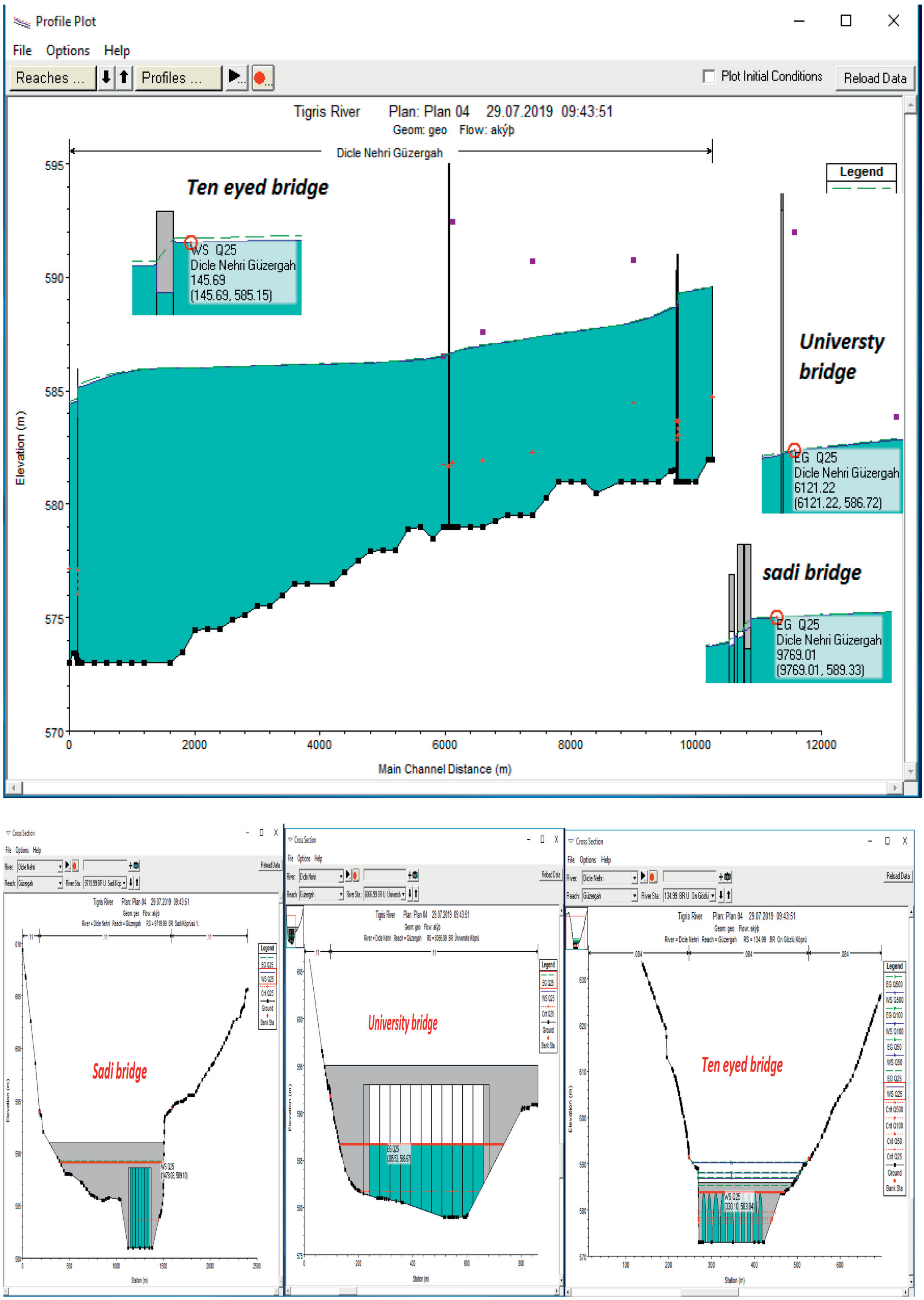

Figure 6: Water surface profiles for bridges (Q_{25}).

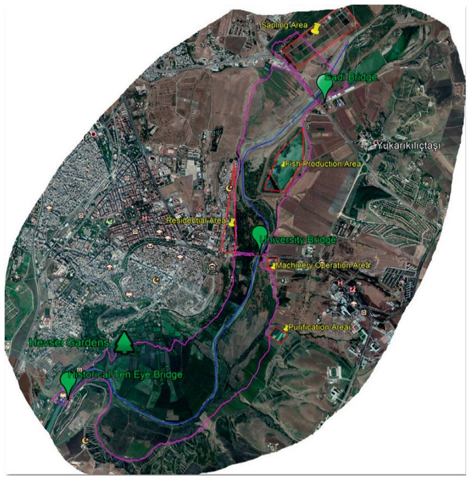

FIGURE 7: Flood boundary with HEC-RAS (Q_{25}).

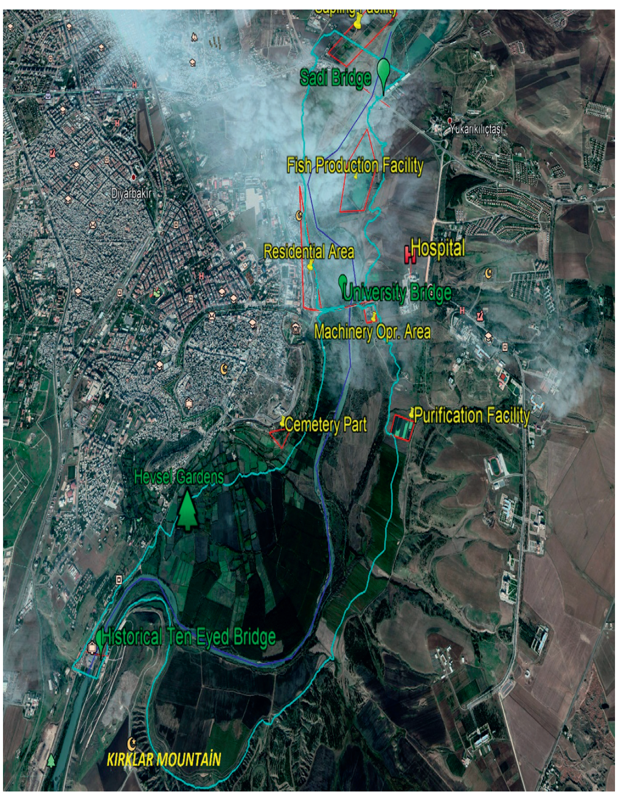

FIGURE 8: Flood boundary with HEC-RAS (Q_{100}).

are important in terms of tourism, and the Hevsel Gardens in the UNESCO World Heritage List were determined.

2. Material and Method

2.1. Studied Area and Characteristics. Tigris River is the second largest river in Turkey after the Euphrates. The total length of the Tigris river is 1840 km and the part of the territory of Turkey in the Tigris River is 523 km. Annual soil water potential in Tigris subbasin within the borders of Turkey, which has 57 614 km^2 in area, is 21.3 billion m^3. There are very serious erosion and sediment problems in the Tigris River. The amount of sediment carried was 15.189×10^6 m^3/year and 9.8% in the form of Turkey. The accumulation of sediments, losses in the fields, floods caused by the filling of natural and artificial channels with sediments, and siltation problems in reservoirs are not to be underestimated. The Tigris basin is generally low mountainous, but the high mountains in the north have a distinct impact on the local climate. The high-pressure area in winter causes the winter months to be cold. It is very hot during the summer months due to the influence of the southern desert climate and also because the high mountains in the north prevent the cool air masses from entering the south. The average rainfall in the region is 44% in winter, 38% in spring, 3% in summer, and 15% in the fall season. On the Tigris River, Diyarbakir, Batman, and Cizre provinces are located in the floodplain of the Tigris River. Especially in the fall of 2006, 41 citizens lost their lives as well as hundreds of houses; farmland and workplaces have become unusable [23].

"Hydrology" is of great importance in the healthy selection and project planning of flood protection measures for all existing and planned structures in river basins with flood problems. Within the scope of meteorological observations, precipitation, temperature, evaporation, humidity, and wind measurements are taken. In determining floods, total areal precipitation data are often used for years to calculate the relationship between precipitation and flow [24]. Therefore, the basin size will affect the total volume of flow in the stream and the shape of the hydrograph.

Perennial streams or streams that flow continuously throughout the year are most likely to be fed by groundwater [25]. These streams contain a base flow component and are candidates for hydrograph analyses. Five flood distribution models were tested for frequency analysis which are frequency distribution functions, namely, normal distribution, log-normal distribution (3 parameters), log-Pearson type III (Gama type III), log-Pearson type III distribution, and Gumbel's distributions. While our current data were tested in 1946-2000 years in order, the 10th value (2633.00) and 17th value (2864.00) were perceived as outlier (extreme) values by the program. However, the results were made by including all values. Since the obtained 0.018 Kolmogorov–Smirnov p (sig.) value is less than 0.05 limit value, the result is not suitable for normal distribution (Table 1). The Shapiro–Wilk test is like the Kolmogorov–Smirnov test. It gives safe results for less than 50 data groups. The analysis results obtained are consistent with each other. According to the results of the analysis, the histogram of the maximum daily precipitation is shown in Figure 1. In addition, our current data were found to be left-prone according to the box plot chart (Figure 2). The LP3 distribution was found to be the best distribution for the Tigris River using the Kolmogorov–Smirnov (K-S) test to calculate overflows with different rotation times. Daily maximum current data of the Station between 1946-2000 years on the Tigris River were used by using LP3 distribution and the Q_{25}, Q_{50}, Q_{100}, and Q_{500} year-repeat flow rates of 2598.18 m^3/s, 3209.47 m^3/s, 3871.28 m^3/s, and 5450.71 m^3/s were calculated, respectively.

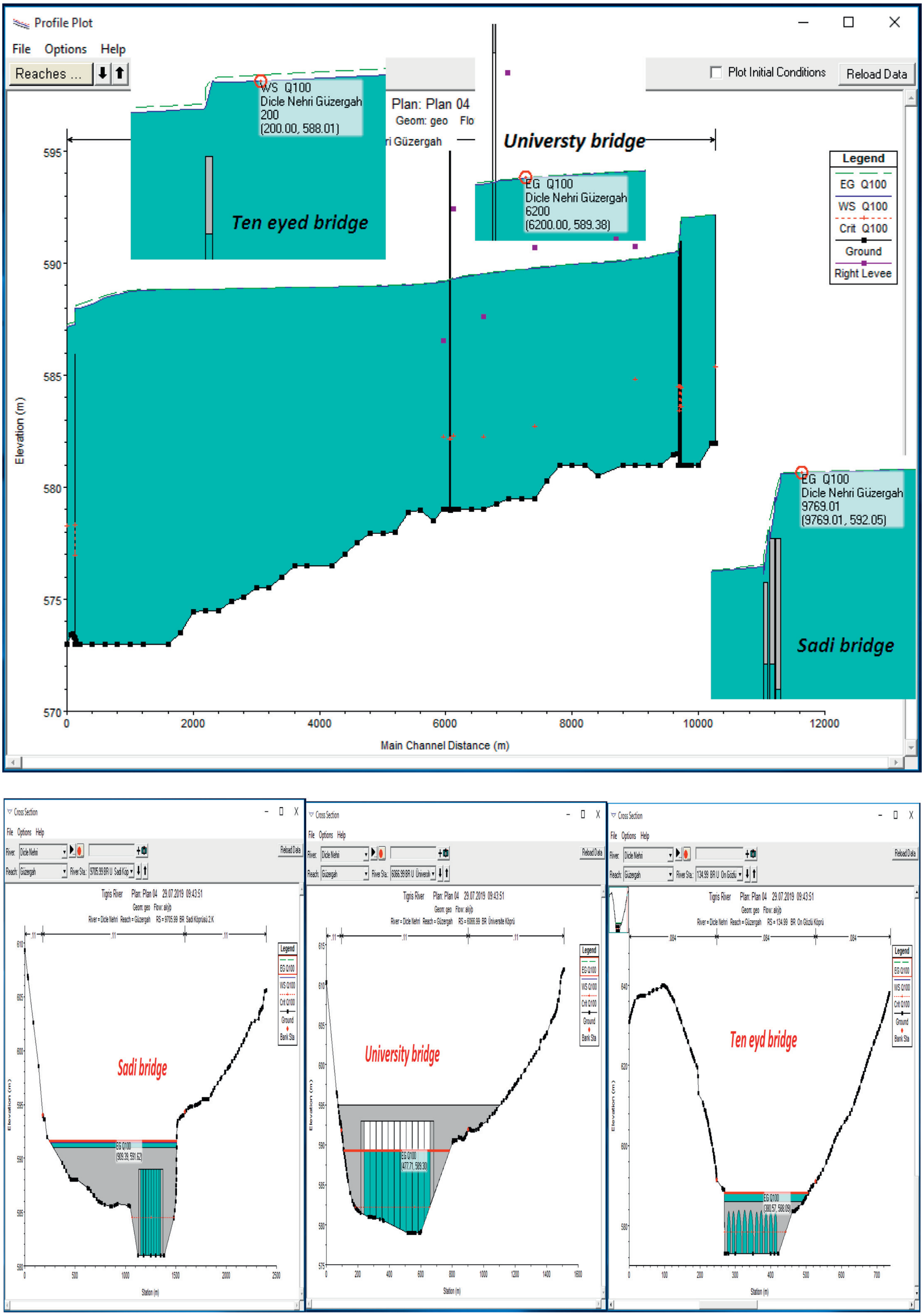

Figure 9: Water surface profiles for bridges (Q_{100}).

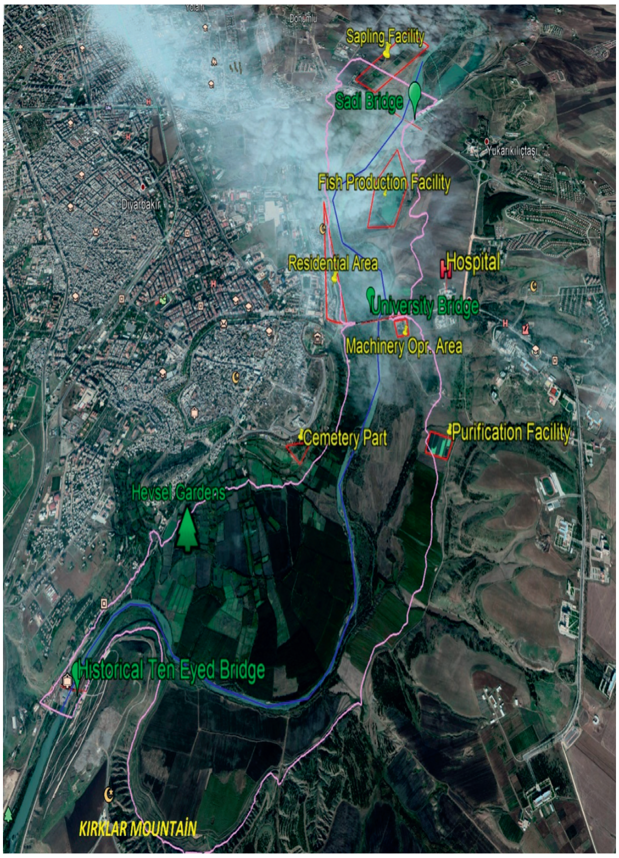

Figure 10: Flood boundary with HEC-RAS (Q_{500}).

The 10 km section between the Sadi Bridge on the Diyarbakir-Silvan highway and the historical Ten-Eyed Bridge (Dicle Bridge) was considered as a study area. The Tigris River, which flows in a wide valley with a low slope, is characterized by lowland streams, so there are settlements along the river and fertile farmland (Figure 3).

"n" roughness coefficient plays an important role in obtaining full and accurate water profile. This value varies depending on many factors. In general, if the profile information is well known, the value of "n" must be adjusted more precisely. If there is no specific case, then the near "n" values obtained from the experiments can be used. There are many reference values available to the user for many different channel types. However, when data obtained from the prepared graphs were used, significant differences were observed between the predicted velocities and the actual flow rates [26]. For this reason, besides the data in the table, a more effective result can be obtained by comparing the photographs taken in the study area by using empirical/physical relations and by using the method developed by Cowan [27]. He has developed an equation that shows the effect of all these factors on the roughness value:

$$n = \left(n_b + n_1 + n_2 + n_3 + n_4\right)m, \tag{1}$$

where n_b = the value of the natural material contained in the proper channels, n_1 = the value used for taking surface irregularities, n_2 = the value used for the shape of the channel and the cross section changes, n_3 = the value used for the obstacles in the channels, n_4 = the value used for the vegetation in the channels, and m = the correction factor to take into account the meandering of the channel.

In this study, two different roughness coefficients were calculated between the kilometers mentioned below (Table 2) as a result of the photographs taken in the route and observations made in the Tigris River natural state investigations to estimate the Manning values.

The data obtained as a result of the observations and researches in the 10 km section (Figure 3) around the Diyarbakır settlement of the Tigris River were brought together, and the calculation was made by defining the HEC-RAS program. Thus, water surface profiles formed from upstream to downstream, velocity graphs, graphs showing the relationship between elevation and discharge, and perspective views of the route were obtained. There are three hydraulics structures on our route, which are Sadi Bridge (L = 200 m), University Bridge (L = 400 m), and historical Ten-Eyed Bridge (L = 170 m) (Figure 4). Sadi Bridge consists of three different bridges that are built side by side at different times. The effects of these different bridges on the water surface profiles were determined by defining the HEC-RAS program. In addition, some important places are located on our route which are Hevsel Gardens, social and production (nursery, fishery, and fruit growing) facilities, partial settlements, and the hospitals and settlements of Dicle University.

2.2. Method. The method followed in this study is as follows: 1/1000 maps of the study area were obtained. Current flows and hydrological data were obtained from previous years. Hydraulic structures in the working route were determined. Cross sections along the route at 200 m intervals with the aid of the AutoCAD Civil3D package program and 2000 m wide at the right and left chambers were created (Figure 5). Due to the fact that hydraulic structures such as bridges are critical structures, it was tried to make a better analysis by reducing the cross section of these structures up to 5 m. Water surface profiles and flood boundaries were determined by hydraulic structures and hydrological parameters defined in the HEC-RAS program.

2.3. HEC-RAS Program. This program, which performs river analysis developed by the US Land Forces Engineering Group, makes hydraulic calculations in semiunsteady, unsteady flows with one- and two-dimensional unsteady river flow calculations with one-dimensional steady hydraulic flow. The first version of HEC-RAS was released in July 1995. Since then, the versions of this software package include 1.1/1.2/2.0/2.1/2.2/3.0/3.1/4.0/4.1/5.0/5.01/5.03/5.04/5.05/5.06 and the latest version of 5.07. The 4.1 version was used in this study.

In this program, subcritical, supercritical, and mixed flow solution options are provided for the determination of water surface profiles under stable current conditions. In this program, one-dimensional energy equation is used for the solutions made under steady flow conditions. Friction

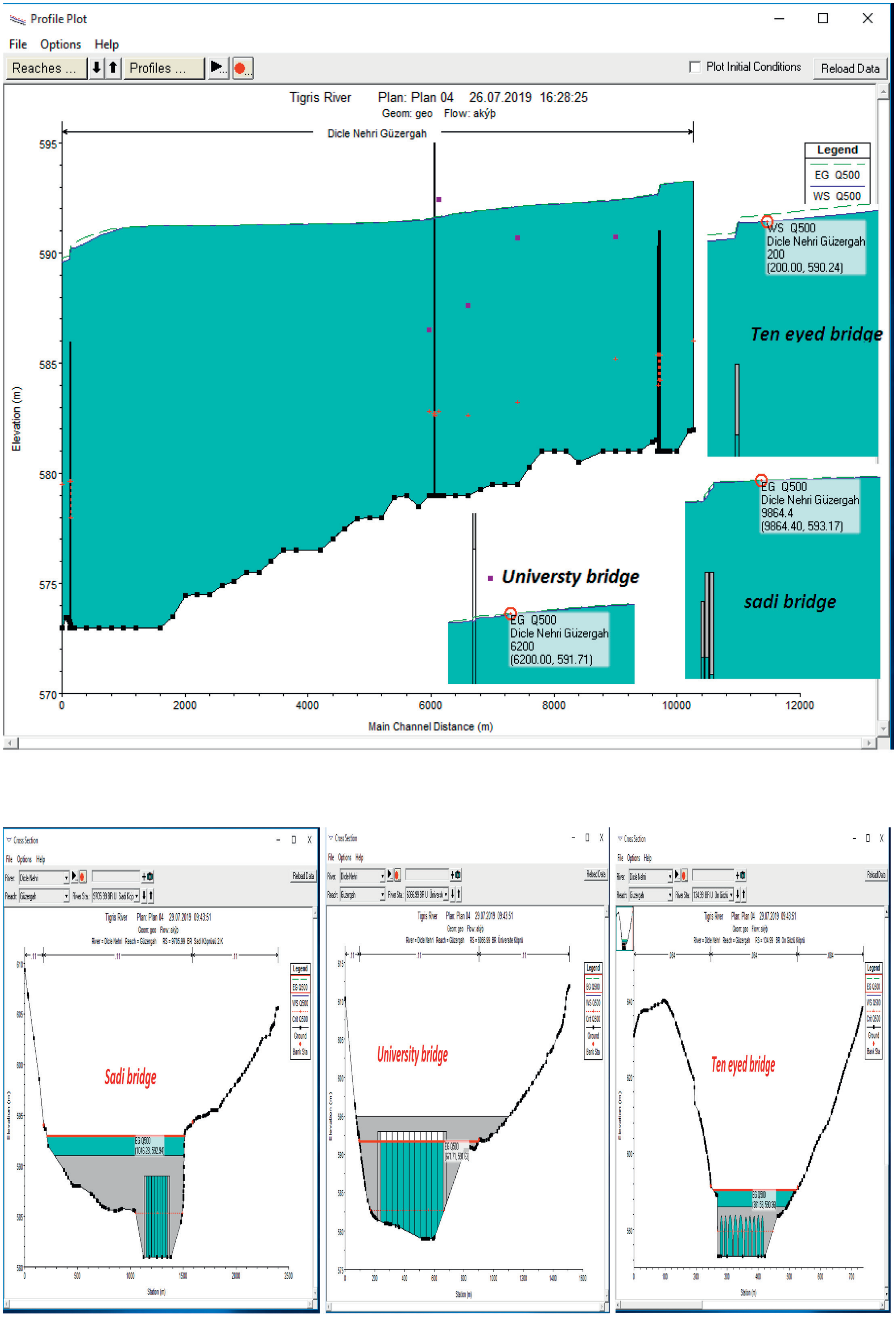

Figure 11: Water surface profiles for bridges (Q_{500}).

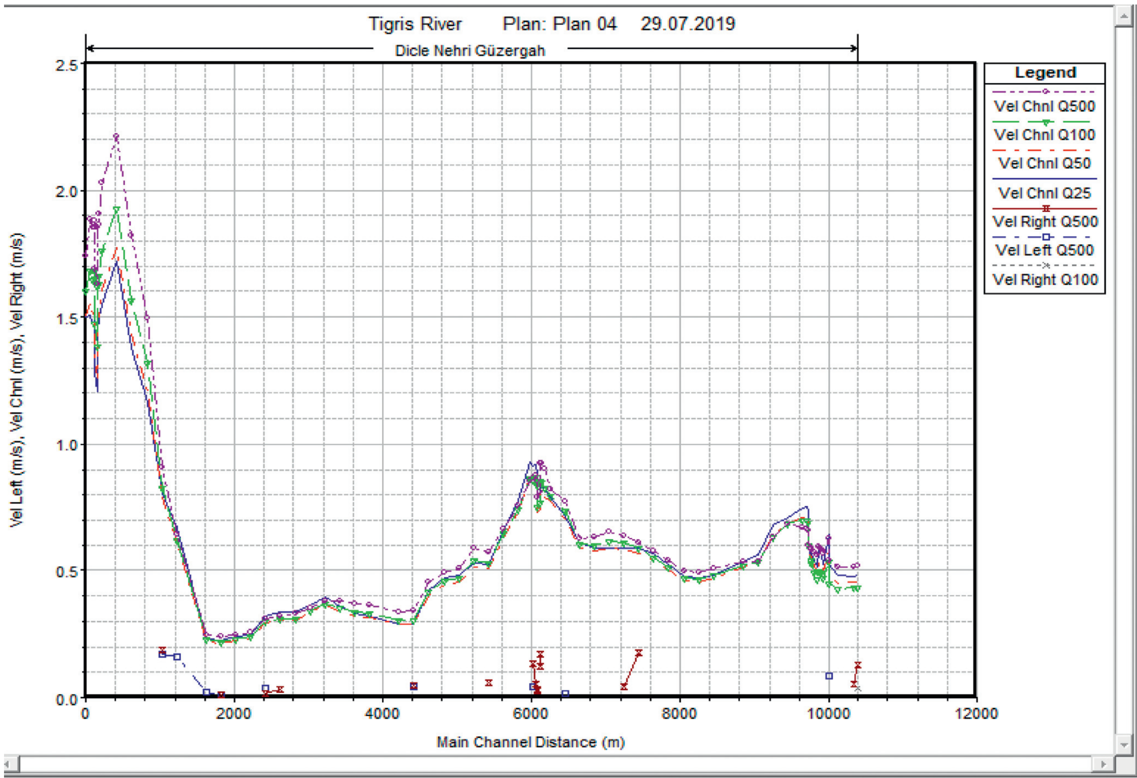

Figure 12: General profile plot velocities.

Table 3: Profile output tables of the Tigris River (partially).

Reach	River station	Profile	Q total	Min ch el	W.S. Elev	E.G. Elev	Vel chnl	Flow area	Froude chl
			(m3/s)	(m)	(m)	(m)	(m/s)	(m2)	
Reach	9727.81	Q_{25}	2598.18	581.00	589.29	589.31	0.58	4495.68	0.09
Reach	9727.81	Q_{50}	3209.47	581.00	590.62	590.63	0.53	6036.81	0.08
Reach	9727.81	Q_{100}	3871.25	581.00	592.03	592.04	0.50	7792.43	0.06
Reach	9727.81	Q_{500}	5450.72	581.00	593.11	593.13	0.59	9199.47	0.07
Reach	9720	Q_{25}	2598.18	581.00	589.29	589.30	0.51	5049.12	0.08
Reach	9720	Q_{50}	3209.47	581.00	590.62	590.63	0.49	6590.76	0.07
Reach	9720	Q_{100}	3871.25	581.00	592.03	592.04	0.46	8346.40	0.06
Reach	9720	Q_{500}	5450.72	581.00	593.11	593.13	0.56	9753.25	0.07
Reach	**9719.99 Sadi Bridge_1.**		**Bridge**						
Reach	9708	Q_{25}	2598.18	581.00	589.06	589.08	0.54	4807.17	0.08
Reach	9708	Q_{50}	3209.47	581.00	590.27	590.28	0.52	6183.16	0.07
Reach	9708	Q_{100}	3871.25	581.00	591.65	591.67	0.49	7877.11	0.06
Reach	9708	Q_{500}	5450.72	581.00	592.95	592.96	0.57	9548.96	0.07
Reach									
Reach	9706	Q_{25}	2598.18	581.00	589.06	589.08	0.54	4808.13	0.08
Reach	9706	Q_{50}	3209.47	581.00	590.27	590.28	0.52	6184.39	0.07
Reach	9706	Q_{100}	3871.25	581.00	591.65	591.67	0.49	7878.52	0.06
Reach	9706	Q_{500}	5450.72	581.00	592.95	592.96	0.57	9550.30	0.07
Reach	**9705.99 Sadi Bridge_2.**		**Bridge**						
Reach									
Reach	9694	Q_{25}	2598.18	581.00	588.90	588.91	0.57	4586.13	0.09
Reach	9694	Q_{50}	3209.47	581.00	589.95	589.97	0.56	5774.89	0.08
Reach	9694	Q_{100}	3871.25	581.00	591.12	591.13	0.54	7168.48	0.07
Reach	9694	Q_{500}	5450.72	581.00	592.76	592.78	0.59	9268.95	0.07
Reach									
Reach	9693.95	Q_{25}	2598.18	581.00	588.90	588.91	0.57	4592.97	0.09
Reach	9693.95	Q_{50}	3209.47	581.00	589.95	589.97	0.56	5781.73	0.08

Table 3: Continued.

Reach	River station	Profile	Q total	Min ch el	W.S. Elev	E.G. Elev	Vel chnl	Flow area	Froude chl
Reach	9693.95	Q_{100}	3871.25	581.00	591.12	591.13	0.54	7175.28	0.07
Reach	9693.95	Q_{500}	5450.72	581.00	592.76	592.78	0.59	9275.79	0.07
Reach									
Reach	9690	Q_{25}	2598.18	581.00	588.90	588.91	0.55	4715.72	0.08
Reach	9690	Q_{50}	3209.47	581.00	589.95	589.97	0.54	5904.80	0.08
Reach	9690	Q_{100}	3871.25	581.00	591.12	591.13	0.53	7298.57	0.07
Reach	9690	Q_{500}	5450.72	581.00	592.76	592.78	0.58	9399.21	0.07
Reach	**9689.99 Sadi Bridge_3.**	**Bridge**							
Reach									
Reach	9680	Q_{25}	2598.18	581.00	588.73	588.75	0.60	4366.48	0.09
Reach	9680	Q_{50}	3209.47	581.00	589.66	589.68	0.59	5400.88	0.09
Reach	9680	Q_{100}	3871.25	581.00	590.56	590.57	0.60	6444.70	0.08
Reach	9680	Q_{500}	5450.72	581.00	592.66	592.68	0.60	9096.17	0.07
Reach									
Reach	9678.54	Q_{25}	2598.18	581.50	588.72	588.75	0.74	3507.89	0.13
Reach	9678.54	Q_{50}	3209.47	581.50	589.65	589.68	0.71	4548.64	0.11
Reach	9678.54	Q_{100}	3871.25	581.50	590.55	590.57	0.69	5598.82	0.10
Reach	9678.54	Q_{500}	5450.72	581.50	592.65	592.68	0.66	8278.94	0.08

coefficient and contraction/expansion coefficients are needed to calculate energy losses. The momentum equation is used in cases where the current regime changes abruptly. The effect of the hydraulic structures such as bridges, culverts, water mass, and full spillways to the current flow can be taken into consideration through the program. In addition, changes in the analysis region can be reflected in the program and the model can be updated [28].

Parameters to be defined are as follows:

(a) Section numbers and section geometries along the creek route

(b) Distance between sections

(c) Roughness coefficient

(d) Channel contraction and expansion coefficients

(e) Geometries of transverse structures that create obstacles along the route

3. Results and Discussion

Hydraulic analyses of the study were carried out using the HEC-RAS package program version of 4.1. The data obtained as a result of the observations and the measurements of the existing art structures (bridges) were defined in the HEC-RAS program. Then, the calculations and the water surface profiles formed in 25-, 50-, 100-, and 500-year recurrence flows were determined.

When the length profiles obtained in the different recurrence rates of the route are examined, the Sadi Bridge and the historical Ten-Eyed Bridge are insufficient to pass the flood flow while the capacity of the University Bridge is sufficient (Figure 6). The upper water elevations of the six-footed, seven-span Sadi Bridge built on the Tigris River according to Q_{25} year's flood recurrence rate are shown in Figure 6. In the first bridge that was built, the flood water level reached the lower level of the bridge beam at the 25-year flood recurrence rate, while the second and third bridge sections constructed later were found to be sufficient. The reason for this is that the beam thickness of the first bridge is larger than the other bridge beam thicknesses. However, it was found that the bridge capacity was insufficient in the other recurrence flow rates. Due to the insufficient section of the Sadi Bridge, for Q_{25} flow rates, the flood waters swell and affect the sapling and fishery production facilities.

It has been determined that the facilities, farmland, and settlements in the downstream of Sadi Bridge are in the floodplain and also the Hevsel Gardens, which is located in the section between University Bridge and the historical Ten-Eyed Bridge, are also in the floodplain Figures 6–11.

The Tigris River is mainly supercritical stream. Flow velocities increases in areas with hydraulic structures, especially in terms of hydraulically insufficient bridge inlets and outlets after decreasing (Figure 12). The hydraulic condition in some parts of our study is given in Table 3.

4. Conclusions

The aim of this study is to show that the HEC-RAS model is able to simulate the surface profiles formed in different recurrent flows of the Tigris River in Diyarbakır, as well as that the flood boundaries in a public area can be easily obtained by using the HEC-RAS package program.

Manning's roughness coefficient value and the slope of the route significantly affect the water surface profile. For this reason, while preparing roughness values, observations were made on the route by using prepared charts and photographs were taken. In this way, real results about Manning roughness coefficients were approached as much as possible.

When the results of the flood analysis made with the HEC-RAS program are examined, it is seen that the bed width increases to 2500 meters in places. It is of course difficult to make a suitable flood analysis in natural rivers with such floodplain width and low slope. However, the current maps to be obtained and the suitability of these maps to the land, the precise hydrological data obtained from the study area, and the accuracy of the acquired data as a result of the observations made in the field are very important. In addition to gathering all these data through an effective user, the flood analysis studies will be much suitable by ensuring the compatible between land and computer.

Significant damages occur during the flood due to the existence of social and production (nursery, fishing, and fruit) facilities, fertile agricultural lands, hospitals, and partial settlements in the studying route. Due to insufficient span of the Sadi Bridge at the beginning of our study, this section of the route narrows. Significant changes were observed in the surface profiles of the bridges due to the differences in the gap and beam heights of the bridges built side by side at different times. When the bridges were defined to the program, respectively, it was observed that the differences in the openness and height caused the increase in the water level. Even during the 25-year recurrence flow, flood waters swell due to lack of section of bridges and leave backward settlements and production facilities inundated. It was observed that the machinery operation area and the purification facility were at the boundary of flood. The Hevsel Gardens, which were included in the World Cultural Heritage List by UNESCO in 2015 between the University Bridge and the historical Ten-Eyed Bridge, were influenced by the flooding. It was observed that private and commercial business areas, which are at upstream and downstream of the historical Ten-Eyed Bridge, remained below the flood waters.

In order to minimize the possible flood losses, the reclamation of the route will result in a decrease in the roughness coefficient and thus a decrease in the flood surface elevations. Sadi Bridge's capacity is not sufficient, and therefore, its openness needs to be increased. Considering the University Bridge clearance (about 400 m) on the same route, the situation will be clearer. Again, since it is not possible to intervene in the historical Ten-Eyed Bridge, which is insufficient in capacity, it is possible to build a tunnel connected to the Tigris River on the outskirts of Mount Kırklar and extracting flooding waters to prevent possible damages. Hevsel Gardens on the route should be protected from flood waters. Given the fact that the gap of the University Bridge which is at the upstream of the Hevsel Gardens is sufficient for this, diversion structures such as regulators or upstream cofferdam can be constructed. Thus, the level of the flood water will be increased to the desired level and then the flood water will be stored and then the flood water going to the Hevsel Gardens will be derived in a controlled manner by changing the water direction. Finally, the structures within the flood boundaries should be moved to the higher elevations that will not be affected by the flood waters.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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References

[1] G. Onuşluel, *Floodplain management based on HEC-RAS modelling system*, Ph.D. thesis, Dokuz Eylül Üniversitesi Fen Bilimleri Enstitüsü, Izmir, Turkey, 2005.

[2] C. Erkek and N. Ağıralioğlu, *Su Kaynakları Mühendisliği*, p. 394, Beta Yayınevi, Istanbul, Turkey, 2013.

[3] G. Seckin, "Comparison of sediment Transport rates between symmetric and asymmetric straight compound channels," in *Proceedings of the Eighth International Symposium on Stochastic Hydraulics*, pp. 139–144, Beijing, China, 2000.

[4] R. Yurtal, G. Seçkin, D. Kaya, and S. Atabay, "Seyhan nehri su yüzü profillerinde köprülerden kaynaklanan kabarmaların HEC-RAS paket programı kullanılarak modellenmesi," *DMO Teknik Dergi*, vol. 14, no. 2, pp. 2935–2948, 2003.

[5] Ö Kara, "*Su yüzü profillerinin hec-ras paket programiyla incelenmesi*," M.S. thesis, Erciyes Üniversitesi, Fen Bilimleri Enstitüsü, Kayseri Turkey, 2009.

[6] İ Tuncer, "*Açik kanallarda su yüzü profilinin belirlenmesi, nakkaş dere örneğinde bir hec-ras uygulamasi*," M.S. thesis, Gazi Üniversitesi, Fen Bilimleri Enstitüsü, Ankara, Turkey, 2011.

[7] X. Y. Deng and W. F. Li, "Application of HEC-RAS model for evaluation of flood control of Mijiang Super-long Bridge," *South-to-North Water Diversion and Water Science and Technology*, vol. 1, p. 034, 2012.

[8] L. K. Hameed and S. T. Ali, "Estimating of Manning's roughness coefficient for Hilla River through calibration using HEC-RAS model," *Jordan Journal of Civil Engineering*, vol. 159, no. 701, pp. 1–10, 2013.

[9] H. Efe, "*Batman çayi'nin taşkin analizinin hec-ras programiyla yapilmasi*," M.S. thesis, Dicle Üniversitesi, Fen Bilimleri Enstitüsü, Diyarbakir, Turkey, 2014.

[10] T. Bagatur and N. Hamidi, "Evaluation with stream characteristics of downstream flood problems after dam construction," *Journal of Environmental Engineering and Landscape Management*, vol. 22, no. 2, pp. 96–104, 2014.

[11] M. Abdelbasset, L. Abderrahim, A. C. A. Chaouni, B. Abdellah, B. Lahcen, and B. Laila, "Integration of GIS and HEC-RAS in floods modeling of the Ouergha river, Northern Morocco," *Environmental Science*, vol. 11, no. 2, pp. 1857–7881, 2015.

[12] M. S. Khattak, F. Anwar, T. U. Saeed, M. Sharif, K. Sheraz, and A. Ahmed, "Floodplain mapping using HEC-RAS and ArcGIS: a case study of Kabul River," *Arabian Journal for Science and Engineering*, vol. 41, no. 4, pp. 1375–1390, 2016.

[13] A. Rajib, V. Merwade, and Z. Liu, *Large Scale High Resolution Flood Inundation Mapping in Near Real-Time*, Lyles school of Civil Engineering, Purdue University, West Lafayette IN, USA, 2016.

[14] S. Ullah, M. FarooQ, T. Sarwar, M. J. Tareen, and W. M. Abdul, "Flood modeling and simulations using hydrodynamic model and ASTER DEM-A case study of Kalpani river," *Arabian Journal of Geosciences*, vol. 9, p. 439, 2016.

[15] M. Yaylak, "Coğrafi bilgi sistemleri (cbs) yardimiyla bitlis deresi taşkin risk analizi. yüksek lisans tezi," Bitlis eren üniversitesi, fen bilimleri enstitüsü, Bitlis, Turkey, 2016.
[16] F. Onen and T. Bagatur, "Prediction of flood frequency factor for Gumbel distribution using regression and GEP model," *Arabian Journal for Science and Engineering*, vol. 42, no. 9, pp. 3895–3906, 2017.
[17] T. Bagatur and F. Onen, "Development of predictive model for flood routing using genetic expression programming," *Journal of Flood Risk Management*, vol. 11, pp. 444–454, 2018.
[18] N. S. Romali, Z. Yusop, and A. Z. Ismail, "Application of HEC-RAS and Arc GIS for floodplain mapping in Segamat town, Malaysia," *International Journal of GEOMATE*, vol. 14, no. 43, pp. 125–131, 2018.
[19] C. B. Khalfallah and S. Saidi, "Spatiotemporal floodplain mapping and prediction using HEC-RAS-GIS tools: case of the Mejerda river, Tunisia," *Journal of African Earth Sciences*, vol. 142, pp. 44–51, 2018.
[20] T. Dysarz, "Application of Python scripting Techniques for control and automation of HEC-RAS simulations," *Water*, vol. 10, no. 10, p. 1382, 2018.
[21] M. B. Baniya, T. Asaeda, K. C. Shivaram, and S. M. D. H. Jayashanka, "Hydraulic parameters for sediment Transport and prediction of suspended sediment for Kali Gandaki River basin, Himalaya, Nepal," *Water*, vol. 11, no. 6, p. 1229, 2019.
[22] T. Hırca and O. Sönmez, "Determination of flood inundation maps: a case study of Akyazi industrial zone," *Sakarya University Journal of Science*, vol. 23, no. 2, pp. 301–307, 2019.
[23] S. Ogras, "*Dicle nehri'nin taşkın analizinin hec-ras programıyla yapılması*," M.S. thesis, Dicle Üniversitesi, Fen Bilimleri Enstitüsü, Diyarbakir, Turkey, 2018.
[24] M. E. Ulugur, *Su Mühendisliği*, Çağlayan Kitabevi, İstanbul, Turkey, 1972.
[25] I. Mondal, J. Bandyopadhyay, and A. K. Paul, "Estimation of hydrodynamic pattern change of Ichamati River using HEC RAS model, West Bengal, India," *Modeling Earth Systems and Environment*, vol. 2, no. 3, p. 125, 2016.
[26] V. T. Chow, *Open Channel Hydraulic*, pp. 1–728, McGraw-Hill, New York, NY, USA, 1959.
[27] W. L. Cowan, "Estimating hydraulic roughness coefficients," *Agricultural Engineering*, vol. 37, no. 7, pp. 473–475, 1956.
[28] G. W. Brunner, *HEC-RAS River Analysis System Hydraulic Reference Manual*, Version 4.1, U.S. Army Corps of Engineers, Washington, DC, USA, 2010.