FLOOD MAPPING in MIDDLE PORSUK BASIN USING GEOGRAPHICAL INFORMATION SYSTEM, HYDROLOGIC AND HYDRAULIC MODELING

Undergraduate Thesis

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JURY APPROVAL

Within the lecture CEV450 Graduation Project in Environmental Engineering, Ahmet Ali MERT, Bayram KÜÇÜKKAYA and Yavuz AYDOĞAN's **"FLOOD MAPPING in PORSUK BASIN USING GEOGRAPHIC INFORMATION SYSTEM, HYDROLOGIC AND HYDRAULIC MODELING"** titled science thesis is evaluated and approved by jury.

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ANADOLU UNIVERSITY

FACULTY OF ENGINEERING AND ARCHITECTURE

DEPARTMENT OF ENVIRONMENTAL ENGINEERING

UNDERGRADUATE THESIS

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ABSTRACT

UNDERGRADUATE THESIS

FLOOD MAPPING in MIDDLE PORSUK BASIN USING GEOGRAPHIC INFORMATION SYSTEMS (ARCGIS), HYDROLOGIC (HEC-HMS) and HYDRAULIC (HEC-RAS) MODELLING

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Floods and inundations as a result of sudden excessive rainfall around the globe, especially in our country have caused disasters almost every year resulting heavy losses on human lives and property. Floods, following earthquakes, are the second most cause of loss of lives and property in our country. There have been 288 floods reported in Turkey over the last 20 years causing 436 deaths.

In this study, Porsuk Basin a branch of Sakarya River, which is divided into three parts as Upper, Middle and Lower Porsuk has been discussed. Basin characteristics are obtained using Geographic Information Systems (GIS) as a first step in the study. Using these data and precipitation-flow data taken from government offices, for hydrologic modelingin HEC-HMS software, precipitation-flow correlation has been found for Middle Porsuk Basin. Flood mapping for Middle Porsuk Basin for various scenarios has been created in HEC-RAS software using flow data taken from HEC-HMS and topographic data taken from GIS software.

ÖZET

LİSANS BİTİRME TEZİ

ORTA PORSUK HAVZASI'NDA COĞRAFİ BİLGİ SİSTEMLERİ (ARCGIS), HİDROLOJİK (HEC-HMS) ve HİDROLİK (HEC-RAS) MODELLEME KULLANILARAK TAŞKIN ANALİZİ

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Dünyada, özellikle ülkemizde hemen hemen her yıl felaketlere, önemli can ve mal kaybına neden olan ve ani aşırı yağışlar sonucu oluşan sel ve taşkın olayları meydana gelmektedir. Taşkınlar, ülkemizde depremlerden sonra en büyük can ve mal kayıplarına sebep olan doğal afetlerdendir. Türkiye'de son 20 yılda 288 taşkın olayı yaşanmış ve bu taşkınlarda 436 kişi hayatını kaybetmiştir.

Bu çalışmada, Sakarya Havzasının bir alt kolu olan ve Yukarı, Orta ve Aşağı Porsuk olmak üzere üç bölüme ayrılan Porsuk Havzası ele alınmıştır. Çalışmada ilk olarak Coğrafi Bilgi Sistemleri (CBS) kullanılarak havza karakteristikleri elde edilmiştir. Bu bilgiler ve devlet kurumlarından alınan yağış ve akış verileri yardımıyla, HEC-HMS yazılımı kullanılarak Orta Porsuk Havzasında hidrolojik modelleme yapılarak yağış-akış ilişkisi bulunmuştur. HEC-HMS de üretilen akış verileri ve CBS kullanılarak elde edilen topoğrafik veriler HEC-RAS yazılımı kullanılarak Orta Porsuk Havzası için çeşitli senaryolarla taşkın haritaları oluşturulmuştur.

Acknowledgments

We would especially like to thank our family members. We owe a deep feeling of gratitude towards them, because without their support, it would not have been possible to write this graduation project.

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1. Introduction

1.1. Flood and Affects

Flooding and flash flooding are the deadliest of natural disasters. Floodwaters claim thousands of lives every year and render millions homeless. One of the more frightening things about flooding is that it can occur nearly anywhere, at any time. It can result from excess water jams on rivers, even moderate rain, or a single very heavy downpour.

Heavy down pore in the form of rain, brings down more water than can be disposed of by combined factors natural and manmade systems causes flooding. The rivers overflow embankments may be breached. Generally rains following storm and hurricane are heavy and bring unmanageable amount of water causing flash floods. (vigyanprasar)

Floods are one of the main disasters in different regions of countries which effect economic and social life of people. Today, many methods are used for flood investigations. Especially improvements in the space technologies and in geographic information system (GIS) provide many advantages in natural disaster investigations. (Akar, Maktav,2008)

There are many disruptive effects of flooding on human settlements and economic activities. However, floods (in particular the more frequent/smaller floods) can also bring many benefits, such as recharging ground water, making soil more fertile and providing nutrients in which it is deficient. Flood waters provide much needed water resources in particular in arid and semi-arid regions where precipitation events can be very unevenly distributed throughout the year. Freshwater floods particularly play an important role in maintaining ecosystems in river corridors and are a key factor in maintaining flood plain biodiversity. Flooding adds a lot of nutrients to lakes and rivers which leads to improved fisheries for a few years, also because of the suitability of a floodplain for spawning (little predation and a lot of nutrients). Fish like the weather fish make use of floods to reach new habitats. Together with fish also birds profit from the boost in production caused by flooding. (Wikipedia)

1.2. Floods in Turkey

- May 1998: Eleven reported dead and thousands homeless near Black Sea
- June 1998: Eight killed in flash flood in south-eastern Turkey
- December 2001: Two ships sunk and four people killed in floods, storms and blizzards
- July 2002: At least 40 people are now known to have died in rainstorms and flooding in Turkey over the past few days. Rescue efforts were continuing on Friday in Rize on Turkey's eastern Black Sea coast.
- November 2006: At least 10 people are reported to have lost their lives overnight in flooding in south-east Turkey, taking the total to at least 32.

Up to a meter of water fell overnight in parts of north-west Turkey, including in the city of Istanbul where large sections of the Ikitelli neighborhoods on the city's European side and many major roads were submerged. At least 23 people have died, and this figure is expected to rise as a number of people swept away by the floodwaters are still missing. Dozens of houses and workplaces in Istanbul were flooded after two of Istanbul's rivers overflowed.

Torrential rain has lashed the north-west region of Turkey since the beginning of the week, with floods killing nine people on 8 September in the town of Saray in the far west province of Tekirdağ.

At least 31 people have been killed in flash floods in Istanbul, Turkey's largest city, which has left cars and lorries stranded across highways after the heaviest rains in the region in 80 years (09.09.2009).

Torrential downpours paralyzed life in the Turkish capital, Ankara. An underpass was submerged and several cars were trapped in flood waters (16.06.2011).

Many of the areas worst-hit are places where illegal construction has taken place on flood plains. (Gürer,2007)

1.3. Flood in Eskişehir

Eskişehir city has significantly been protected from flooding with helping Porsuk Dam. However, besides increasing flooding utility and irrigation, it was needed to increase the capacity of the dam in order to satisfy Eskişehir city's drinking and domestic water demand which meant to heighten the dam. Porsuk Dam is constructed to confirm flooding utility and to decrease Eskişehir's flooding risk.

Figure 1.1. Flood water at Köprübaşı, Eskişehir on 5 March, 1950

Figure 1.2. Flood water at Atatürk High School, Eskişehir on 5 March, 1950

On March, 1950 as a result of overflow of Porsuk River, flooding hazard occurred and 50 thousand people were homeless. Marshall Plan helped to victims of the disaster which affected flood destroyed 2500 houses and 6 people drowned. Eskişehir is shown under the flood water in Figure 1.1. – 1.2. – 1.3 – 1.4.

Figure 1.3. Flood water front of Officer's Club, Eskişehir on 5 March, 1950

Figure 1.4. Flood water at Köprübaşı and Adalar, Eskişehir on 5 March, 1950

Table 1.1. Flood Chronologies for Turkey [Gürer,2007]

Year	Number of Flood	Death	Damaged Area (Ha)	Financial Loss ($)	Year	Number of Flood	Death	Damaged Area (Ha)	Financial Loss ($)
1955	27	-	86 675	3 122 733	**1983**	12	6	1 588	21 154 159
1956	22	90	178 668	11 324 144	**1984**	12	-	28 457	2 602 760
1957	22	13	49 336	7 617 225	**1985**	7	-	300	211 636
1958	49	190	61 266	20 276 255	**1986**	8	-	-	-
1959	50	17	21 954	11 564 586	**1987**	7	-	915	1 275 708
1960	98	1	78 123	12 370 351	**1988**	24	17	3 910	10 030 206
1961	42	24	45 860	15 510 580	**1989**	11	1	9 550	3 252 309
1962	117	15	94 014	16 423 257	**1990**	22	56	5 508	207 616 671
1963	122	25	191 983	35 255 747	**1991**	17	52	11 384	6 319 905
1964	69	32	53 149	11 379 669	**1992**	13	1	690	12 644 290
1965	63	3	96 358	24 833 845	**1993**	2	-	60	56 095
1966	90	25	137 971	39 872 782	**1994**	8	4	1 655	1 283 090
1967	81	4	52 466	8 935 221	**1995**	27	164	201 078	202 000 000
1968	170	24	170 029	86 153 068	**1996**	8	-	11 026	1 410 010
1969	30	6	125 104	20 066 068	**1997**	19	-	4 818	60 000
1970	8	3	18 306	876 242	**1998**	59	79	42 345	41 831 770
1971	31	6	4 400	7 831 998	**1999**	21	5	9 889	2 235 967
1972	109	33	21 076	17 462 526	**2000**	25	9	20 367	138 281 040
1973	19	22	44 188	11 090 778	**2001**	56	37	95 545	405 326 632
1974	35	73	2 534	5 366 167	**2002**	48	47	4 494	104 840 590
1975	51	8	7 242	18 141 515	**2003**	22	14	56 111	325 377 200
1976	28	1	324	5 488 901	**2004**	39	15	23 458	307 586 950
1977	26	11	426	4 651 923	**2005**	39	35	53 920	502 706 880
1978	22	-	13 759	1 466 603	**2006**	44	62	76 377	353 682 242
1979	22	61	2 950	13 027 595	**2007**	47	44	1 350	38 416 360
1980	36	9	48 473	12 449 342	**2008**	27	15	10	18 284 150
1981	16	1	1 980	13 740 520	**2009**	100	67	8 000	400 000 000
1982	10	-	2 812	1 307 639	**Total**	**2189**	**1427**	**2 284 231**	**3 546 093 900**

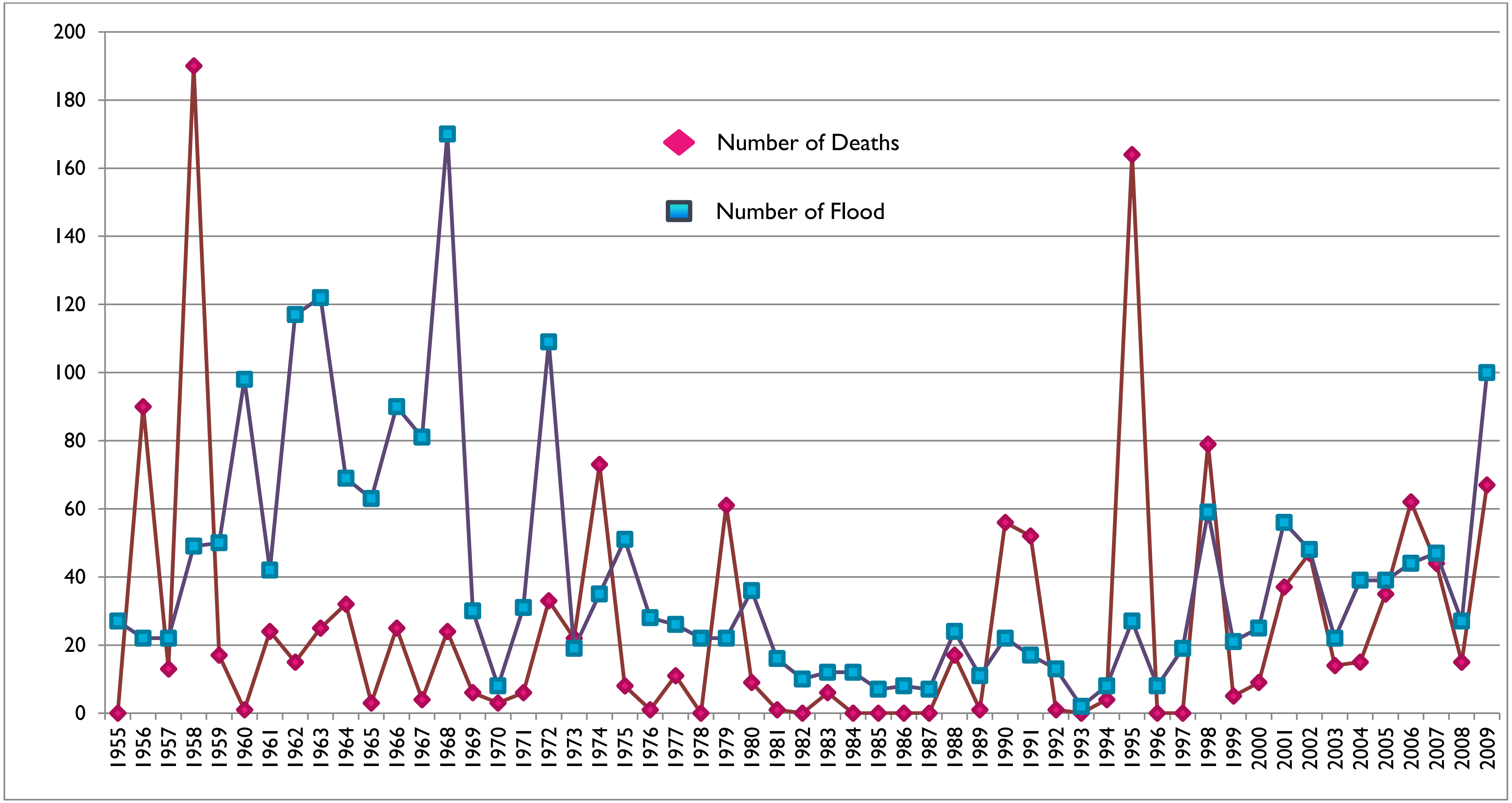


Figure 1.5. Floods and Loss of Life in Turkey [Gürer, 2007]

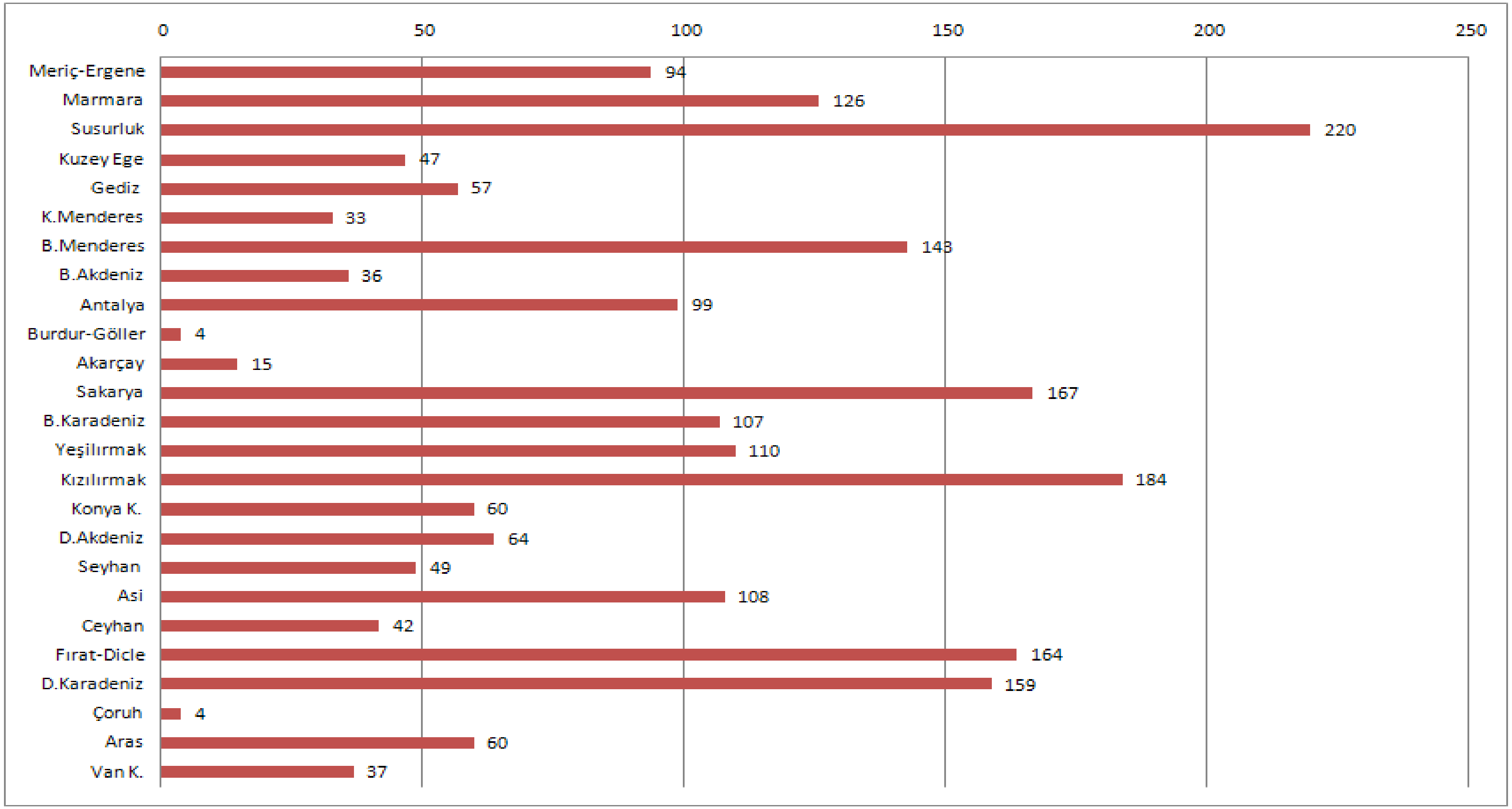


Figure 1.6. Number of Floods in Basins of Turkey [Gürer, 2007]

2. Study Area

2.1. Porsuk Basin

2.1.1 General Information of Porsuk Basin

Porsuk basin, as a sub basin of Sakarya basin, is located at north-west of Anatolia and has an 11325km^2 area. Exact location of Porsuk basin can be given as between 29^0 38' – 31^0 59' east longitudes and 38^0 44' – 39^0 99' north latitudes. Basin lies 202 km in length on east to west direction and 135 km in length on north to south direction. Porsuk basin includes city center of Eskişehir and Kütahya and 7 district centers of these two cities and also includes some areas that are in Ankara, Uşak and Afyon city boundaries. More than 60% of the basin area is mountainous. Surface waters of the Porsuk River and its tributaries and pour to the Sakarya River at 660m elevation, in the vicinity of Sazlılar after covering a distance of 435.8 km. Porsuk basin has a low water potential because of it' considerably low (450mm) long term annual mean precipitation depth. Total water potential of the basin is 481hm3. This means that there is not enough potential to construct high capacity power plants. But basin has found proper to construct smaller power plants.

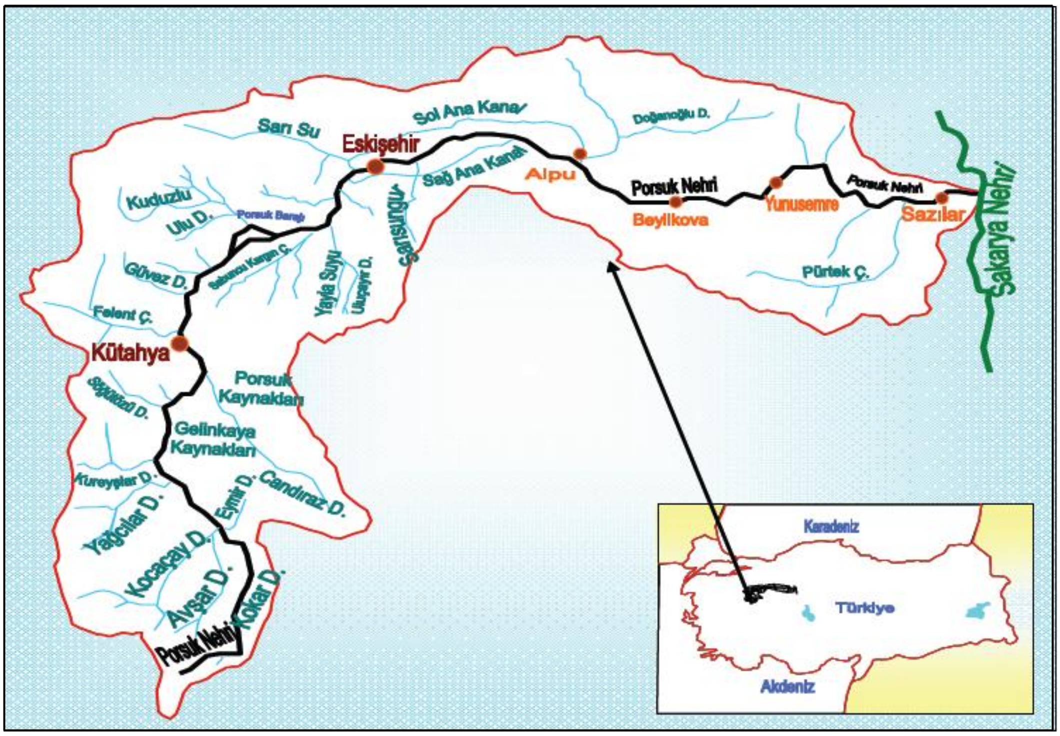


Figure 2.1. Study Area, Porsuk Basin

Preliminary project had been done by Hydraulic Works Council with name of İncesu Dam even before General Directorate of State Hydraulic Works (DSİ) was constructed and Porsuk Dam was put out to tender in 1944, construction finished in 1948 and the dam has come into service since then. Eskişehir city has significantly been protected from flooding. However, besides increasing flooding utility and irrigation, it was needed to increase the capacity of the dam in order to satisfy Eskişehir city's drinking and domestic water demand which meant to heighten the dam. DSİ started heightening operations in 1966 and finished in 1972. Kargın Brook next to the dam also derivatized to the dam reservoir in 1970 to confirm flooding utility and to decrease Eskişehir's flooding risk.

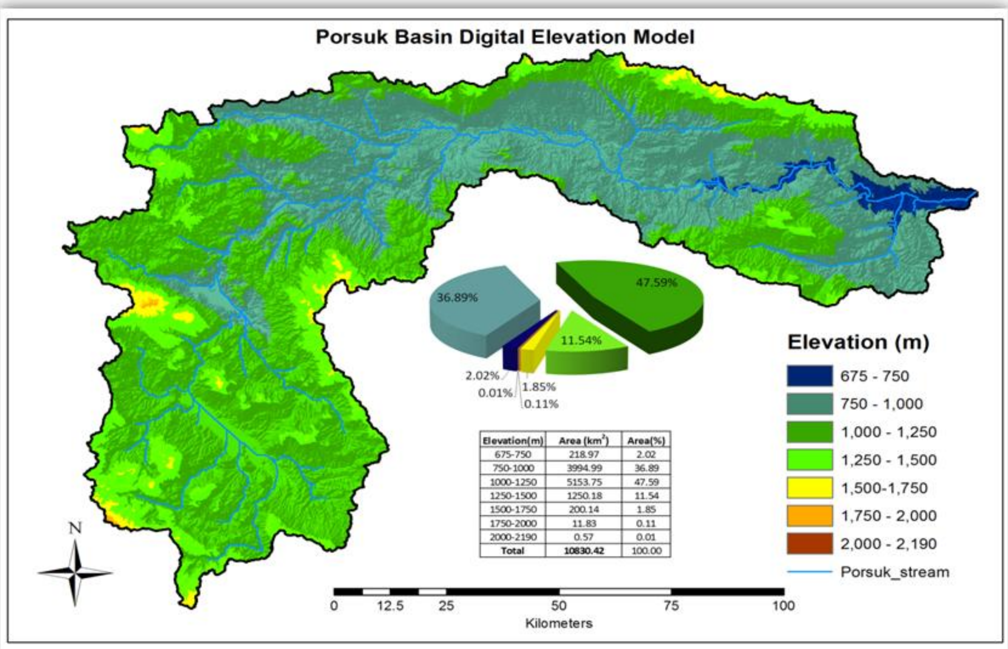


Figure 2.2. Porsuk Basin Elevation Map

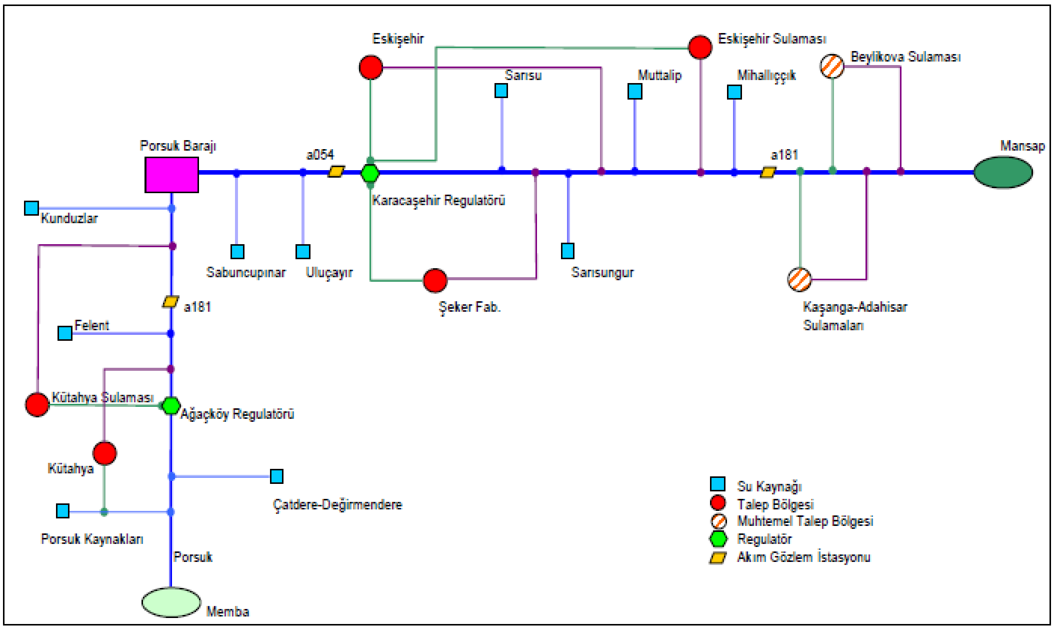


Figure 2.3. Porsuk Creek Basin's Topological Representation

Eskişehir;

DSİ III. Regional Directorate

Allocation of the Facility: Irrigation 41%

Flooding 14%

Drinking Water 32%

Others 13%

In Porsuk Creek Basin;

- Winters are extreme, long and snowy when summers are hot and dry.
- Average precipitation in the project field is 451mm.

Dams in Upper Porsuk Basin: Akçaköy Dam, Kureyşler Dam, Beşkarış Dam, Enne Dam, Dodurga (Dadrıdere) Dam, Aşağıkuzfındık Dam.

Dams in Middle Porsuk Basin: Porsuk Dam, Musaözü Dam, Karacaşehir Regulator.

Dams in Lower Porsuk Basin: There is no dam in this region. Beylikova Pond.

Dams on Porsuk Basin and their some properties are shown in Table 1.2.

Characteristic	Beşkarış Dam	Enne Dam	Kureyşler Dam	Akçaköy Dam	Aşağı Kuzfındık Dam	Dodurga (Darıdere) Dam	Porsuk Dam	Musaözü Dam	Karacaşehir Regulator
Watershed Area (km^2)	216	291	112.7	300+152.50	156.7	-	5018	43	5150
Elevation (m)	54.35	24	40.92	26.6	30.76	26.9	49.7	19	7
Storage Volume(*10^6)	75.6	6.85	29.2	142.4	21.1	31.586	431	1.67	-
Maximum Rezervoir Area	5,12 km^2	100 ha	2,5 km^2	11,40 km^2	2,9 km^2	2,45 km^2	23,4 km^2	0,43 km^2	-
Crest Elevation (m)	393	250	215	287	348	215	258	250	20
Coordinate	X=253250 Y=4317400	29°52.003D 30°28.283K	29°849722D 39°30.278K	30°02.495D 39°03.527K	30°03064D 49°41.567K	29°57986D 39°47.540K	30°46'47D 39°38'.630K	30°19444D 39°41.845	30°27959 39°44650

Table 1.2. Water structure on Porsuk Basin

Station No	Station	Opening Date	Closing Date	Geogr. Coordinate (° ' ")		Elevation (m)	Prec. Area (km^2)	Number of Years
				East	North			
1246	Kınık Deresi - Vezirpınar	01.05.1966	01.10.1969	29 56 47	39 32 58	990	51.6	3
1203	Porsuk Çayı - Beşdeğirmen	19.12.1935		30 02 56	39 31 43	855	3938.4	70
1227	Sarısu - İnönü	26.07.1953	25.10.1968	30 08 44	39 49 17	827	298.8	6
1248	Porsuk Çayı - Eskişehir	01.01.1969	12.01.2004	30 29 09	39 46 06	793	6340	31
1212	Porsuk Çayı - Sazılar	01.07.1943	31.10.1989	31 53 47	39 40 11	679	10822	34
1251	Porsuk Çayı - Kıranharmanı	19.11.1979		29 39 08	4 00 42	334	232.8	17

Table 1.3. Stream Flow Gauge Stations on Porsuk Basin

2.1.2. Rivers

Porsuk Creek springs from the south of the basin, from Murat Mountain foots and near Tokul Village, combining with minor tributaries to flow towards north for a while. It meanders towards Eskişehir after passing by Kütahya city and after passing Eskişehir city center, continues towards east, then after covering ground for 436km joins to Sakarya River. Porsuk Creek's main channel's minor tributaries are Kokar Creek, Çat Creek, Felent Creek, Kargın Brook, Sarısu Brook, Mihalıççık Brook and Pürtek Brook (Figure 2.1).

2.1.3. General Geological Situation of Porsuk Basin

Many of geological and hydrogeological surveys for different goals have been made in the basin by General Directorate of State Hydraulic Works (DSİ) and Mineral Research and Exploration Institute (MTA). In Porsuk Basin, Paleozoic, Mesozoic and Cenozoic aged units are considered as dominants. Paleozoic aged units are represented by metamorphic rocks. In Mesozoic upper system there are metamorphic and ophiolite below. There are carbonate and carbonated formations dominating upwards. In this upper system there is also ophiolite allocation. In Cenozoic upper system, fragments of sediments are mostly dominants. Carbonated and igneous rocks can also be seen in these layers. All these units are covered by current sediments over the river valley, plains and hillsides. In the region it is also possible to see the units created by igneous lava, granitic intrusions and pyroclastics with epigenetic igneous activity.

2.1.4 .Earthquake Situation

According to the "Map of Turkey's Earthquake Zones", having 5 zones, issued in 1996 by Ministry of Public Works and Settlement of Republic of Turkey, Porsuk basin is in 1st, 2nd, 3rd, 4th and 5th zones and according to the Mercalli intensity scale in the VII and VIII zones which are the maximum values of the scale. Active large-scale faults around the field of study are Kuzey Anadolu fault 80km away in the north and Simav fault 80 km away in the southeast with Gediz fault. Aslanapa-Altıntaş and Kütahya faults in the south, İnönü-Dodurga and Eskişehir faults in the north are of the active faults in the basin. These faults in the basin can be said as secondary faulting with respect to the activity, according to the Kuzey

Anadolu (North Anatolian) fault and Ege (Aegean) grabens. Between years 1881 and 1986, 299 earthquakes of magnitude over 4.2 have been recorded by General Directorate of Disaster Affairs (AİGM)- Earthquake Research Department also in the field including the basin region[(38,68-40,84)N - (28,52-32,56)E coordinates].

2.1.5. Basin Hydrogeology

Hydrogeological characteristics of Porsuk basin, of geological units, of plains and of resources are represented by Paleozoic-Sub Triassic aged Porsuk basin metamorphic gneiss, schist and marbles as stratigraphic base. In schist and gneiss dominant locations, metamorphic are impervious or low-permeable when they are permeable in marble dominant sections. Mezzo-Upper Triassic aged formations are partially impervious or low-permeable when limestone levels are permeable. Based on their lithology, ophiolites settled by triassic drift are impervious.

2.1.5.1. Hydrogeological Characteristics of Plains Enclosed in Porsuk Basin

In Porsuk basin, there are Aslanapa, Altıntaş, Kütahya and Köprüören plains in the south, İnönü, Eskişehir plains in the north and Alpu and Lower Porsuk plains in the northeast. From Altıntaş plain, Kokar Creek, streaming in the east-west direction, Değirmen Brook, streaming in the west-east direction, are drained and connected near Adaköy before reaching to Porsuk Creek. Felent Creek and its' branches, streaming in the west-east direction, drains Köprüören plain. This creek joins Porsuk Creek in the north of Kütahya. İnönü plain is drained by Sarısu Creek and its' branches, streaming in the west-east direction, and this creek joins Porsuk Creek at the entrance of Eskişehir city. A lot of minor brooks join this plain creek. Underground water stands to benefit with deep and shallow wells in these plains. Underground water level gets deeper towards the hillsides in alluvial plains; it gets shallow near the stream and in patches gets swamps. Underground water level can again be raised ,by channel-system surface irrigations made in these plains, as a far amount.

2.1.5.2. Water Resources

In Porsuk basin, there are various water resources as underground water discharges. Drinking and domestic water is provided by most of the resources. There is detailed information about the resources studied before by DSİ and determined by hydrogeological surveys in the basin. Ilıca resource in Eskişehir, Yoncalı resource in the northeast of Kütahya and Uyuz Hamamı resource in the south of Alpu establish geysers of the basin.

2.1.6. Climate of the Basin

2.1.6.1. Stream Gauges and Climate Characteristics

44 stream gauges' data have been used to determine water potential of Porsuk basin enclosed in Porsuk basin, including the field of study. Names of the gauges are shown in Figure 5. Long-term measured monthly average precipitations in these gauges are also given in mm. Porsuk basin is in a location that constitutes a passage between the climate of Central Western Anatolia Region and Aegean and Marmara Region's transition climates and Central Anatolia Region's continental climate. Winters are extreme, long and snowy when summers are hot and dry. In general, Central Anatolia Regional precipitation characteristics are dominant in the region. Precipitations of Porsuk dam precipitation area, which are more than continental climate of Central Anatolia, coincides winter and spring months. Snowfall occurs between November and April.

2.1.6.2. Rainfall and Meteorological Stations

Porsuk basin precipitation area is in a transition region. The effects of this transition observed in precipitation. Generally, precipitation patterns of Central Anatolia are dominant. Porsuk basin precipitation area and around meteorological observation stations' monthly average total precipitation is shown in Figure 2.4. Porsuk basin precipitation falls 34% of winter, 31% spring. It has to known that seasonal distribution of precipitation during the dam plans and construction of the dam. Therefore, Porsuk basin meteorological observation stations' seasonal precipitation distribution is shown in Figure 2.5. Under the influence of Marmara Basin, İnönü plain and Sarısu Basin has taken more precipitation than Eskişehir Plain. Porsuk Creek Basin's total annual rainfall is found 451mm according to calculation method of isohyetal (DSİ). There are 24 meteorological observation stations operated by the General Directorate of Meteorology that represents the precipitation area of Porsuk basin as two synoptic climates, 5 large climates, 13 small climates and 4 meteorological stations. There are also 20 meteorological observation stations operated by General Directorate of State Hydraulic Works that work as a precipitation observation station, 9 of them also work as an evaporation observation station. Stations on the Porsuk Basin and their characteristics shown in Table 1.3. (TABAD, 2011)

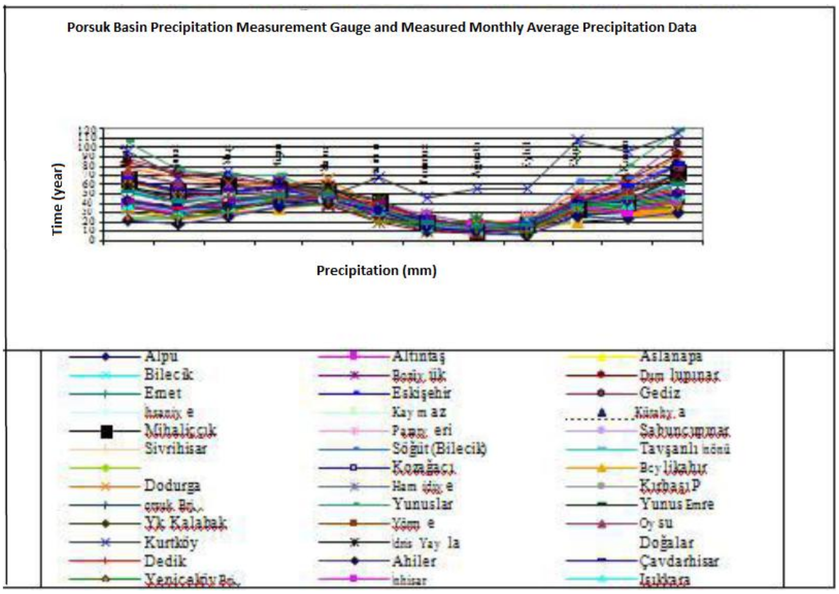


Figure 2.4. Monthly average precipitation for meteorological stations in and around Porsuk Basin

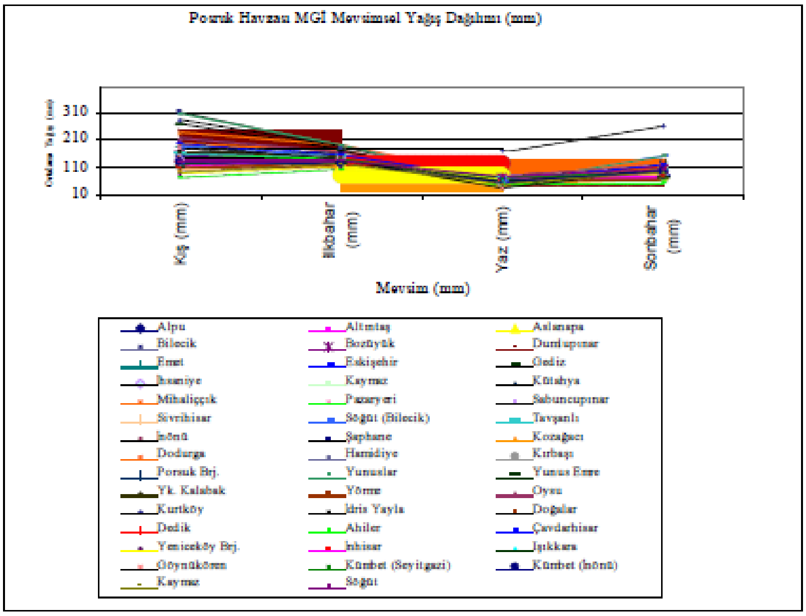


Figure 2.5. Seasonal average precipitation for meteorological stations in and around Porsuk Basin

2.1.6.3. Temperature

In the basin; Central Anatolia's terrestrial climate is dominant. In the region; the coldest month is January and the warmest month is July. Monthly average temperatures in the meteorological observation stations monitoring temperature are given figure-5; where Porsuk basin precipitation area and around. An annual average temperature in the basin varies between 8.8 ° C and 12.3 °. Porsuk basin monthly average temperature rating is shown in Figure 2.6. (TABAD, 2011)

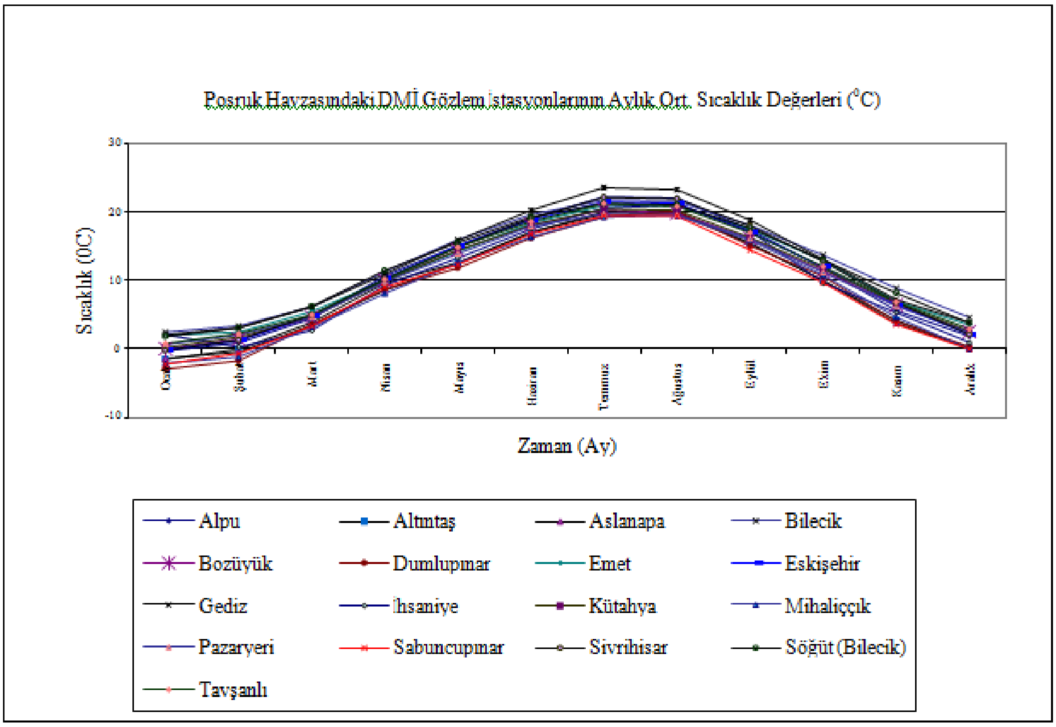


Figure 2.6. Monthly average temperature rating for DMİ meteorological stations in and around Porsuk Basin

2.1.6.4. Evaporation

In Porsuk basin; monitoring of the evaporation with using evaporation pan, meteorological observation station' monthly total evaporation is shown in Figure 7. Evaporation occurs the maximum in June, July and August. Months of July and August; with respect to rise of temperature evaporation losses are increased. Porsuk basin monthly total evaporation rating is shown in Figure 2.7 (TABAD, 2011).

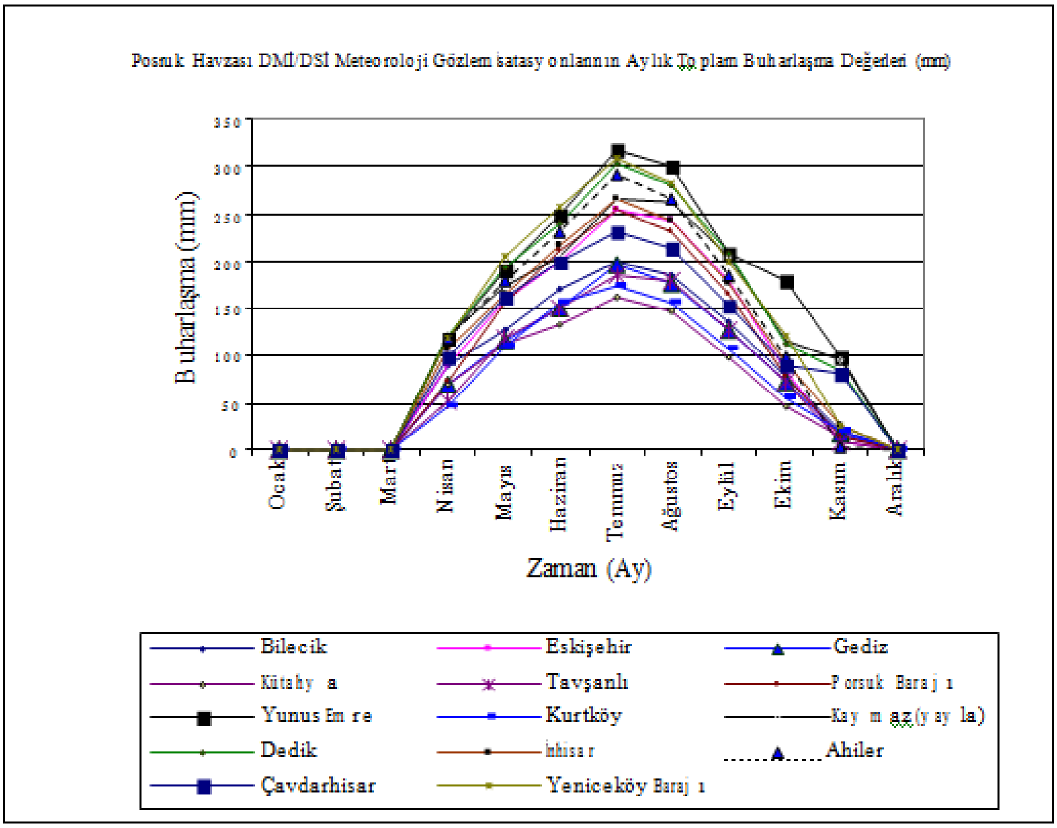


Figure 2.7. Monthly total evaporating rate of meteorological stations in and around Porsuk Basin

2.2 Basin Delineation

2.2.1. Basin Delineation Steps in ARCGIS

- First step is that we should have a DEM map related that basin region.
- The next step is determination of the flow direction from cell values, but in ARCGIS software it is not dealt with any cell values, because all values about map come with DEM map.
- Flow Direction: to find the path of the direction of flow by DEM.
- Sink: If there are sink or peaks the program should be run to lose these sinks or peak values from DEM (by sink from spatial analyst tool).
- Flow Accumulation: to create the line of direction of flow-by-flow direction input.
- Basin: to create the basin using the flow direction raster in order to create a snap pour point as the initial branch of the desired section of watershed by flow direction raster.
- Snap Pour Point: adding the initial point of the desired watershed section to be created (subbasin or main basin etc.) by the point data created by editing tool.
- Watershed: to obtain the desired watershed section finally using flow direction raster and the snap pour data as input.

After all these steps, the desired section can be obtained as a different part from the layers and maps, by clipping tool from analysis>extract, and by extracting by mask option via spatial analyst>extraction>extract by mask.

2.2.2. Basin Delineation Steps' Flow Chart

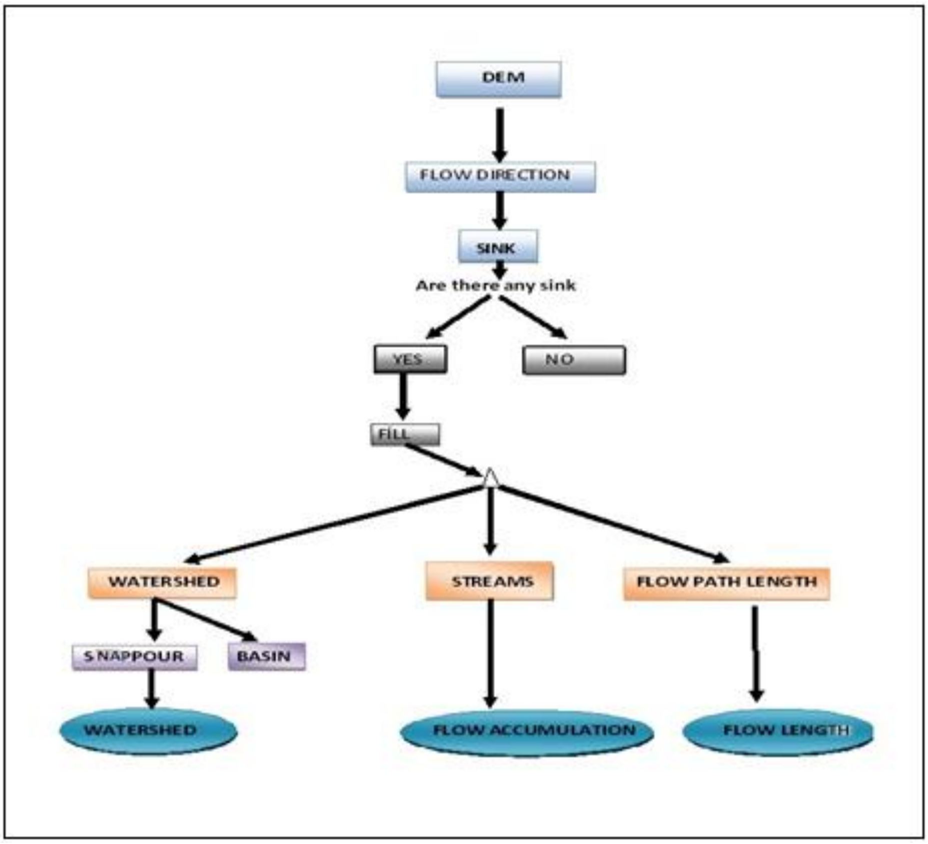


Figure 2.8. Basin delineation steps

2.2.3. Digital elevation model (DEM)

A digital elevation model (DEM) is a digital representation of ground surface topography or terrain. It is also widely known as a digital terrain model (DTM). A DEM can be represented as a raster (a grid of squares) or as a triangular irregular network. DEMs are commonly built using remote sensing techniques; however, they may also be built from land surveying. DEMs are used often in geographic information systems, and are the most common basis for digitally- produced relief maps. Digital elevation models may be prepared in a number of ways, but they are frequently obtained by remote sensing rather than direct survey. Digital elevation model is shown in figure 2.9.

2.2.3.1. Uses of DEM

- Determining attributes of terrain, such as elevation at any point, slope and aspect
- Finding features on the terrain, such as drainage basins and watersheds, drainage networks and channels, peaks and pits and other landforms
- Modeling of hydrologic functions, energy flux and forest fires
- Modeling water flow or mass movement
- Creation of relief maps
- Rendering of 3D visualizations.
- Creation of physical models

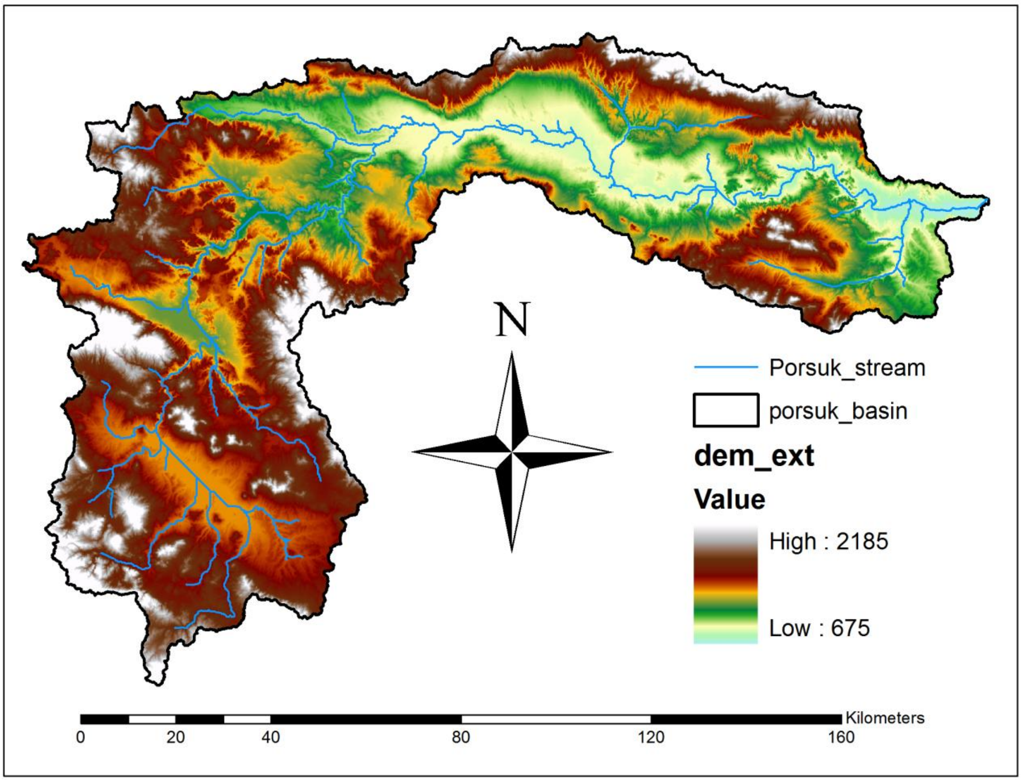


Figure 2.9. Digital elevation model (DEM)

2.2.4. Fill

First of all, Fill application is run to find the map without any sink. So next process can be done which name is Flow direction. Files which are in .mxd extension are used for this application the map will be used must be a Digital elevation model map. This command is placed inside the Hydrology extension, ArcToolbox tool box.

2.2.5. Flow Direction

Flow direction is used to determine the water ways in basin. The output of the Fill process is used as input data to find the flow direction. This command is again placed inside the Hydrology extension, in ArcToolbox toll box. Flow direction map is shown in figure 2.10

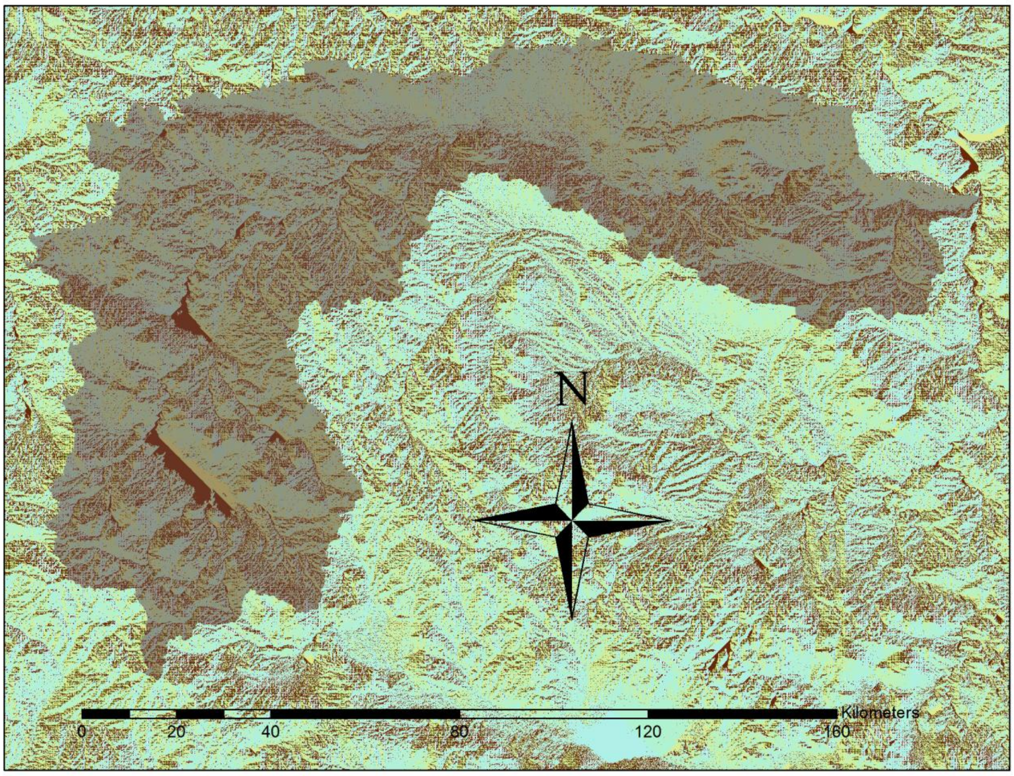


Figure 2.10. Flow direction

2.2.6. Flow Accumulation

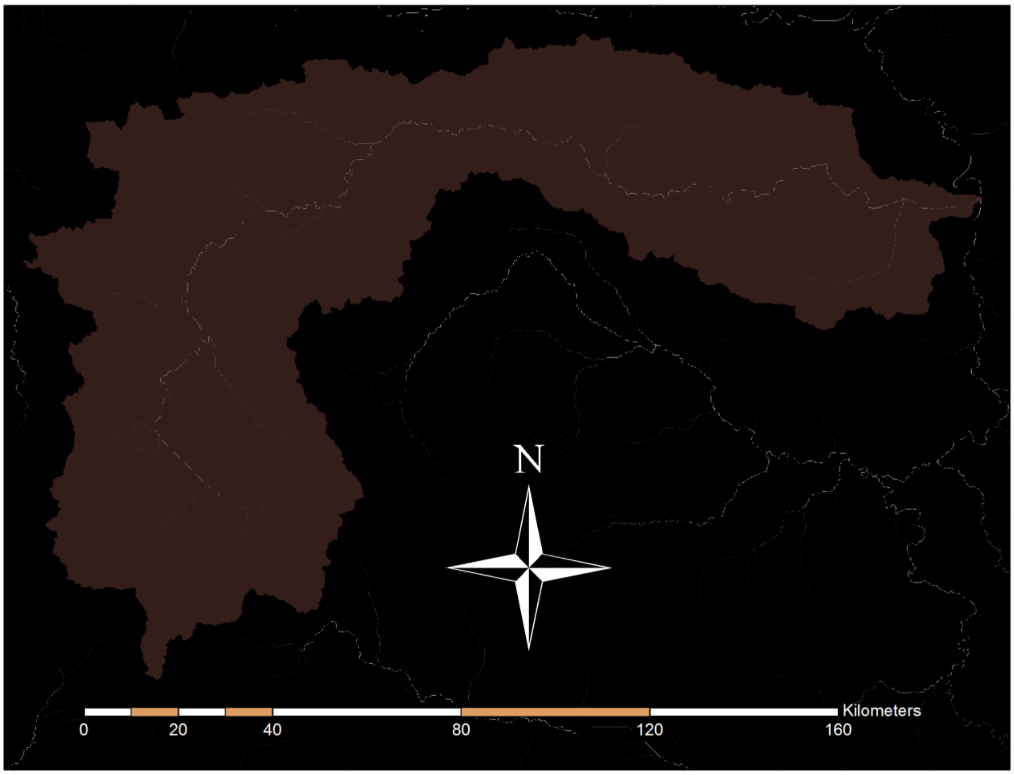


Figure 2.11. Flow accumulation

The amount of drops of precipitation in a basin boundary as raster data is defined with terms of Flow Accumulation. Flow accumulation area measurement that placed around the acclivity is done by calculation of amount of income flow. Most of cells will have small accumulation, but it will show rivers will have big accumulations. Flow accumulation application is placed in arc toolbox in hydrology. Flow accumulation map is shown in Figure 2.11

2.2.7. Set Null

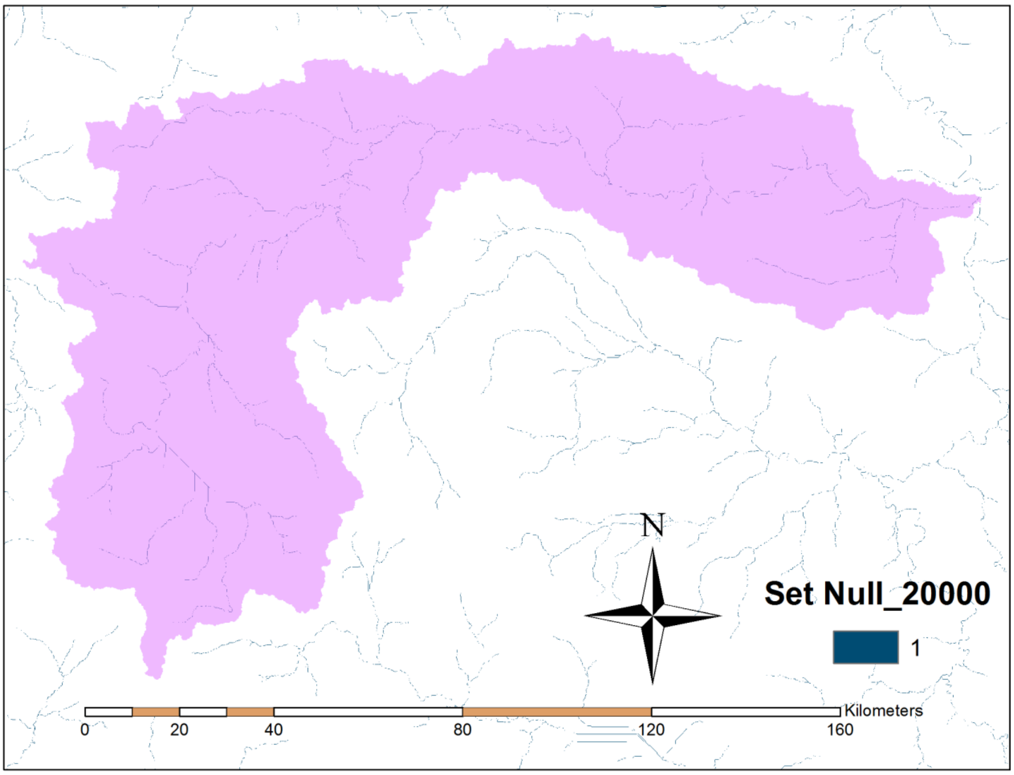


Figure 2.12. Set Null

This application is used to subtract big valued cells from drainage area. This cells show rivers and valleys. So set null application is used to subtract the high valued cells and to convert the remained cells as No DATA. This result is a raster projection of the drainage network, created for surface. To do this process, a threshold value should be selected to find the river or valleys or other water ways. Set null application is placed in ArcToolbox in hydrology extension. Set Null map is shown in figure 2.12.

2.2.8. Basin

Basin application is used to define the basin boundaries, because if an analysis should be run in limited drainage area, the basin boundaries must cut from whole area. BASİN application is placed in arc toolbox in hydrology. We run this process by defining another special pour point. This point becomes basin’s start point.

2.3. Geographical Information Systems (GIS)

2.3.1. Definitions

Several definitions have been put forward for Geographic Information Systems and some of these are:

• A powerful set of tools for storing and retrieving at will, transforming and displaying spatial data from the real world for a particular set of purposes

• Geographic Information Systems are a specialized class of database management systems that allow users to analyze, relate and display the spatial attributes of data in addition to conventional relational data

• Geographic Information Systems are essentially digital maps linked to database management systems which can be used for the purposes of displaying and querying information, carrying out spatial analysis and assisting in the decision-making process

The above definitions vary slightly in emphasis, although they all acknowledge the spatial focus of GIS and its considerable potential to facilitate analysis and decision making. Within the context of this thesis, the following working definition has been adopted:

Geographic Information Systems are management systems that allow for the integration of disparate spatial datasets to reveal the complex patterns and relationships that can be seen when analyzed together rather than singularly.

2.3.2. Main Concepts of a Geographic Information System

There are variations in the literature on the concepts of a GIS. Figure 2.13 illustrates the main components of a GIS. These are briefly explained below:

GIS Database: The database enables both spatial and non-spatial data to be stored and retrieved. Spatial data have a physical geographical location associated with them. The database is a fully integrated relational database with the additional capability to link with a graphical user-interface (GUI).

User Interaction: The user of a GIS system has the capacity to interact with the GIS database. He/she can input data, query the database or update the information stored. 'What if' analysis can also be conducted through an appropriate combination of queries to generate useful information?

Outputs: The information requested by the user can be produced in different formats such as maps, charts, tables and reports.

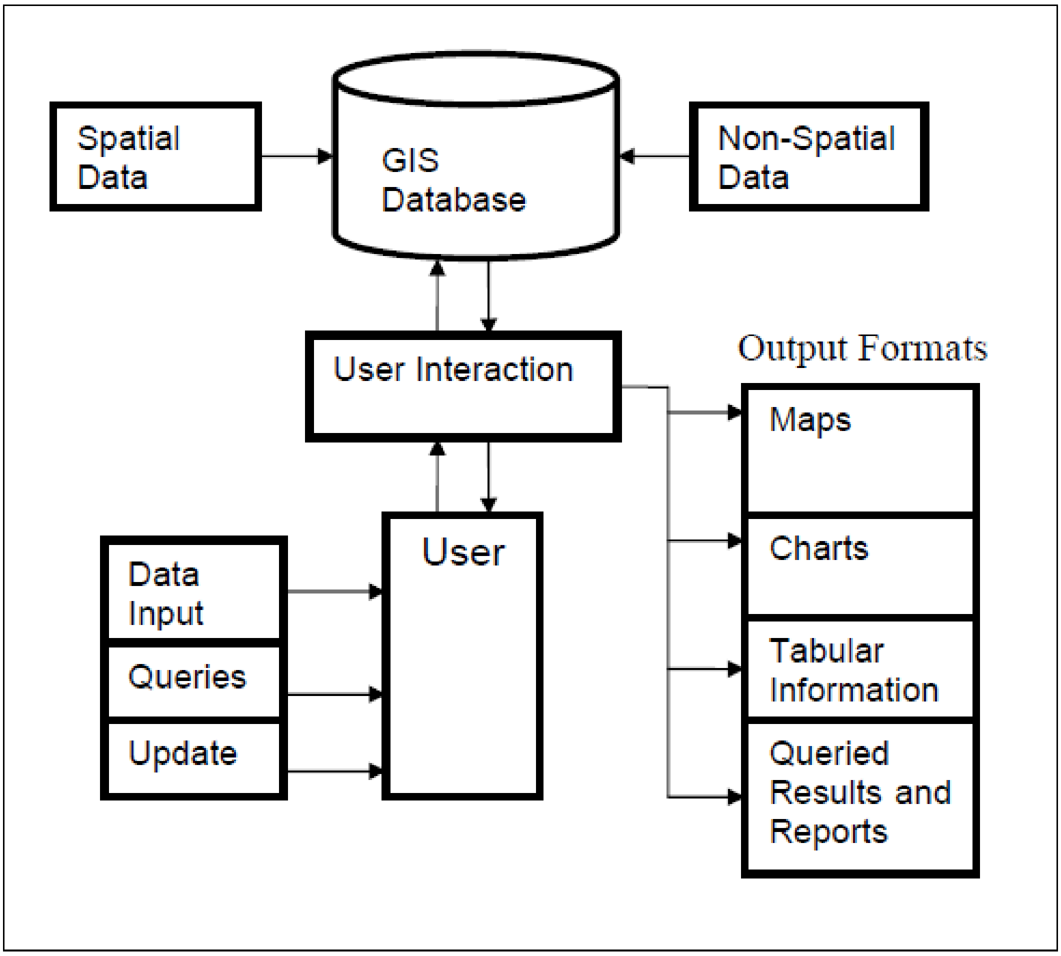


Figure 2.13. Main components of a GIS

2.3.3. Benefits of GIS

As previously alluded to, Geographic Information Systems offer numerous benefits. Burrough (1996) outlines the following benefits of GIS in labour market planning:

• There is ease of data distribution and access - as a central resource for construction labour market information it will be easy to access and distribute the information to users;

• There is ease of data integration and analysis - different labour market information can be integrated and analyzed to reveal the patterns and relationships that exist within the different datasets;

• It has the ability to create highly detailed maps to enhance presentations and aid decision-making having labour market information on detailed maps can give a greater understanding of the geographical issues that affect labour market planning;

• It reveals patterns and trends in the data that cannot be readily seen - the same data over a period of time can reveal geographical trends in labour market information that aid decision-making for the future;

• The option to convert and combine manual records to bring to light errors and omissions that might exist in certain datasets - manual records can be inaccurate due to human error. Converting and combining manual labour market information to populate a GIS database will bring to light errors and omissions that exist in the dataset or information. Most GIS systems will allow users to access data from most databases, which save time that might be required to input data into the software;

• The query mechanism allows different scenarios to be viewed, which will enable decision-makers to come up with positive solutions – asking questions such as "What is there?" "Why are they there?" "What will happen if?" "What might happen if?" of the data to simulate different scenarios and help strategists when planning for the future of the labour market.

Despite these benefits, the performance and utility of a GIS is wholly dependent on the quality of data. Inadequate or incomplete information will dilute the extent to which a GIS application can deliver the above benefits. Data must also be structured in a way which accords with the input requirements of the system.

2.3.4. GIS Applications and Results of Porsuk Basin

2.3.4.1. Digital Elevation Model (DEM)

Digital Elevation Models are data files that contain the elevation of the terrain over a specified area, usually at a fixed grid interval over the surface of the earth. The intervals between each of the grid points will always be referenced to some geographical coordinate system. This is usually either latitude-longitude or UTM (Universal Transverse Mercator) coordinate systems. The closer together the grid points are located, the more detailed the information will be in the file. The details of the peaks and valleys in the terrain will be better modeled with a small grid spacing than when the grid intervals are very large. Elevations other than at the specific grid point locations are not contained in the file. As a result peak points and valley points not coincident with the grid will not be recorded in the file.

The DEM does not contain elevation contours, only the specific elevation values at specific grid point locations.

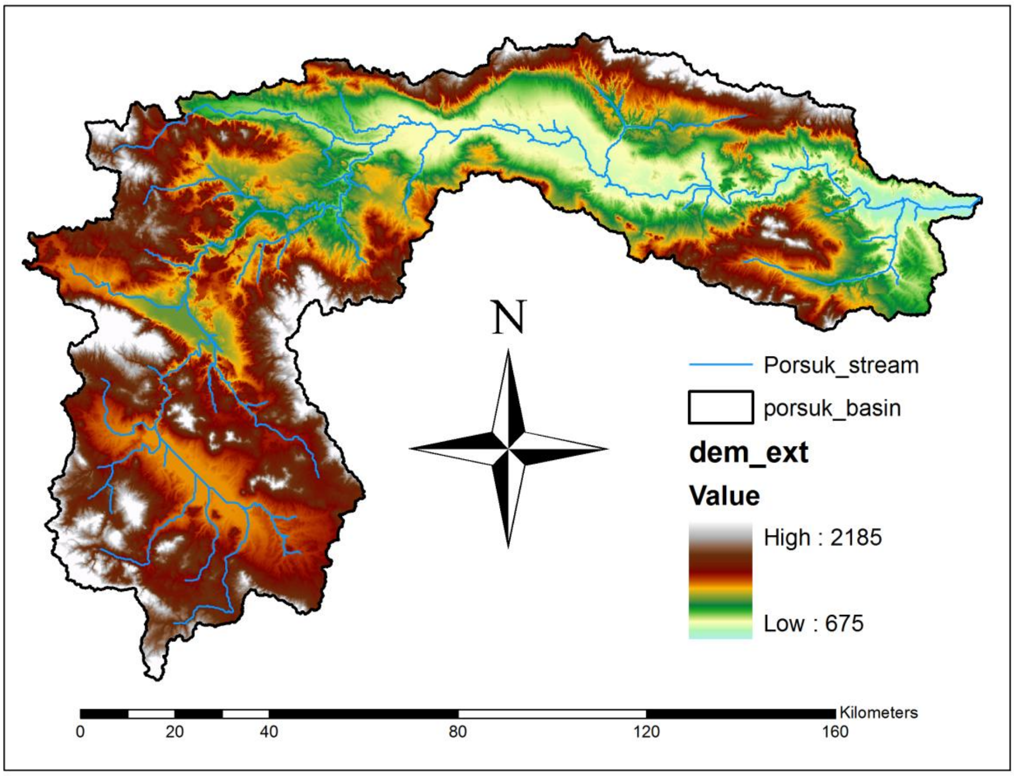


Figure 2.14. Digital Elevation Model (DEM) of Porsuk Basin

2.3.4.2. Slope Analysis

From the topographical map we can actually identify:

- Area coordinate
- Environment status
- Contours for the surface area

From the above references of information, analysis was done on the slope stability of Porsuk Basin by using software named GIS. This software was used as a tool to model the area for spatial data processing. The analysis involves scanning, digitizing, modeling and result interpretation.

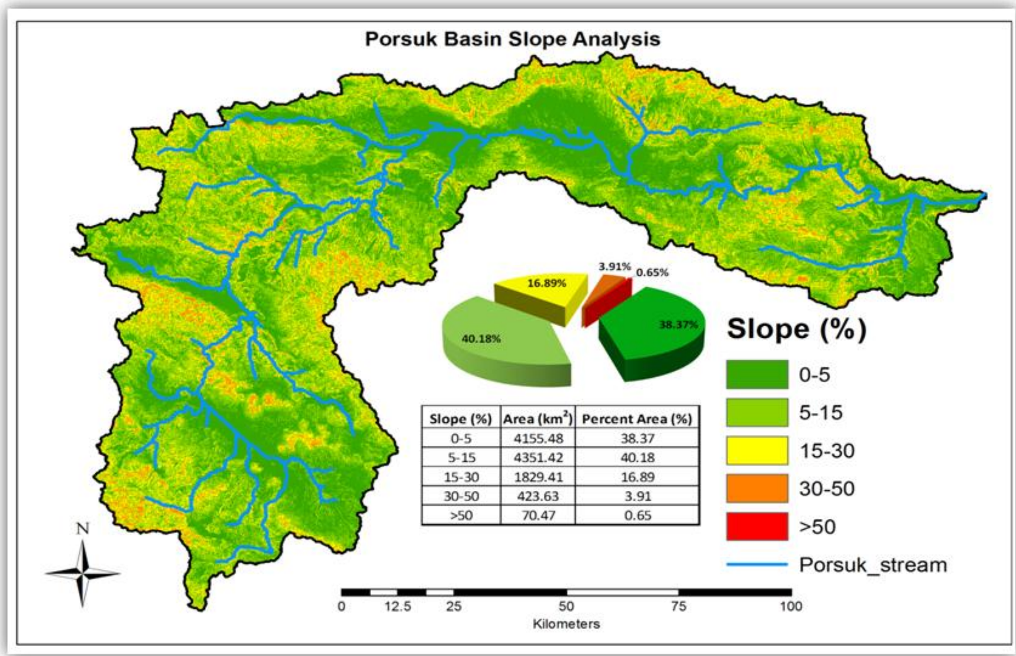


Figure 2.15. Slope analysis of Porsuk Basin

In Porsuk Basin, with using DEM; slope analysis is made. The elevation at a point will have perpendicular tangents (slope) passing through the point, in an east-west and north-south direction.

2.3.4.3. Aspect Analysis

Generally, aspect refers to the compass direction that a hillside or slope faces. Aspect can be generated from continuous elevation surfaces. A southern aspect is the same as a south-facing slope. Many geographic information systems (GIS) can analyze digital elevation data (elevation points, contour lines, digital elevation models, etc.) and derive both slope and aspect data sets.

The degree to which sunlight strikes a hillside depends on its aspect; north-facing hillsides receive little or no sunlight; east- and west-facing slopes receive sunlight for a portion of each day (unless they are shaded by another hill or mountain); and south-facing slopes receive the greatest amount of sunlight. Because aspect affects the amount of sunlight striking the land's surface, aspect can be an important metric that aids in the sitting of buildings to maximize or minimize solar gain. Aspect also can be one of a number of determinants of vegetation communities, habitat, soil moisture, evapotranspiration, and other biological and physical landscape characteristics.

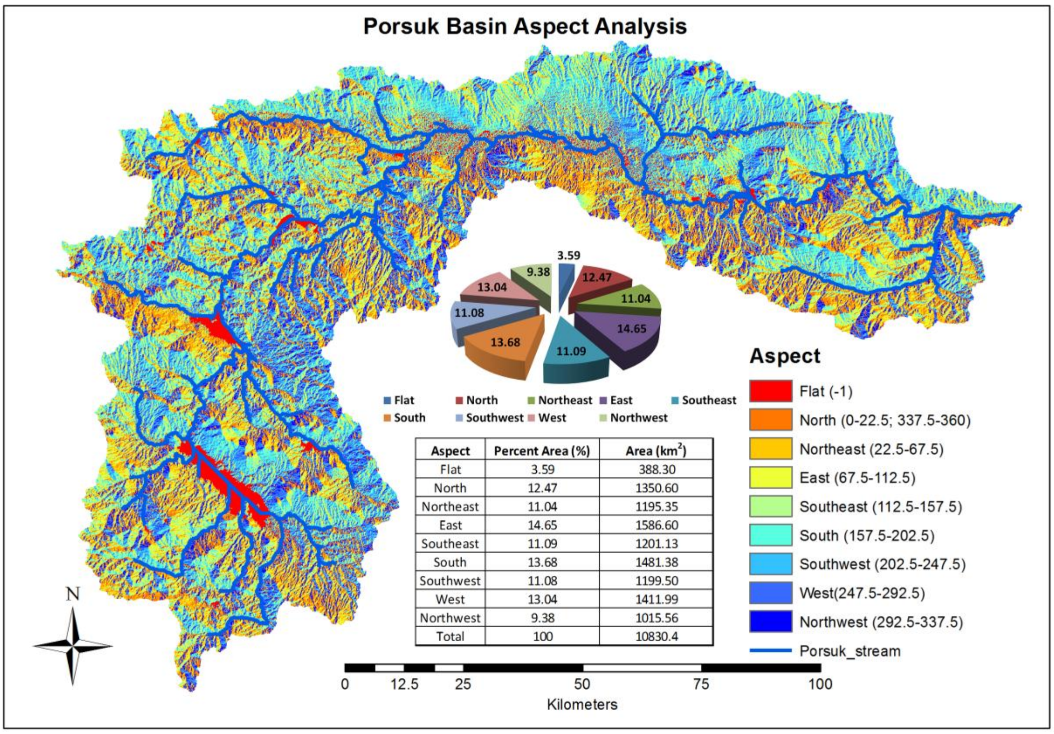


Figure 2.16. Aspect analysis of Porsuk Basin

3. Hydrological Modeling

3.1. HEC-HMS

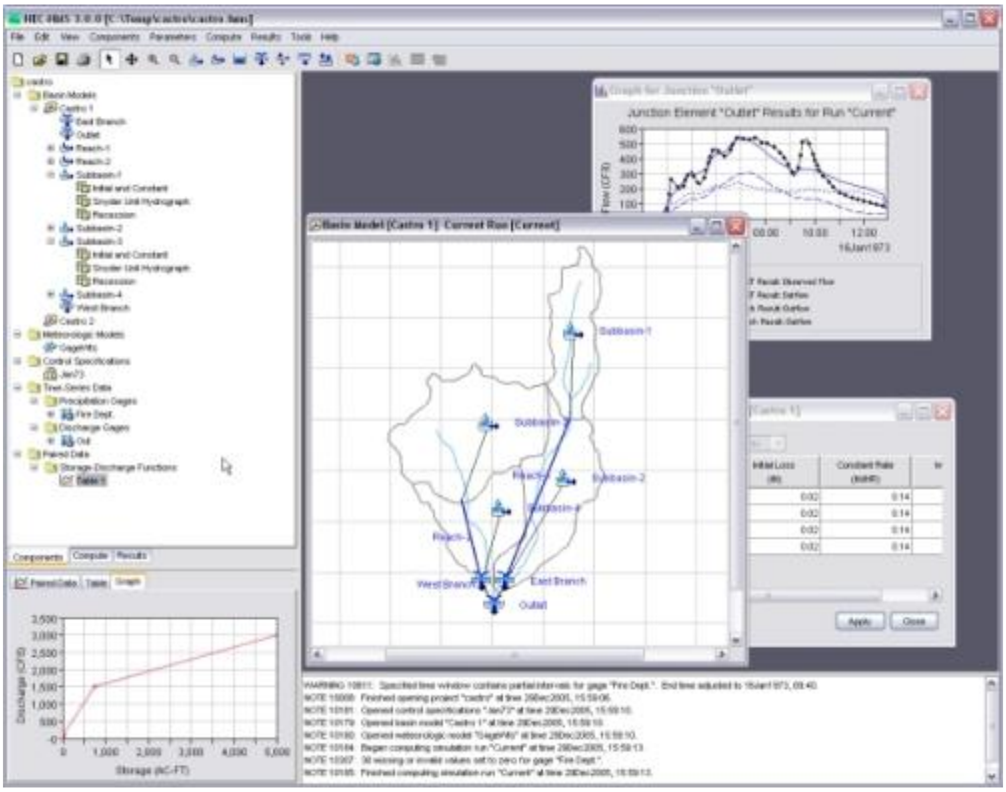


Figure 3.1. Main Window of HEC-HMS Software (HEC-HMS)

3.1.1. Introduction - What is HEC-HMS

The hydrological modeling system is designed to simulate the precipitation-runoff process of dendritic watershed systems. It is designed to be applicable in a wide range of geographic areas for solving the widest possible range of problems. This includes large river basins water supply and flood hydrology, and small urban or natural watershed runoff. (HEC-HMS)

3.1.2. Scope of HEC-HMS

The program is generalized modeling system capable of representing many different watersheds. A model of watershed is constructed by separating by hydrologic cycle into manageable pieces of constructing boundaries around the watershed of interest. Any mass or energy flux in the cycle can then be represented with a mathematical model. In most cases, several model choices are available for representing each flux. Each mathematical model include in the program is suitable in different environments and under different conditions. Making the correct choice requires knowledge of the watershed, the goals of the hydrologic study, and engineering judgment.

3.1.3. History of HEC-HMS

The computation engine draws on over 30 years' experience with hydrologic simulation software. Future versions of the program will continue to modernize desirable algorithms from legacy software.

The initial program didn't introduce several notable improvements over the legacy software including an unlimited number of hydrograph ordinates and gridded runoff representation. The tools for parameter estimation with optimization were much more flexible than previous programs. The second major release with the addition of soil moisture accounting method extended the program from event-simulation package to one that could work equally well with event or continuous simulation applications. The reservoir element was also expanded to include physical description for an outlet, spillway, and overflow. An overtopping dam failure option was also added.

The third-party graphics libraries used to implement the multi-platform interface used in first versions were sold and soon became unavailable. Faced with the prospect of using unsupported graphics tools, the design team evaluated alternatives and chose to move program to the Java™ language. The simulation engine was converted to Java™ and completely new interface was designed. During the process, careful attention was paid to lessons learned from earlier versions. The result was Version3.0 with the new interface plus new simulation capabilities for infiltration, reservoir outlet structures, piping dam failure, and analysis tools.

Enhancement of the program is ongoing. Plans are already underway to add new features in a future version that will make the program easier to use by providing more flexible ways to accomplish work. (HEC-HMS)

3.1.4. Capabilities

The program has an extensive array of capabilities for conducting hydrologic simulation. Many of most common methods in hydrologic engineering are included in such a way that they are easy to use. (HEC-HMS)

3.1.4.1. Watershed Physical Description

The physical representation of a watershed is accomplished with a basin model. Hydrologic elements are connected in a dendritic network to simulate runoff process. Available elements are: sub basin, reach, junction, reservoir, diversion, source, and sink. Computation proceeds from upstream elements in a downstream direction. (HEC-HMS)

3.1.4.2. Meteorology Description

Meteorological data analysis is performed by the meteorologic model and includes precipitation, evapotranspiration, and snowmelt. Six different historical and synthetic precipitation methods are included. Three evapotranspiration methods are included at this time. Currently, only two snowmelt methods are available. (HEC-HMS)

3.1.4.3. Hydrological Simulation

Time span of simulation is controlled by control specifications. Control specifications include a starting date and time, ending date and time, and time interval.

A simulation run is created by combining a basin model, meteorological model, and control specifications. Run options include a precipitation or flow ratio, capability to save all basin state information at a point in time, and ability to begin a simulation run from previously saved state information.

Simulation results can be viewed from the basin map. Global and element summary tables include information on peak flow and total volume. A time-series table and graph are available for elements. Results from multiple elements and multiple simulation runs can also be viewed. (HEC-HMS)

3.1.4.4. Parameter Estimation

Most parameters for methods include in sub basin and reach elements can be estimated automatically using optimization trials. Observed discharges must be available for at least one element before optimization can begin. Parameters at any element upstream of the observed flow location can be estimated. Seven different objective functions are available to estimate to goodness-of-fit between the computed results and observed discharges. Two different search methods can be used to minimize the objective function. Constraints can be imposed to restrict the parameter space of the search method. (HEC-HMS)

3.1.4.5. Analyzing Simulation

Analysis tools are designed to work with simulation runs to provide additional information or processing. Currently, the only tool is the depth-area analysis tool. It works with simulation runs that have a meteorological model using the frequency storm method. Given a selection of elements, the tool automatically adjusts the storm area and generates peak flows represented by the correct storm areas. (HEC-HMS)

3.1.4.6. GIS Connection

The power and speed of the program make it possible to represent watershed with hundreds of hydrologic elements. Traditionally, these elements would be identified by inspecting a topographic map and manually identifying drainage boundaries. While this method is effective, it is prohibitively time consuming when the watershed will be represented with any elements. A geographic information system (GIS) can use elevation data and geometric algorithms to perform the same task much more quickly. A GIS companion product has been developed to aid in the creation of basin models for such projects. It is called the Geospatial Hydrologic Modeling Extension (HEC- GeoHMS) and can be used to create basin and meteorological models for use with the program. (HEC-HMS)

3.1.5. Limitations of HEC-HMS

Every simulation system has limitations due to the choices made in the design and development of the software. The limitations that arise in this program are due to two aspects of the design: simplified model formulation, and simplified flow representation. (HEC-HMS)

3.1.5.1. Model Formulation

All of the mathematical models included in the program are deterministic. This means that the boundary conditions, initial conditions, and parameters of the models are assumed to be exactly known. This guarantees that every time a simulation is computed it will yield exactly the same results as all previous times it was computed. Deterministic models are sometimes compared to stochastic models where the same boundary conditions, initial conditions, and parameters are represented with probabilistic distributions.

All of the mathematical models included in the program use constant parameter values, that is, they are assumed to be time stationary. During long periods of time it is possible for parameters describing a watershed to change as the result of human or other processes at work in the watershed. These parameter trends cannot be included in a simulation at this time. There is a limited capability to break a long simulation into smaller segments and manually change parameters between segments.

All of the mathematical models included in the program are uncoupled. The program first computes evatranspiration and the computes infiltration. In the physical world, the amount of evatranspiration depends on the amount of the soil water. The amount of the infiltration also depends on the amount of soil water. However, evatranspiration removes water from the soil at the same time infiltration processes should be simulated simultaneously with the mathematical equations for both processes numerically linked. This program does not currently include such coupling of the process models. Errors due to the use of uncoupled models are minimized as much as possible by using a small time interval for calculations. (HEC-HMS)

3.1.5.2. Flow Representation

The design of the basin model only allows for dendritic stream networks. The best way to visualize a dendritic network is to imagine a tree. The main tree is trunk, branches, and twigs corresponding to the main river, tributaries, and headwater streams in a watershed. The key idea is that a stream does not separate into two streams. The basin model allows each hydrologic element to have only one downstream connection so it is not possible to split the outflow from an element into two different downstream elements.

The design of the process for computing a simulation does not allow for back water in the stream network. The compute process begins at head water sub basins and proceeds down through the network. Each element is computed for the entire simulation time window before proceeding to the next element. There is no iteration or looping between elements.

Therefore, it is not possible for an upstream element to have knowledge of downstream flow condition, which is the essence of backwater effects. There is a limited capability to represent backwater if it is fully contained within a reach element. However, in general, the presence of backwater within the stream network will require a separate hydraulic model. (HEC-HMS)

3.1.6. Methods Used in HEC-HMS

3.1.6.1. Meteorology Description

Meteorological data analysis is performed by the model that includes precipitation, evatranspiration, and snowmelt. Precipitation and snowmelt methods used in HEC-HMS version 3.3 is shown in Table 3.1. (HEC-HMS)

Table 3.1. Precipitation and Snowmelt Methods

Precipitation Methods	Description
Frequency Storm	Used to develop a precipitation event where depths for various duration within the storm have a consistent exceedance probability
Gauge Weights	User specified weights applied to precipitation gauges.
Inverse Distance	Calculates sub basins average precipitation by applying inverse distance square weighting with gauges/
SCS Storm	Applies a user specified SCS time Distribution to a 24-hour total storm depth
Specified Hyetograph	Applies a user defined hyetograph to a specified sub basin element
Standard Project Storm	Uses a time distribution to an index precipitation depth
Snowmelt Method	
Temperature	Typically, the base temperature is 0 ºC or close to it

3.1.6.2. Watershed physical description

The physical description representation of a watershed is accomplished with a basin model. Hydrological elements are used in a program such as sub basin, junction, etc… it may additionally contain components for representing engineered structures such as diversions, reservoirs, and pump stations. (HEC-HMS)

After entering watershed information to the program, methods should be selected for elements used. For example, loss method, transform methods and base flow methods should be selected for sub basin elements. Methods used in program are shown in Table 3.2.

Table 3.2. Hydrologic Model Methods in HEC-HMS

Hydrologic Element	Calculation Type	Method
Sub basin	*Loss Rate*	☐ Deficit and Constant Rate ☐ Exponential ☐ Green an Ampt ☐ Gridded DC ☐ Gridded SCS CN ☐ Gridded SMA ☐ Initial and Constant Rate ✓ SCS Curve Number ☐ Soil Moisture Accounting
	Transform	☐ Clark`s UH ☐ Kinematic wave ☐ ModClark ☐ SCS UH ☐ Snyder's UH ☐ User specified s-graph ✓ User specified UH
	Baseflow	☐ Bounded Recession ☐ Constant monthly ☐ Linear Reservoir ✓ Recession
Reach	*Routing*	☐ Kinematic wave ☐ Lag ☐ Modified pulse ☐ Muskingum ☐ Muskingum-cunge

3.1.7. Some of the other methods used in HEC-HMS

3.1.7.1. Rainfall analysis methods

Hydrologist almost interested in precipitation over a region, such as a drainage basin, rather than at a point. Several approaches have been devised for estimating regional precipitation from point values. Some of these approaches provide estimates only of the spatial averaged precipitation; others provide an estimate of the spatial distribution of the precipitation within the region of interest as well as of the spatial average. (Dingman, 2002)

Gauge weights: This method is one of the methods used in HEC-HMS version3.3. Gauge data is input as storm totals for selected gauges and relative weights assigned to these gauges (Hoggan, 1997). Weights reflect the effect of the spatial to the calculation. User should define the gauge weights to the program. These weights could be found in several methods. In this thesis study, thiessen polygon weights are used.

In the application of thiessen polygons, adjacent stations are joined by straight lines, thus dividing the entire area into a series of triangle. While doing this, it is better to try to obtain triangles as close to equilateral triangles as possible. Then bisectors (perpendicular lines at midpoint) are drawn to the sides of these triangles forming polygons around each station. It is assumed that the polygon of any station shows the influence area of the station. (Usul, 2005)

3.1.7.2. Selecting loss analysis method

Not all the rainfall from a storm contributes to a flood; some is detained within the basin. These losses that are significant in analyzing flood events include land-cover, interception storage and infiltration. Formulations of rainfall loss functions have been developed, ranging from very simple lumped parameter method to complete systems that continuously account for soil moisture and evatranspiration. (Hoggan, 1997),

Exponential loss method will be examined in detail in this study, and five of these loss methods are shown in Table 3.3. and some of characteristics are shown in this table.

Table 3.3. Loss Methods in HEC-HMS

Loss Technique	Units of Computation	Nonlinear Function of Time or Moisture	Evapotranspiration Recovery During Dry periods
Initial and Constant Rate	cm/h		
Exponential	cm/h	Moisture	
SCS	%	Moisture	
Soil Moisture Accounting	cm/h	Moisture	X
Green and Ampt	cm/h	Moisture	
Loss Technique	**Function of Rainfall Intensity**	**Direct Accounting of Detention Storage**	**Estimation From Geographic Characteristics**
Initial and Constant Rate		X	Poor
Exponential	X	X	Poor
SCS		X	Good
Soil Moisture Accounting	X	X	Fair-good
Green and Ampt			Fair

3.1.7.3. Unit hydrograph analysis and base flow methods

The unit hydrograph of a basin is defined as the hydrograph of surface runoff resulting in 1 cm (or 1 mm) or excess rainfall generated uniformly over the basin area at a uniform rate during a specified period of time. Unit hydrograph theory was first proposed by Sherman (1932), and expanded by others. It is assumed that the unit hydrograph is representative for the runoff process of a basin.

The unit hydrograph may be derived with different methods. These methods may be applied only if the records of rainfall and their corresponding runoff data are available. In this situation, user can specify the unit hydrograph for sub basin in HEC-HMS program. (HEC-HMS)

3.1.7.3.1. User specified unit hydrograph transform

The user specified unit hydrograph method is not synthetic. Consequently, a separate unit hydrograph must be developed for each sub basin. Usually these unit hydrographs are developed from multiple storm observations when precipitation and flow have been measured at the same time interval. The unit hydrograph so-called duration that is equal to the time interval of the precipitation measurements. The program will automatically adjust the duration of the user-specified unit hydrographs using the s-graph technique so that it matches the simulation time interval. (HEC-HMS)

3.1.8. Methodology

In this study, for basin model: SCS Curve Number method has been used as loss method, User-Specified Unit Hydrograph has been used as transform method and Recession has also been used as base flow method.

For meteorologic model, Specified Hyetograph has been used as precipitation input. One day's precipitation with half an hour interval has been modeled for different precipitation gauges in sub basin 1 and sub basin 2.

Sub basin 1 is the sub basin between Sarısu Creek (before Porsuk Creek meets Eskişehir's entrance) and Darıdere Dam with an area of 495 km^2 and a curve number of 75 and sub basin 2 is the sub basin between Porsuk Creek (before Eskişehir's entrance meets Sarısu Creek) and Porsuk Dam, Kargın Regulator, Uluçayır Flood Detention Dam with an area of 512.6 km^2 and curve number of 76 (Table 3.4.). Also in Figure 3.2. sub basins and meteorological gauges with stream gauges can be seen.

Table 3.4. State Hydraulic Works' Calculated Data for Sub Basin 1& 2

Flood Calculated Sections	Prec. Area (km^2)	Method	Q_2 (m^3/s)	Q_5 (m^3/s)	Q_{10} (m^3/s)	Q_{25} (m^3/s)	Q_{50} (m^3/s)	Q_{100} (m^3/s)	Q_{500} (m^3/s)	Q_{1000} (m^3/s)	Considerations
Uluçayır Flood Detention Dam Basin	160	BTFA	20.5	41.0	55.4	73.8	88.2	104.6	138.6	153.3	CN_{II} = 77
		NTFA									
		Mockus	12.0	29.0	46.0	75.0	100.0	130.0	188.1	213.1	12-63AGİ (BA)
		DSİ	12.0	25.9	38.8	59.4	77.9	99.5	141.9	160.1	
Kargın Regulator Section	317.3	BTFA	26.0	52.0	70.2	93.6	111.8	132.6	175.8	194.4	CN_{II} =78
		NTFA	18.0	40.8	58.3	81.8	99.6	117.2	158.0	175.5	12-06 AGİ
		Mockus	15.0	35.0	53.0	84.0	113.0	148.0	214.0	242.0	12-06AGİ (BA)
		DSİ	19.0	36.0	52.0	77.0	101.0	129.0	183.0	206.0	
Darıdere Dam Basin	182	BTFA	21.2	42.4	57.2	76.3	91.2	108.1	143.3	158.5	CN_{II} = 75
		NTFA	17.5	40.9	57.4	76.7	89.3	100.3	130.0	143.0	12-53 AGİ
		Mockus	26.0	48.0	64.0	86.0	102.0	119.0	156.8	173.5	12-53AGİ (BA)
		DSİ	25.1	44.3	58.4	77.0	91.3	105.8	138.4	152.7	
Sub Basin 1	495	BTFA	29.5	59.0	79.7	106.2	126.9	150.5	199.4	220.5	CN_{II} = 75
		NTFA									
		Mockus	10.0	26.0	41.0	65.0	86.0	111.0	159.0	180.0	12-02AGİ (BA)
		DSİ	18.0	40.0	59.0	89.0	116.0	145.0	206.0	232.0	
Sub Basin 2	512.6	BTFA	30.0	60.0	81.0	108.0	129.0	153.0	202.8	224.3	CN_{II} = 76
		NTFA	25.0	56.0	80.0	113.0	137.0	162.0	219.0	243.0	12-06 AGİ
		Mockus	16.0	37.0	56.0	84.0	109.0	136.0	191.0	215.0	12-63AGİ (BA)
		DSİ	25.0	50.0	70.0	101.0	127.0	154.0	212.0	238.0	

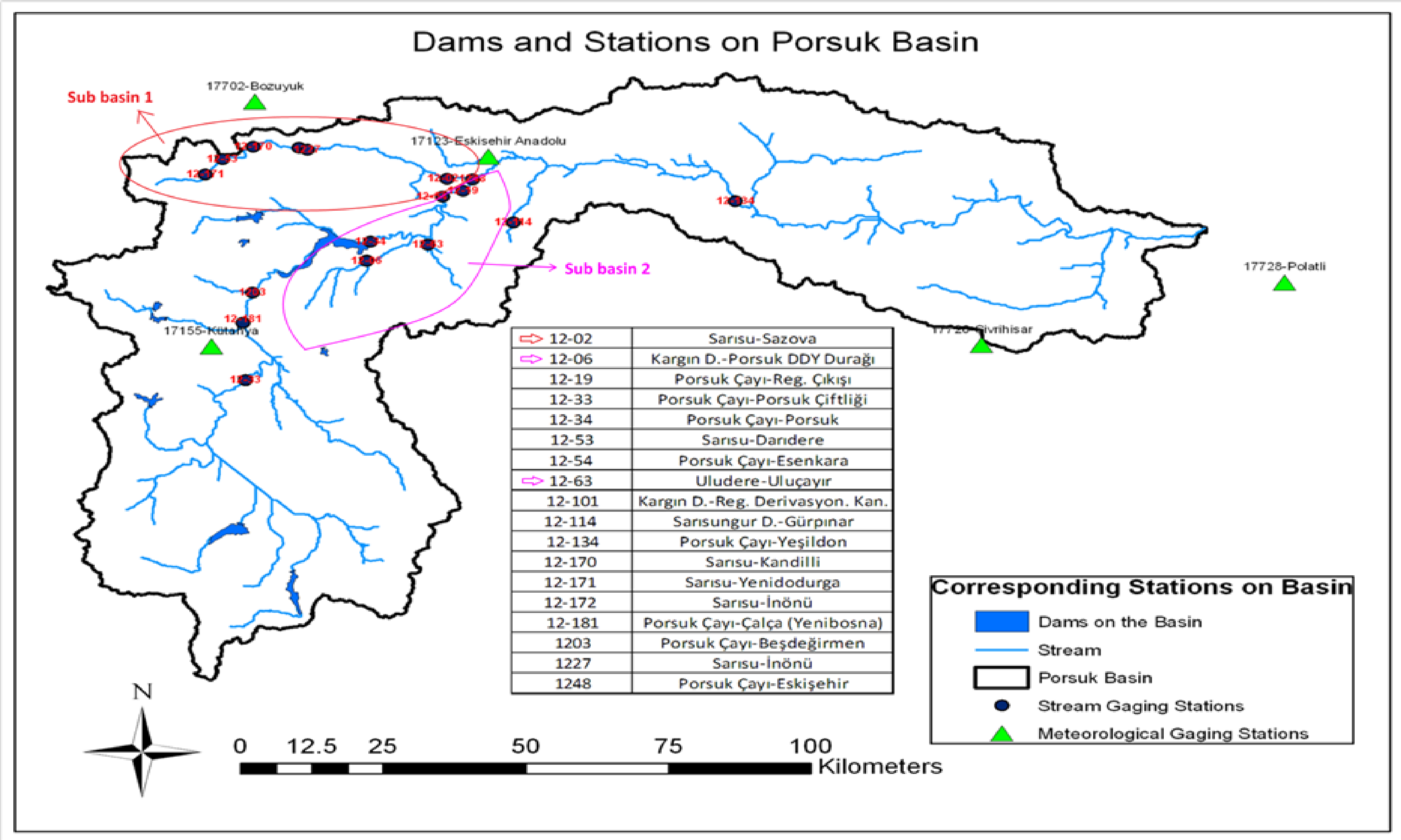


Figure 3.2. Dams and Gauges with Illustration of Sub basin 1& 2

Incremental precipitation values have been obtained using SCS Type-II Distribution Table (Table 3.6.) for depth of 59.74mm based on 100 years for Eskişehir (Table 3.5.) and used as input for specified hyetograph in the software. Scale Factors, Incremental Depth and Intensity according to this table is also given in Figure 3.3, 3.4 and 3.5.

Table 3.5. Maximum Observed Precipitation Values in Standard Times on Eskişehir Meteorological Gauge

Tablo 4.8 - Eskişehir Meteoroloji İstasyonunda Standart Zamanlarda Gözlenen En Büyük Yağış Değerleri (mm)

GÖZLEM	DAKİKA				SAAT										
YILI	5	10	15	30	1	2	3	4	5	6	8	12	18	24	24 +
1995	10.30	17.50	20.40	20.60	20.60	20.90	21.00	21.00	21.00	21.00	21.00	21.30	26.40	29.80	
1994	2.70	3.50	3.50	3.50	5.60	7.90	8.60	10.10	12.40	14.50	18.40	22.30	26.90	27.30	
1993	6.00	10.30	14.30	17.90	18.90	20.40	20.40	20.40	20.40	20.40	20.40	26.20	32.10	32.20	
1992	6.10	8.60	11.30	17.30	30.20	33.10	33.10	33.10	33.10	33.10	33.10	33.10	33.10	40.90	
1991	7.60	11.40	12.60	13.50	14.40	14.50	20.60	25.10	29.30	31.70	35.00	35.30	35.70	51.30	
1990	2.20	3.20	3.80	4.00	6.80	12.30	18.00	20.60	22.20	28.90	35.00	39.30	39.30	39.30	
1989	4.40	6.20	7.50	8.20	9.70	18.90	20.00	20.00	20.00	20.00	20.00	20.00	22.70	34.00	
1988	8.70	11.30	16.80	33.30	41.20	41.80	41.80	41.80	41.80	42.40	42.40	42.40	42.40	42.40	
1987	1.50	2.50	3.40	4.20	5.60	7.40	7.80	8.10	8.10	8.10	15.30	17.10	17.50	34.00	*
1986	0.50	0.80	1.20	2.70	6.00	11.70	14.90	18.10	20.90	21.90	25.70	26.50	27.20	27.20	
1985	3.20	4.40	5.20	7.00	9.70	11.10	11.30	12.80	15.50	16.90	20.90	21.10	21.30	21.50	
1984	0.80	1.50	1.80	1.80	2.20	4.90	6.70	7.70	9.10	10.00	11.60	17.80	19.50	29.50	
1983	9.80	12.90	19.20	28.40	29.70	29.80	29.80	29.80	29.80	38.20	38.20	38.20	38.20	38.20	
1982	5.00	6.60	7.70	8.80	9.40	10.50	13.50	15.90	16.00	16.00	16.00	16.00	16.00	17.80	
1981	5.60	7.10	7.60	9.40	10.60	14.90	16.30	21.60	26.80	27.10	27.40	31.00	33.00	33.00	
1980	3.00	4.00	4.30	4.60	6.00	12.00	15.30	15.80	15.80	15.80	22.50	23.20	23.40	25.00	
1979	3.20	3.20	4.50	6.30	9.00	16.70	20.80	23.40	24.80	28.00	35.40	44.40	53.40	54.10	
1978	2.80	3.50	4.10	5.80	7.60	12.20	13.40	14.10	14.50	14.50	15.50	19.50	19.50	21.60	
1977	6.10	9.70	10.50	10.80	11.60	12.90	13.30	13.30	13.30	13.30	15.80	15.80	23.00	35.50	
1976	5.80	8.00	9.50	13.70	18.80	19.20	19.20	20.40	20.40	20.40	20.60	20.60	20.60	24.60	
1975	6.80	10.30	15.40	20.30	20.60	20.70	20.70	20.70	20.70	20.70	20.70	20.70	23.30	27.70	
1974	6.90	10.10	13.00	13.00	13.00	13.00	14.20	14.20	14.20	14.20	21.50	25.10	25.30	25.30	
1973	10.30	18.60	24.80	33.10	42.60	44.90	14.90	44.90	44.90	44.90	44.90	44.90	44.90	48.60	
1972	11.00	12.00	14.20	16.50	16.50	16.60	16.80	17.00	17.50	20.30	22.90	22.90	22.90	22.90	
1971	5.40	5.60	5.80	6.00	10.30	11.50	15.60	20.40	20.60	20.70	21.80	22.10	23.70	24.10	
1970	7.00	10.40	14.90	20.90	20.90	20.90	21.70	21.70	21.70	21.70	21.70	21.70	22.20	24.00	
1969	3.00	4.00	4.20	4.20	6.20	12.20	14.60	14.80	15.00	15.00	15.00	21.10	21.10	24.00	
1968	1.00	1.40	1.60	1.90	3.00	6.00	18.70	19.20	19.20	19.20	19.20	19.20	22.50	24.00	
1967	6.30	8.90	10.40	13.60	15.60	20.10	21.60	22.40	22.40	22.40	22.40	22.60	22.60	22.60	
1966	7.50	12.00	15.50	16.50	16.50	21.00	23.40	23.40	23.40	23.40	23.40	25.00	25.00	25.00	
1965	6.50	10.90	15.20	21.70	22.00	24.00	26.00	26.00	26.00	26.00	26.00	27.10	33.90	35.20	
1964	6.00	10.00	12.00	20.00	20.00	20.00	20.20	20.80	20.80	20.80	20.80	20.80	26.60	28.90	
1963	5.40	7.50	8.00	12.60	14.00	16.20	17.20	17.20	18.00	18.80	21.30	21.30	30.30	33.80	
1962	11.50	15.50	18.00	22.50	24.00	24.00	24.00	24.00	24.00	24.00	24.00	27.00	27.00	29.00	
1961	9.00	11.00	20.00	42.00	42.00	42.10	43.10	43.10	43.10	43.10	43.10	43.10	43.10	43.10	
1960	11.50	14.50	17.50	18.50	20.00	20.00	20.30	20.30	21.30	21.30	27.20	27.20	27.20	27.20	
1959	6.00	10.00	12.00	15.00	17.50	17.50	21.00	25.50	28.10	31.10	31.10	31.10	31.10	31.10	
1958	3.50	4.50	7.50	7.50	7.50	9.00	10.00	13.00	15.30	15.50	15.90	16.90	16.90	21.10	
1957	10.00	19.50	19.50	21.00	23.50	25.50	26.00	26.00	26.00	26.00	26.70	27.40	27.40	32.20	
1956	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
1955	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
1954	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
1953	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
1952	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
1951	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
1950	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
1949	2.90	5.80	11.50	13.40	13.50	13.50	15.20	15.80	15.80	15.80	15.80	15.80	15.80	21.80	
1948	6.00	8.00	14.00	16.00	18.00	23.00	23.00	23.00	23.00	23.00	23.00	23.00	23.80	47.10	*
1947	13.50	13.50	13.50	13.50	14.80	14.80	14.80	14.80	15.00	15.80	17.20	17.90	19.40	20.10	
1946	6.70	6.70	6.70	6.70	9.50	9.50	9.50	9.50	9.50	9.50	9.50	9.50	9.50	48.00	*
1945	4.50	7.70	9.00	18.00	20.50	20.50	20.50	20.50	20.50	20.50	20.50	20.50	20.50	21.10	
1944	7.20	9.20	12.00	13.50	13.50	14.70	14.70	14.70	14.70	14.70	14.70	14.70	14.70	26.70	
1943	3.00	3.00	3.00	3.80	6.80	8.00	12.00	13.30	13.50	13.70	16.90	16.90	16.90	53.70	*
1942	2.50	3.00	4.00	5.50	6.00	8.00	8.00	8.70	9.80	9.80	10.00	11.30	11.90	20.70	
1941	4.30	4.50	4.80	4.80	4.90	7.50	7.50	7.50	7.50	7.70	8.30	12.30	13.20	19.70	
1940	4.00	4.50	5.00	6.90	8.00	8.50	8.70	11.40	12.90	14.40	15.40	15.90	20.40	29.00	
N	45	45	45	45	45	45	45	45	45	45	45	45	45	45	49
Y-ORT	5.94	8.41	10.56	13.78	15.66	17.74	18.61	20.29	21.01	21.82	23.25	24.66	26.37	29.65	30.96
Y-EB	13.50	19.50	24.80	42.00	42.60	44.90	43.10	44.90	44.90	44.90	44.90	44.90	53.40	54.10	54.10
Std.S	3.12	4.61	5.90	8.99	9.84	9.13	7.71	8.33	8.21	8.61	8.60	8.61	8.87	8.63	9.61
Car.K	0.42	0.47	0.31	1.01	1.21	1.39	1.28	1.26	1.20	1.07	0.88	0.97	0.97	1.14	0.95
U.D.F	G2P	LP3	LP3	LN3	G2P	LN2	LN2	LP3	G	LN2	LN2	LP3	LN2	LP3	LP3
2	5.73	7.84	9.58	12.46	13.76	15.78	17.19	18.95	19.73	20.30	21.81	23.03	24.99	27.84	28.98
5	8.48	12.58	15.88	20.49	22.81	23.72	24.03	26.35	27.81	27.95	29.48	30.73	32.92	35.46	37.55
10	10.05	15.16	19.58	25.61	28.77	29.36	28.63	31.16	33.16	33.05	34.51	36.00	38.03	40.84	43.57
25	11.82	17.76	23.58	31.88	36.17	36.86	34.50	37.13	39.93	39.50	40.83	42.87	44.35	48.08	51.60
50	13.02	19.28	26.09	36.44	41.54	42.68	38.92	41.49	44.94	44.32	45.50	48.13	48.97	53.77	57.90
100	14.13	20.52	28.24	40.92	46.81	48.71	43.38	45.78	49.92	49.17	50.17	53.53	53.54	59.74	64.47
PLF	0.24	0.35	0.45	0.61	0.69	0.72	0.69	0.75	0.80	0.80	0.83	0.88	0.91	1.00	1.07
PLV	0.21	0.29	0.36	0.46	0.52	0.60	0.64	0.69	0.71	0.74	0.78	0.83	0.89	1.00	1.00

Table 3.6. SCS Type II Distribution Method Table

Step	Minute	Scale factor	Cumulative Depth (mm)	Incremental Depth (mm)	Intensity	Step	Minute	Scale factor	Cumulative Depth (mm)	Incremental Depth (mm)	Intensity
0	0	0	0	0	0						
1	30	0.005	0.299	0.299	0.597	**25**	750	0.735	43.909	4.301	8.603
2	60	0.011	0.657	0.358	0.717	**26**	780	0.776	46.358	2.449	4.899
3	90	0.017	1.016	0.358	0.717	**27**	810	0.804	48.031	1.673	3.345
4	120	0.023	1.374	0.358	0.717	**28**	840	0.825	49.285	1.255	2.509
5	150	0.029	1.732	0.358	0.717	**29**	870	0.842	50.301	1.016	2.031
6	180	0.035	2.091	0.358	0.717	**30**	900	0.856	51.137	0.836	1.673
7	210	0.041	2.449	0.358	0.717	**31**	930	0.869	51.914	0.777	1.553
8	240	0.048	2.868	0.418	0.836	**32**	960	0.881	52.631	0.717	1.434
9	270	0.056	3.345	0.478	0.956	**33**	990	0.893	53.348	0.717	1.434
10	300	0.064	3.823	0.478	0.956	**34**	1020	0.903	53.945	0.597	1.195
11	330	0.072	4.301	0.478	0.956	**35**	1050	0.913	54.543	0.597	1.195
12	360	0.08	4.779	0.478	0.956	**36**	1080	0.922	55.08	0.538	1.075
13	390	0.09	5.377	0.597	1.195	**37**	1110	0.93	55.558	0.478	0.956
14	420	0.1	5.974	0.597	1.195	**38**	1140	0.938	56.036	0.478	0.956
15	450	0.11	6.571	0.597	1.195	**39**	1170	0.946	56.514	0.478	0.956
16	480	0.12	7.169	0.597	1.195	**40**	1200	0.953	56.932	0.418	0.836
17	510	0.133	7.945	0.777	1.553	**41**	1230	0.959	57.291	0.358	0.717
18	540	0.147	8.782	0.836	1.673	**42**	1260	0.965	57.649	0.358	0.717
19	570	0.163	9.738	0.956	1.912	**43**	1290	0.971	58.008	0.358	0.717
20	600	0.181	10.813	1.075	2.151	**44**	1320	0.977	58.366	0.358	0.717
21	630	0.203	12.127	1.314	2.629	**45**	1350	0.983	58.724	0.358	0.717
22	660	0.236	14.099	1.971	3.943	**46**	1380	0.989	59.083	0.358	0.717
23	690	0.283	16.906	2.808	5.616	**47**	1410	0.995	59.441	0.358	0.717
24	720	0.663	39.608	22.701	45.402	**48**	1440	1	59.74	0.299	0.597

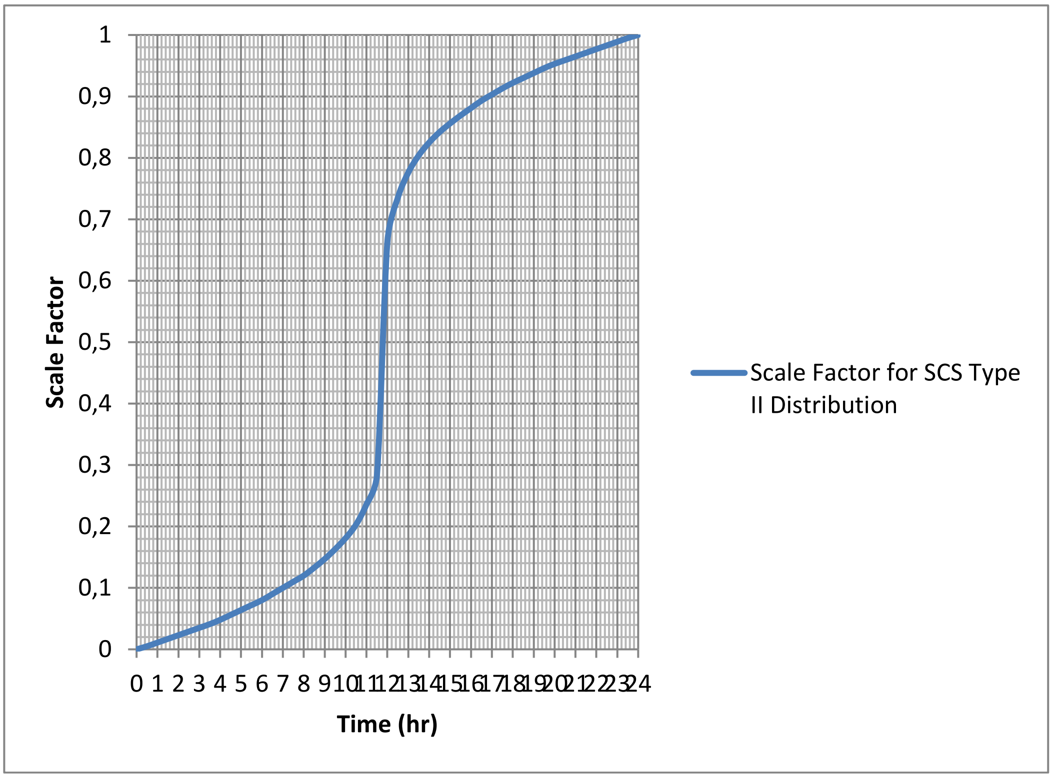


Figure 3.3. Scale Factor for SCS Type II Distribution

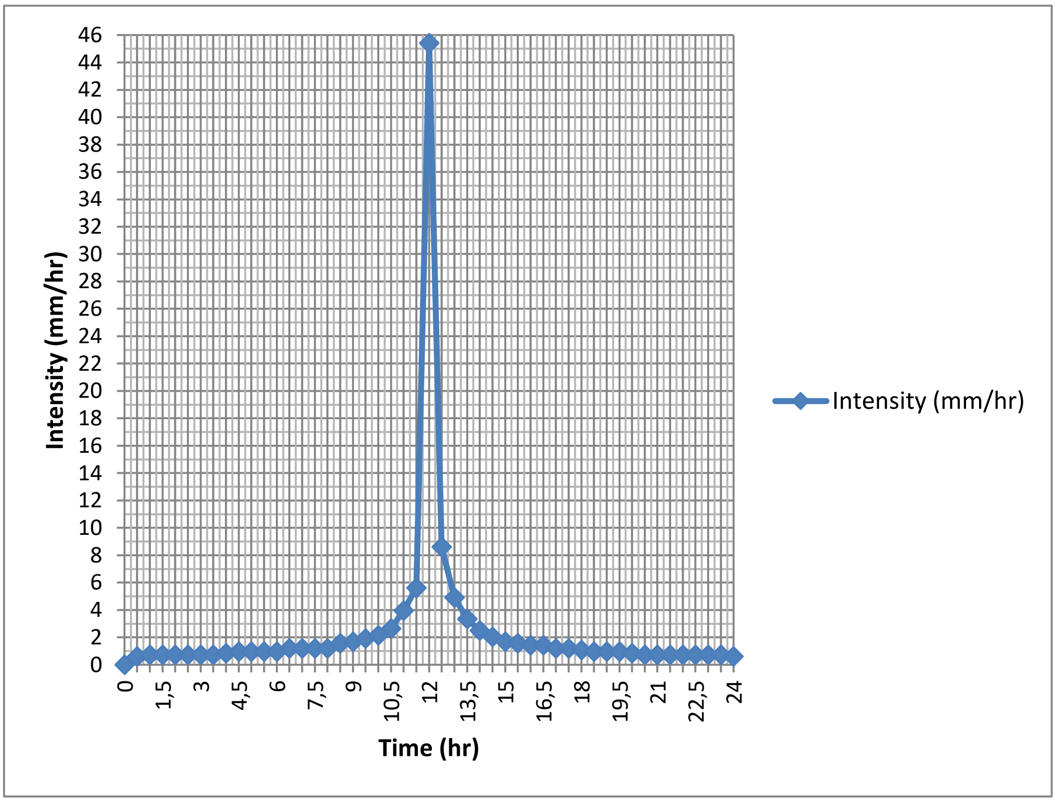


Figure 3.4. Intensity Curve from SCS Type II Distribution Table

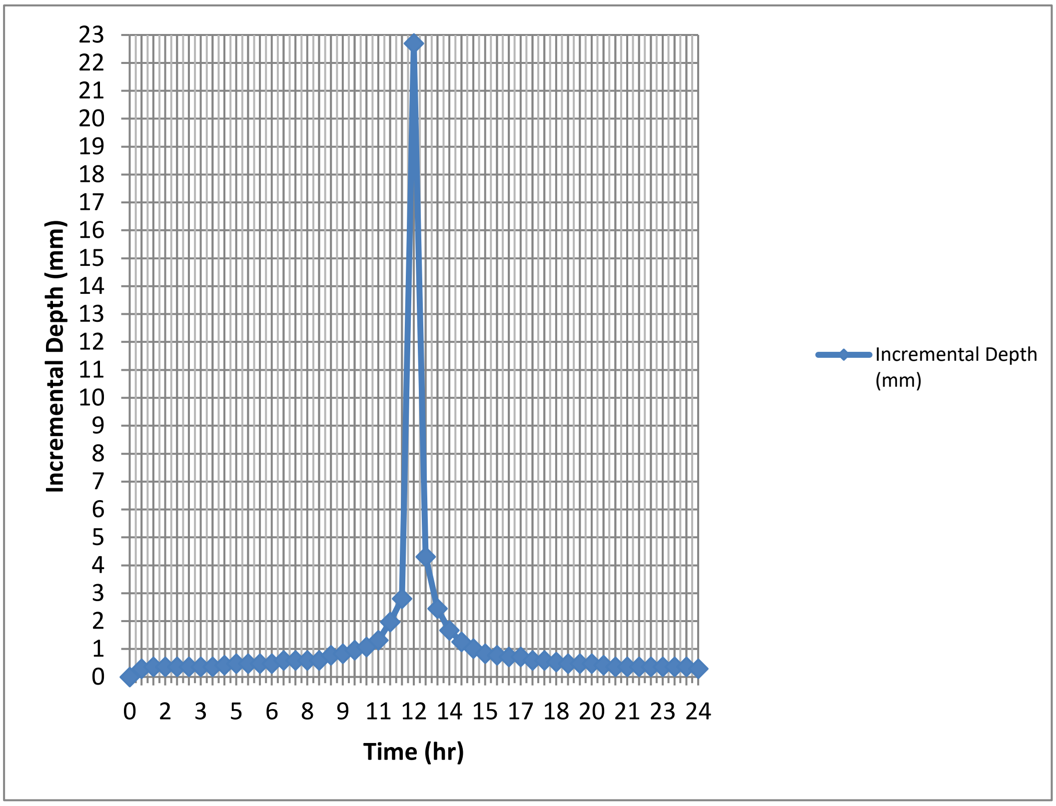


Figure 3.5. Incremental Depth (Precipitation) Curve from SCS Type II Distribution Table

Initial abstraction has been determined due to the following formula to be used in the software:

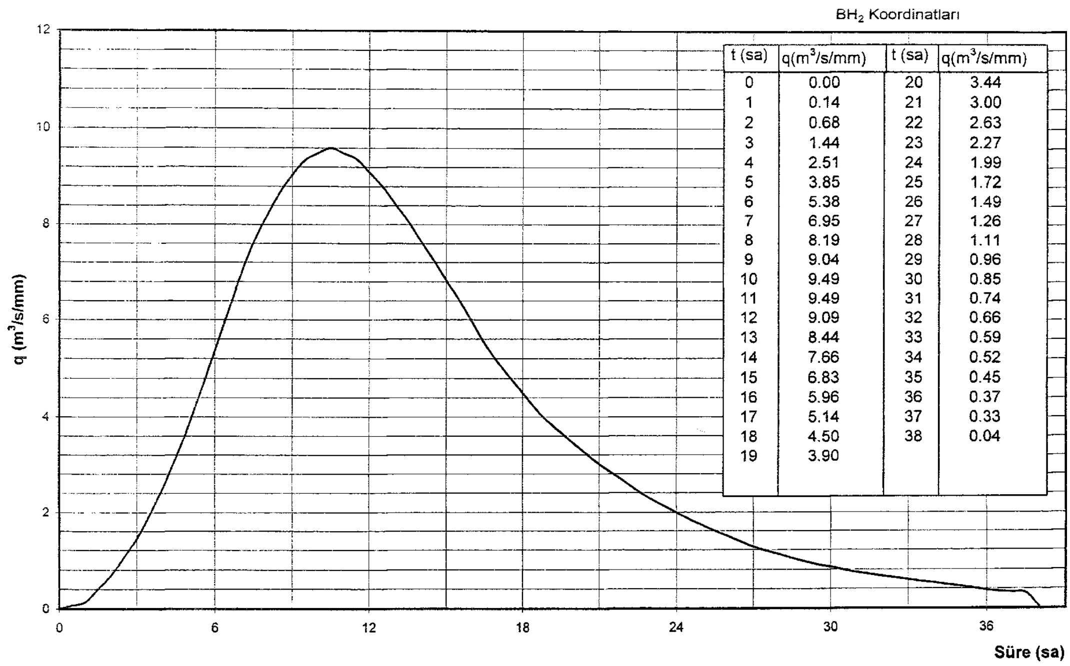
S = (25,400 – 254 * CN) / CN

- S = Potential maximum retention
- CN = Curve Number
- I_a = Initial abstraction = 0.2 * S

According to the calculations, I_a values were 16.93 and 16.04 for sub basin 1 and sub basin 2, respectively. Imperviousness assumed as 15% for both of the sub basins according to their geological situations.

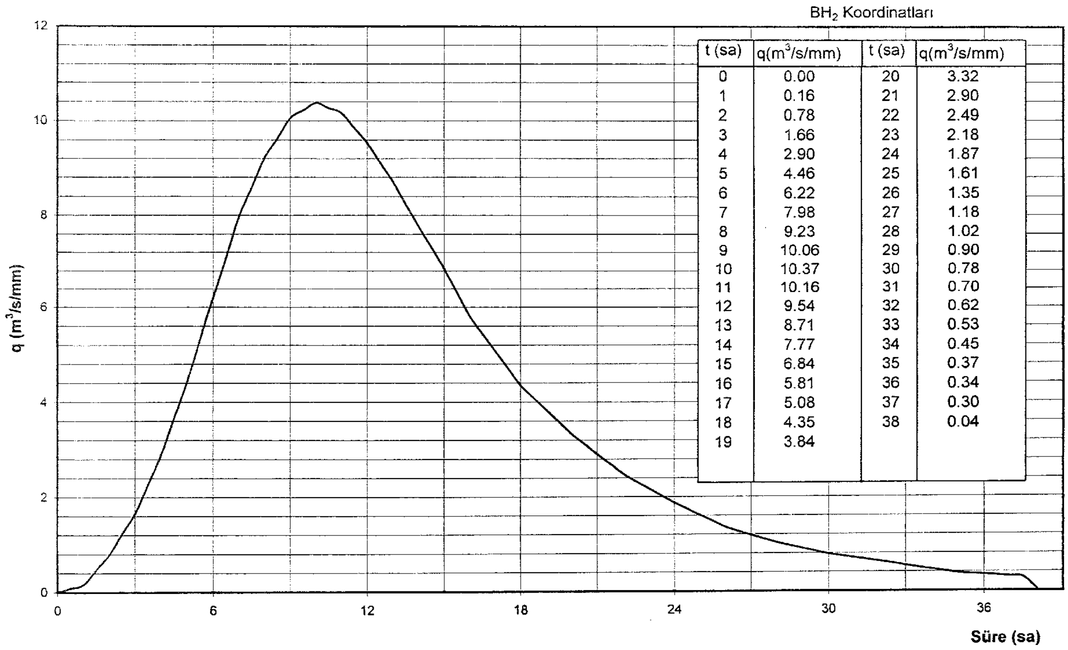
Initial discharge as baseflow has been used as 10 m^3/s as input with a recession constant of 0.97 and minimum flow of 2 m^3/s for threshold discharge (also as threshold type in the software) for both of the basins.

Finally unit hydrograph values have been taken from state hydraulic works' synthetic hydrographs for sub basin 1 and sub basin 2 separately to be used in the software as unit hydrograph curves (Figures 3.6. and 3.7.).



t (sa)	q(m³/s/mm)	t (sa)	q(m³/s/mm)
0	0.00	20	3.44
1	0.14	21	3.00
2	0.68	22	2.63
3	1.44	23	2.27
4	2.51	24	1.99
5	3.85	25	1.72
6	5.38	26	1.49
7	6.95	27	1.26
8	8.19	28	1.11
9	9.04	29	0.96
10	9.49	30	0.85
11	9.49	31	0.74
12	9.09	32	0.66
13	8.44	33	0.59
14	7.66	34	0.52
15	6.83	35	0.45
16	5.96	36	0.37
17	5.14	37	0.33
18	4.50	38	0.04
19	3.90		

Figure 3.6. DSI's Sub Basin 1 Unit Hydrograph



t (sa)	q(m³/s/mm)	t (sa)	q(m³/s/mm)
0	0.00	20	3.32
1	0.16	21	2.90
2	0.78	22	2.49
3	1.66	23	2.18
4	2.90	24	1.87
5	4.46	25	1.61
6	6.22	26	1.35
7	7.98	27	1.18
8	9.23	28	1.02
9	10.06	29	0.90
10	10.37	30	0.78
11	10.16	31	0.70
12	9.54	32	0.62
13	8.71	33	0.53
14	7.77	34	0.45
15	6.84	35	0.37
16	5.81	36	0.34
17	5.08	37	0.30
18	4.35	38	0.04
19	3.84		

Figure 3.7. DSI's Sub Basin 2 Unit Hydrograph

3.2. Literature

3.2.1. Modeling Studies with HEC-HMS and Runoff Scenarios in Yuvacık Basin, Turkey

M., K., Yener et al. studied modeling with HEC-HMS and runoff scenarios in Yuvacık Basin, Turkey, for a drainage area of 257.86 km^2. The modeling studies were carried out by dividing the basin into three sub-basins: Kirazdere, Kazandere, and Serindere and each sub basin was modeled with its own parameters. For the hydrologic modeling studies the version of HEC-HMS hydrologic modeling software released in April 2006 by US Army Corps of Engineers was used. Modeling studies consisted of two items: event-based hourly simulations and runoff scenarios using intensity-duration-frequency curves.

As a result of model application studies, infiltration loss and base flow parameters of each sub basin were calibrated with hourly simulations. Hourly model parameters were used in spring, summer and fall seasons to predict runoff. Runoffs that correspond to different return periods and probable maximum precipitation were predicted using intensity-duration-frequency data as input to frequency storm method of HEC-HMS. The simulated runoff values could be used for flood control and flood damage estimation studies. Results for simulation in the study can be seen in Table 3.7.

Table 3.7. Simulation results for minimum loss parameters and 6-hrs storm

Storm duration 6 hr	Return Period (yr)	2	10	25	50	100
	IDF Precipitation (mm)	34.5	69.5	92.3	111.9	133.7
Qp (m^3/s)	Kirazdere	38.46	89.31	123.49	154.05	188.68
	Kazandere	10.73	24.86	34.35	42.83	52.46
	Serindere	59.24	137.6	190.7	238.36	292.53
	Contributing	17.44	40.14	55.41	69.09	84.62
	Yuvacık	125.87	291.91	403.95	504.33	618.29
Precipitation (mm) & Loss (mm)	Kirazdere	32.34	65.14	86.51	104.88	125.31
		20.09	36.44	46.64	55.1	64.29
	Kazandere	33.77	68.02	90.34	109.52	130.85
		22.06	40.68	52.39	62.16	72.81
	Serindere	31.55	63.56	84.42	102.34	122.28
		19.01	34.21	43.56	51.25	59.54
	Contributing	33.43	67.35	89.44	108.44	129.56
		20.8	37.95	48.66	57.53	67.16
Time to peak (hr)	Kirazdere	7.5	7.5	7.5	7.5	7.5
	Kazandere	7.5	7.5	7.5	7.5	7.5
	Serindere	7.5	7.5	7.5	7.5	7.5
	Contributing	7.5	7.5	7.5	7.5	7.5

3.2.1.1. Comparison of Flood Hydrographs of DSI with HEC-HMS Model Results

In this section the hydrographs obtained from HEC-HMS model simulations using frequency storm method and the hydrographs that are obtained by DSI (DSI, 1983) using statistical techniques are compared (Figure 3.8. and 3.9.). In addition to graphical comparisons, corresponding peak values and volumes of each hydrograph are also presented.

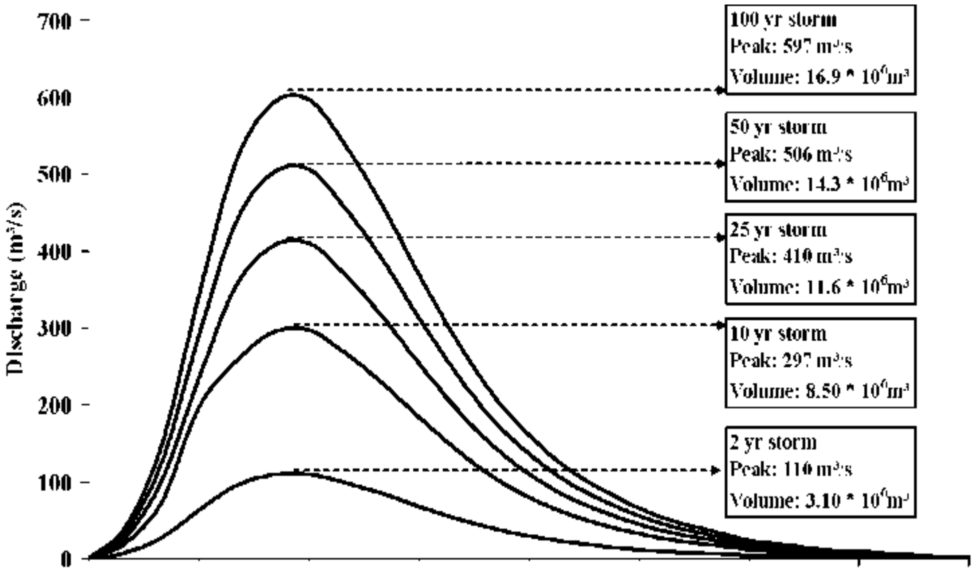


Figure 3.8. DSI hydrographs, peak flows and total volumes (6-hrs storm) (DSI, 1983)

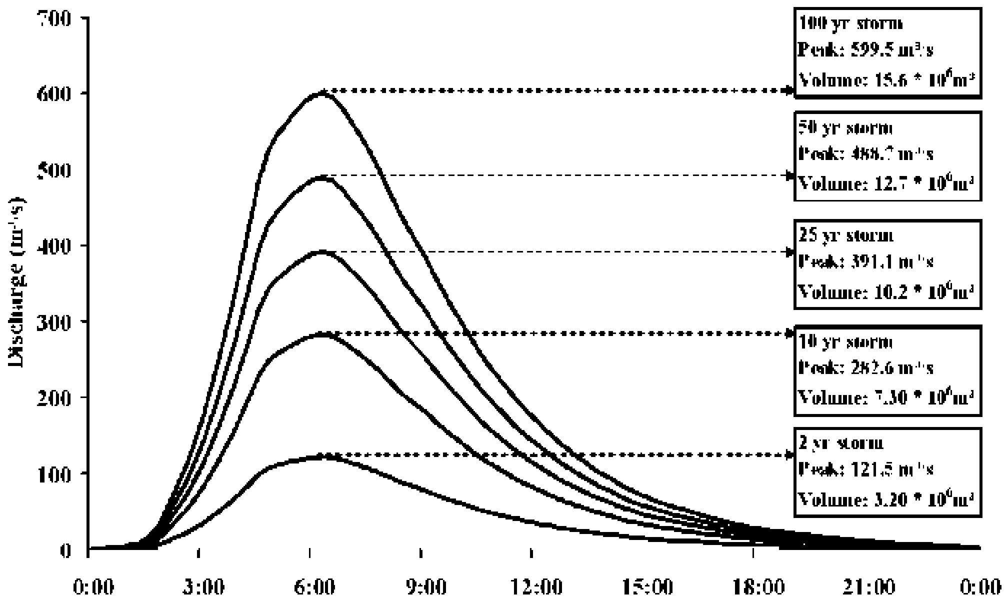


Figure 3.9. HEC-HMS hydrographs, peak flows and total volumes (Frequency storm method, 25% intensity position, 6-hrs storm)

3.2.2. Hydrologic Modeling of Kirazdere and Kazandere Basins using Geographic Information Systems

Gözel, E. studied for Kirazdere and Kazandere Basins in Turkey in order to perform hydrologic modeling in Kirazdere and Kazandere Basins located at the eastern part of Marmara region approximately 12 km towards the southeastern part of Kocaeli city. GIS (Geographical Information System) and HEC-HMS (Hydrologic Engineering Center- Hydrologic Modeling System) were used in the study respectively. In the first part of the study, GIS analysis was applied to delineate the basin boundaries using Digital Elevation Model (DEM) and to create thematic maps of slope, aspect and hillshade. Hypsometry of the basin using 50 m elevation interval was derived and areal average precipitation from point gauge data is determined using Thiessen Polygons method under GIS platform. In the second part of the study, HEC-HMS program was used for hydrologic modeling analysis to formulate a reliable relationship between precipitation and runoff. In the modeling study, several events from 2007 year were selected for daily simulation analysis. Data from the first part of the study was used to input some of the basin and precipitation parameters. As a result, model parameters were calibrated that give a best match between the simulated and the observed hydrographs.

Some of the results as hydrographs obtained by HEC-HMS according to the parameters used are given below.

Table 3.8. Calibrated parameters of Kazandere basin

	KAZANDERE
	EVENT 3
Loss Parameters	
Initial Range (mm)	5.7
Initial Coefficient	0.295
Coefficient Ratio	1
Exponent	0.959
Baseflow Parameters	
Initial Discharge (m/s³)	0.35
Recession Constant	0.66
Flow (m/s³)	4.5
Total Residual (1000m³)	-4.86
Total observed (1000m³)	422.93
Total simulated (1000m³)	447.43
% Residual	1.1516
Observed discharge m³	1.65
Calculated discharge m³	1.65063
% Discharge difference	0.381

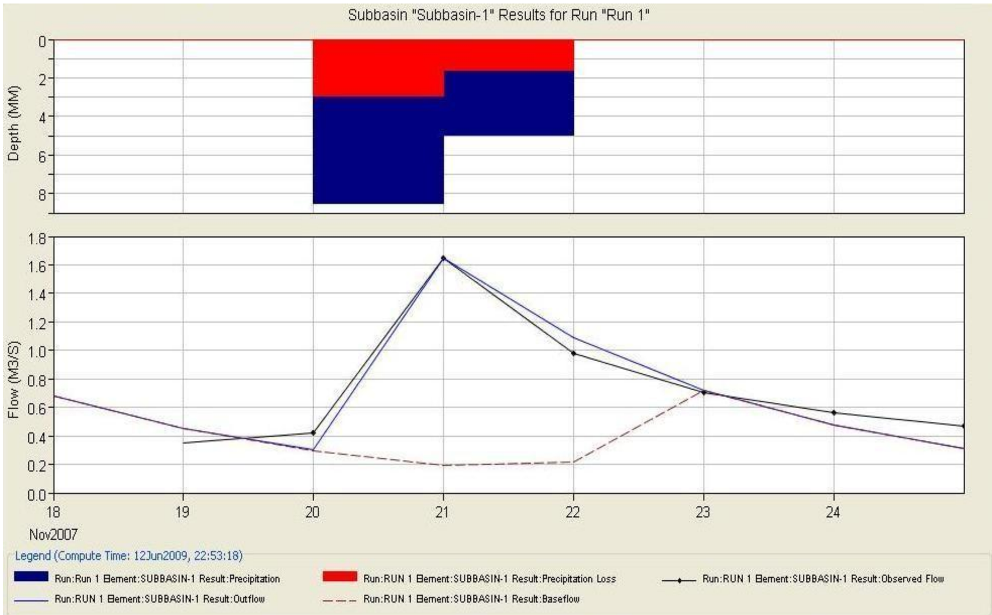


Figure 3.10. Runoff hydrograph of event 3, Kazandere basin

Table 3.9. Calibrated parameters of Kirazdere basin

	KIRAZDERE
	EVENT 3
Loss Parameters	
Initial Range (mm)	10.9
Initial Coefficient	0.702
Coefficient Ratio	1
Exponent	0.94532
Baseflow Parameters	
Initial Discharge (m/s^3)	0.69
Recession Constant	0.88
Flow (m/s^3)	0.75
Total Residual (1000m^3)	-72.05
Total observed (1000m^3)	511.83
Total simulated (1000m^3)	439.78
% Residual	16.41
Observed discharge m^3	1.24
Calculated discharge m^3	1.2588
% Discharge difference	1.516

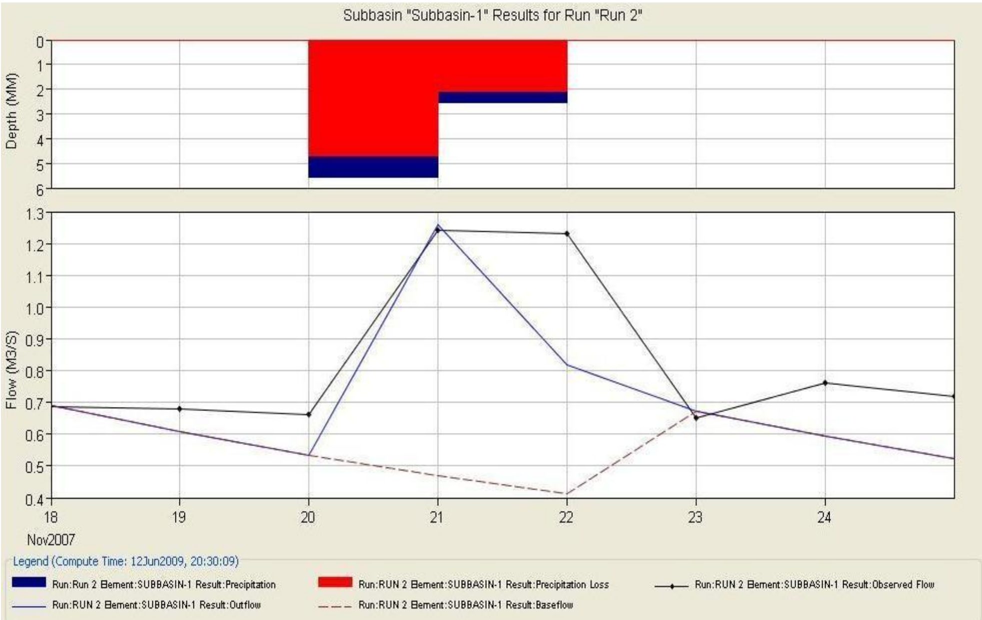


Figure 3.11. Runoff hydrograph of event 3, Kirazdere basin

3.3. Results

The methodology has been mentioned in section 3. 1. 8. According to this methodology and used data, system was run in HEC-HMS. As shown in Figure 3.12. and 3.13., flood hydrographs for sub basin 1& 2 have been obtained separately. Also in Figure 3.14., result of calculation via HEC-HMS using both of the basins at the same time with their own hydrographs, area and curve number methods can be seen. Q_{peak} for cumulative flood hydrograph result is 287.83m^3/s as seen on the same figure.

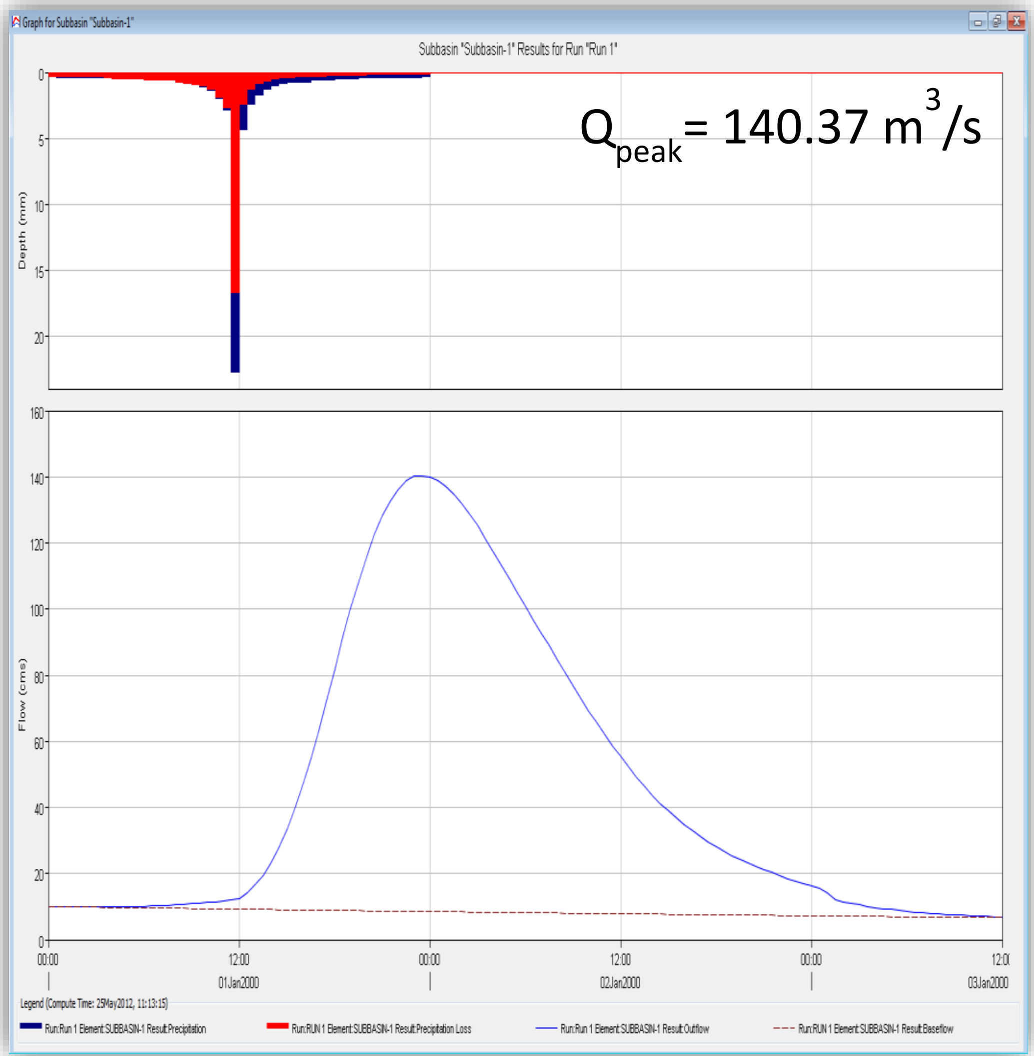


Figure 3.12. Sub basin 1 Flood Hydrograph

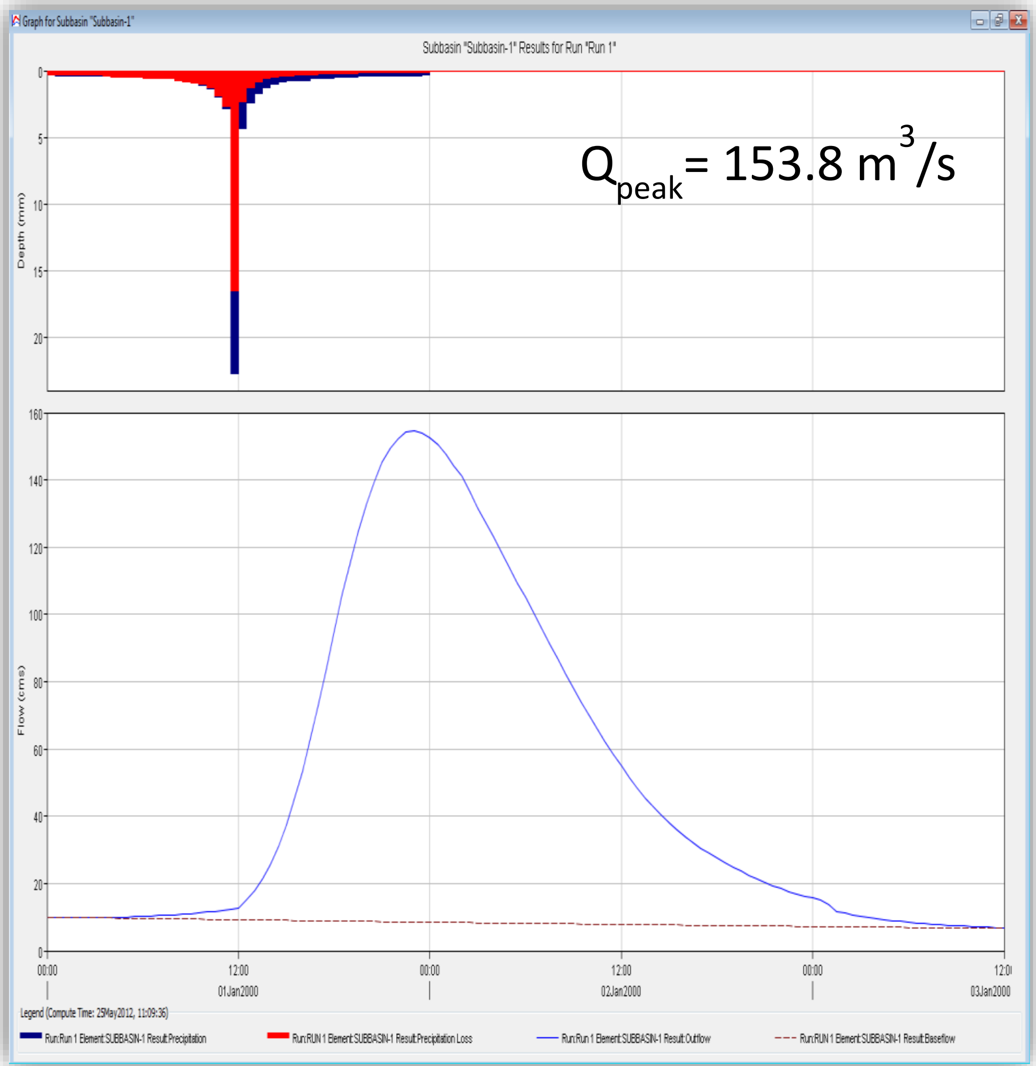


Figure 3.13. Sub basin 2 Flood Hydrograph

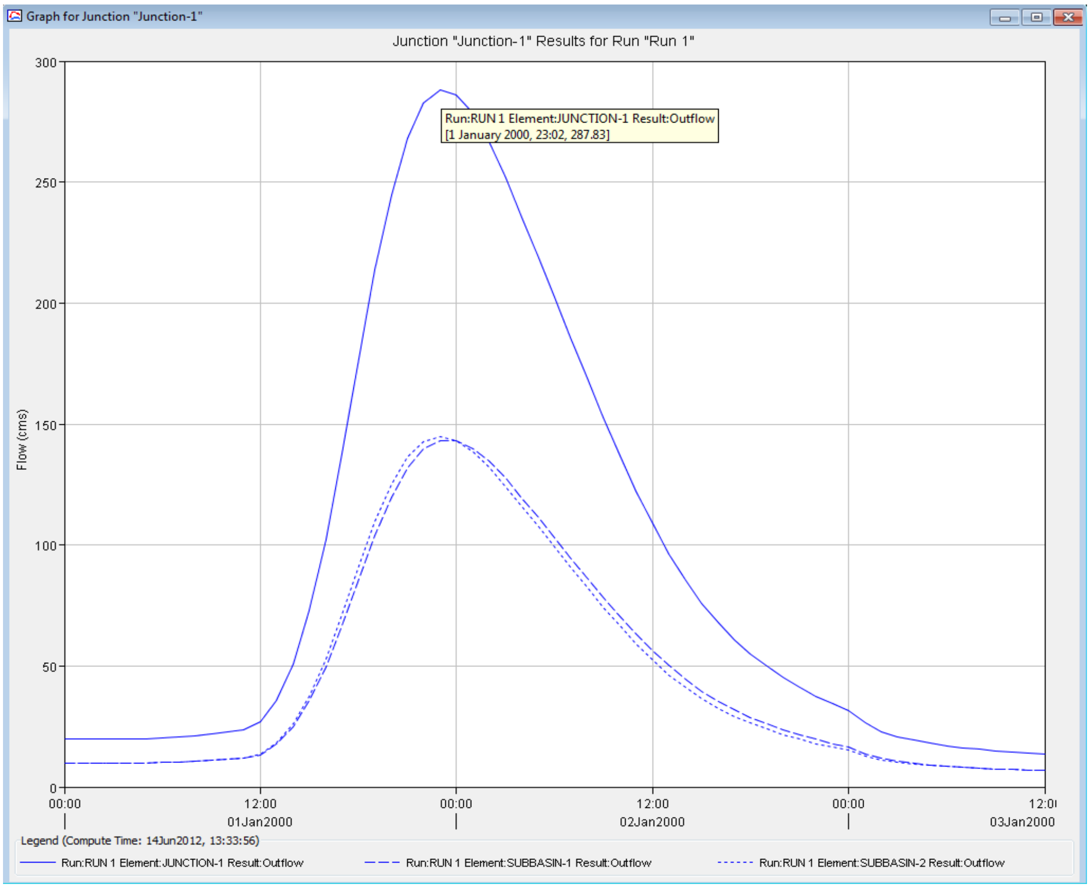


Figure 3.14. Cumulative Flood Hydrograph for Sub basin 1 and Sub basin 2

When it is compared to the synthetically obtained hydrographs of state hydraulic works, which are shown below in Figures 3. 15. and 3. 16. it can be seen that the results for 100 years' storms have very similar values, which may be an indicator for the study have been done to be accurate.

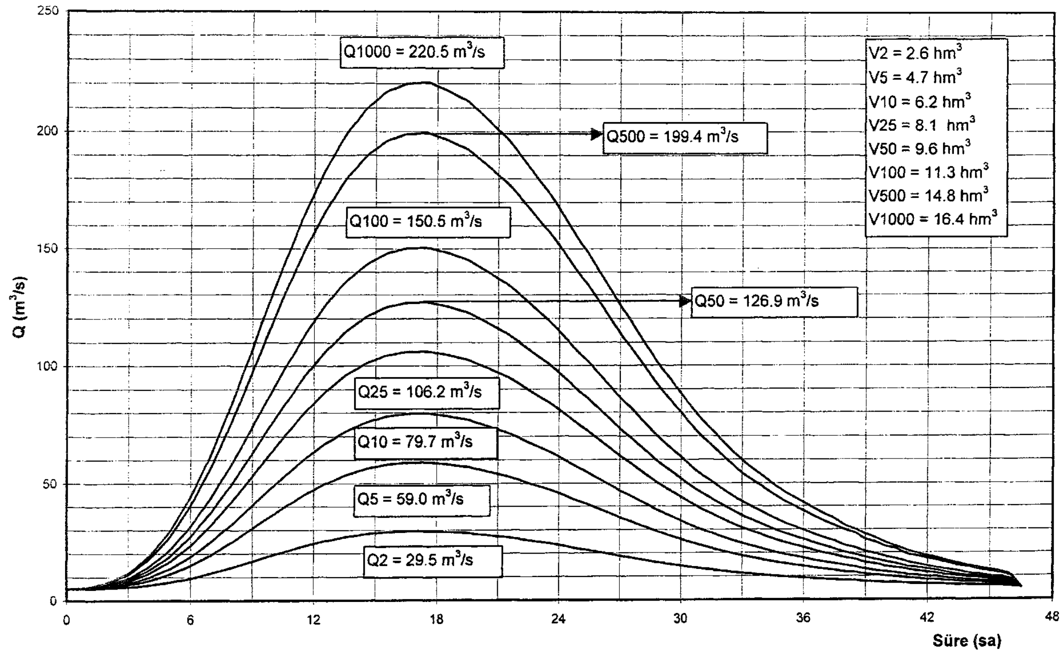


Figure 3.15. DSI's Repetitive Flood Hydrographs for Sub Basin 1

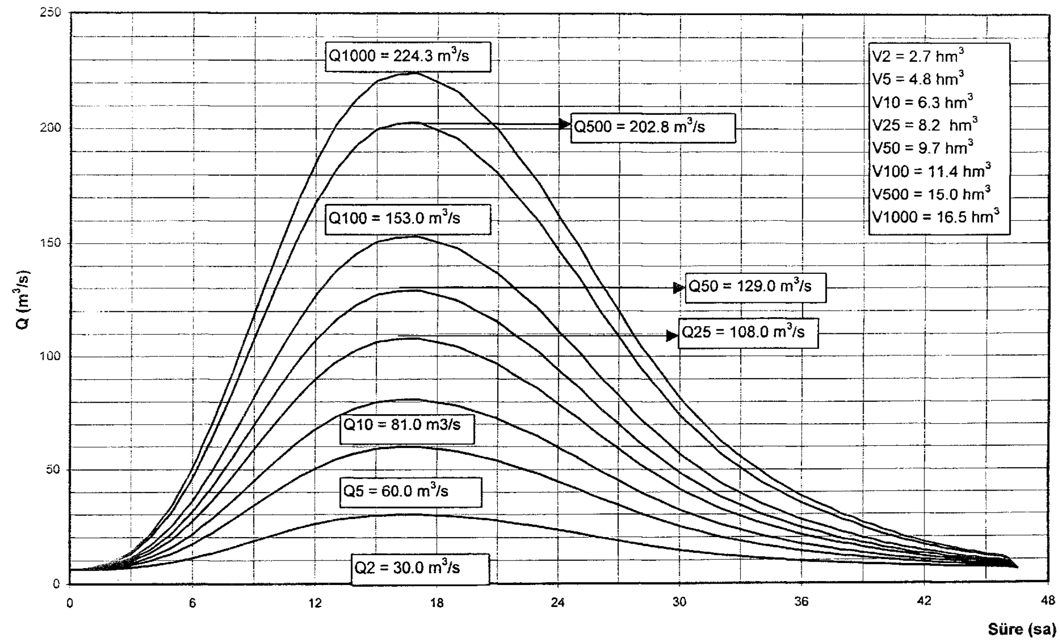


Figure 3.16. DSI's Repetitive Flood Hydrographs for Sub Basin 2

From these results obtained by hydrological modeling, it can be assumed as no problem for flood in Eskişehir city center since it can tolerate flows approximately up to 200 m^3/s due to the rehabilitations in the site.

The sub basins have also been modeled with CN_{III} values of the basins seperately, CN_{III}=89 for sub basin 1 and CN_{III}=88 for sub basin 2. These results can also be seen in figures 3.17. and 3.18.

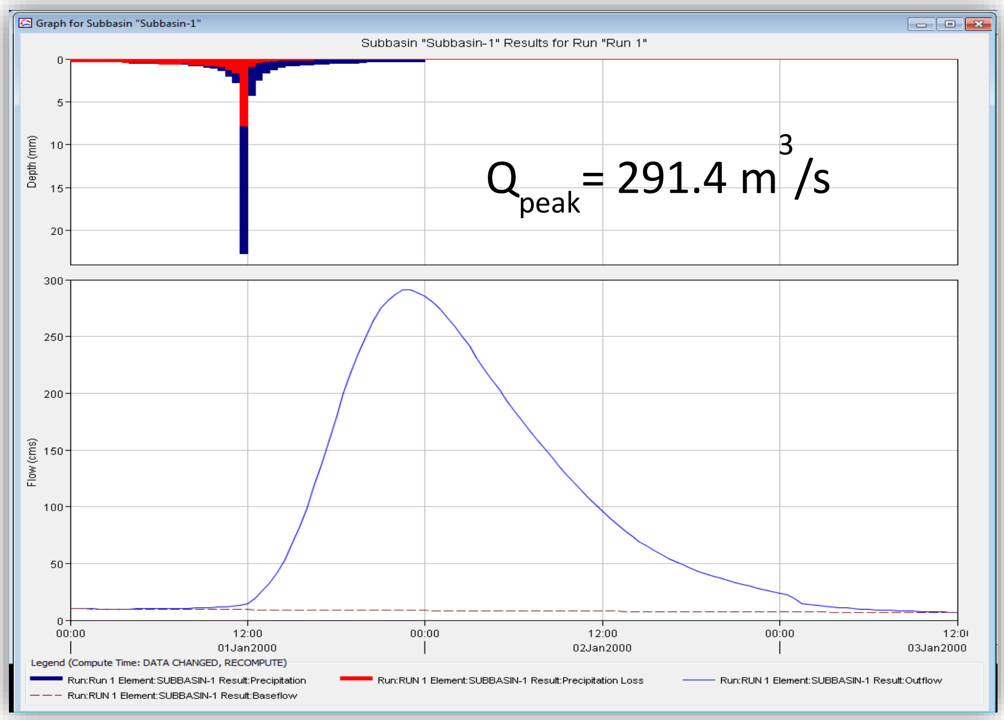


Figure 3.17. CN_{III} (=89) Result for Sub basin 1

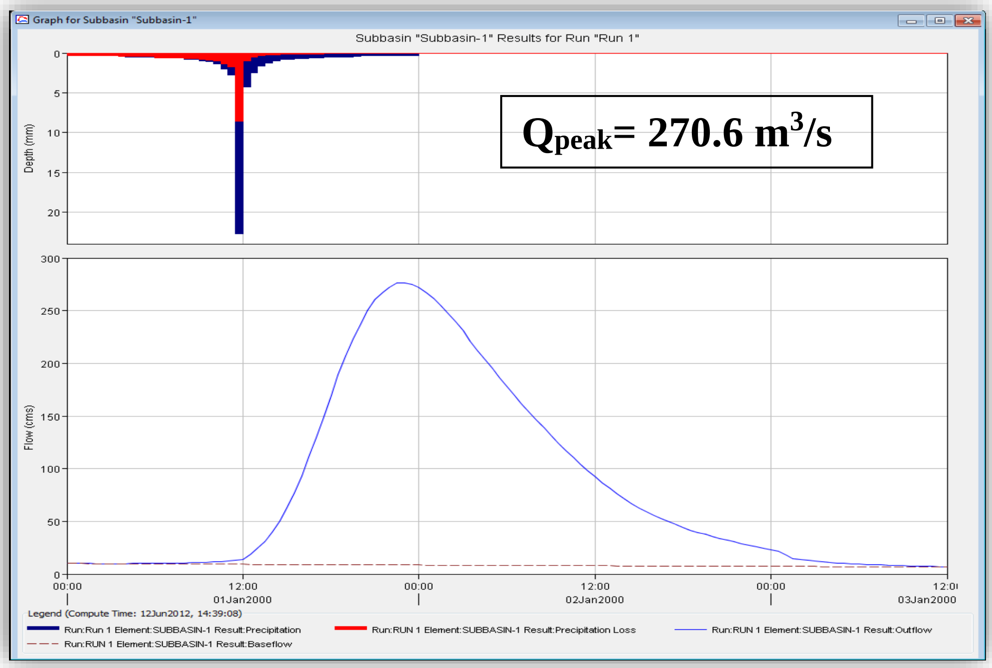


Figure 3.18. CN_{III} (=88) Result for Sub basin 2

Since the results are higher than expected, CN_{II} values have been used for modeling.

3.4. Conclusions

For a study like have been studied, with better topographical layers, it would be more accurate the sections determined. Since the basins in this study are relatively small based on the area, hydrographs for basins are occurring and ending so quickly that it should be modeled hourly in order to have event-based estimations. Due to these reasons, to improve the study, there is a need of more and better precipitation and flow data of each sub branch of the basin in order to do hourly modeling.

Precipitation and flow observation gauges should be positioned well in the basin and on the branches of the stream. In this study, synthetic unit hydrographs have been used since there were lacks of data, but for unit hydrograph input to the software, to have more reliable and accurate results, observed unit hydrographs should be used instead of synthetic ones. In general, in order to have more realistic results for such sort of studies, they should be modeled with observed values and calibration due to these input values.

Curve number should also be confirmed before such modeling studies in case of afforestation, urbanization, drought etc. and if there is a need of replacing it, new curve number should be determined by map overlay technique with land use maps and soil group maps.

4. Hydraulic Modeling

4.1 HEC-RAS

4.1.1. Definition and Development History

The U.S. Army Corps of Engineers' River Analysis System (HEC-RAS) is software that allows you to perform one-dimensional steady and unsteady flow river hydraulics calculations, sediment transport-mobile bed modeling, and water temperature analysis. This software is a product of the Corps' Civil Works System Wide Water Resources Research Program (SWWRP).

The HEC-RAS software was developed at the Hydrological Engineering Center, which is a division of the Institute for Water Resources, U.S. Army Corps of Engineers. The software was designed by Mr. Gary W. Bruner, leader of the HEC-RAS development team.

HEC-RAS is an integrated system of software, designed for interactive use in a multi-tasking environment. The system is comprised of a graphical user interface (GUI), separate analysis components, data storage and management capabilities, graphics and reporting facilities.

The HEC-RAS system contains four one-dimensional river analysis components for: (1) steady flow water surface profile computations; (2) unsteady flow simulation; (3) movable boundary sediment transport computations; and (4) water quality analysis. A key element is that all four components use a common geometric data representation and common geometric and hydraulic computation routines. In addition to the four river analysis components, the system contains several hydraulic design features that can be invoked once the basic water surface profiles are computed.

4.1.2. Overview of Program Capabilities and Components

4.1.2.1. User Interface

The user interface interacts with HEC-RAS through a graphical user interface (GUI). The main focus in the design of the interface was to make it easy to use the software, while still maintaining a high level of efficiency for the user.

4.1.2.2. River Analysis Components

Steady Flow Water Surface Profiles: This component of the modeling system is intended for calculating water surface profiles for steady gradually varied flow. The system can handle a full network of channels, a dendritic system, or a single river reach. The steady flow component is capable of modeling subcritical, supercritical, and mixed flow regime water surface profiles.

The basic computational procedure is based on the solution of the one-dimensional energy equation. Energy losses are evaluated by friction (Manning's equation) and contraction/expansion (coefficient multiplied by the change in velocity head). The momentum equation is utilized in situations where the water surface profile is rapidly varied. These situations include mixed flow regime calculations (i.e., hydraulic jumps), hydraulics of bridges, and evaluating profiles at river confluences (stream junctions).

Unsteady Flow Simulation: This component of the HEC-RAs modeling system is capable of simulating one-dimensional unsteady flow through a full network of open channels. The unsteady flow equation solver was adapted from Dr. Robert L. Barkau's UNET model (Barkau, 1992 and HEC, 1997). The unsteady flow component was developed primarily for subcritical flow regime calculations. However, with the release of version 3.1, the model can now perform mixed flow regime (subcritical, supercritical, hydraulic jumps, and drawdowns) calculations in the unsteady flow computations module.

The hydraulic calculations for cross-sections, bridges, culverts, and other hydraulic structures that were developed for the steady flow component were incorporated into the unsteady flow module.

Sediment Transport/Movable Boundary Computations: This component of the modeling system is intended for the simulation of one-dimensional sediment transport/movable boundary calculations resulting from scour and deposition over moderate time periods (typically years, although applications to single flood events are possible).

The sediment transport potential is computed by gram size fraction, thereby allowing the simulation of hydraulic sorting and armoring. Major features include the ability to model a full network of streams, channel dredging, various levee and encroachment alternatives, and the use of several different equations for the computation of sediment transport.

Water Quality Analysis: This component of the modeling system is intended to allow the user to perform riverine water quality analyses. The current version of HEC-RAS can perform detailed temperature analysis and transport of a limited number of water quality constituents.

4.1.2.3. Data Storage and Management

Data storage is accomplished through the use of "flat" files (ASCII and binary), as well as the HEC-DSS. User input data are stored in flat files under separate categories of project, plan, geometry, steady flow, unsteady flow, quasi-steady flow, sediment data, and water quality information. Output data is predominantly stored in separate binary files. Data can be transferred between HEC-RAS and other programs by utilizing the HEC-DSS. Data management is accomplished through the user interface.

4.1.2.4. Graphics and Reporting

Graphics Include X-Y plots of the river system schematic, cross sections, profiles, rating curves, hydrographs, and inundation mapping. A three-dimensional plot of multiple cross-sections is also provided. Tabular output is available. Users can select from predefined tables or develop their own customized tables. All graphical and tabular output can be displayed on the screen, sent directly to a printer (or plotter), or passed through the Windows Clipboard to other software, such as a word-processor or spreadsheet.

4.1.3. Theoretical Basis for One-Dimensional Flow Calculations

4.1.3.1. Steady Flow water Surface Profiles

HEC-RAS is currently capable of performing one-dimensional water surface profile calculations for steady gradually varied flow in natural or constructed channels. Subcritical, supercritical, and mixed flow regime water surface profiles can be calculated.

4.1.3.2. Equations for Basic Profile calculations

Water surface profiles are computed from one cross section to the next by solving the Energy equation with an iterative procedure called the standard step method. The Energy equation is written as follows:

$$Z_2 + Y_2 + \frac{a_2 V_2^2}{2g} = Z_1 + Y_1 + \frac{a_1 V_1^2}{2g} + h_e$$

Where: Z_1, Z_2 = elevation of the main channel inverts

Y_1, Y_2 = depth of water at cross sections

V_1, V_2 = average velocities (total discharge/ total flow area)

a_1, a_2 = velocity weighting coefficients

g = gravitational acceleration

h_e = energy head loss

A diagram showing the terms of the energy equation is shown below.

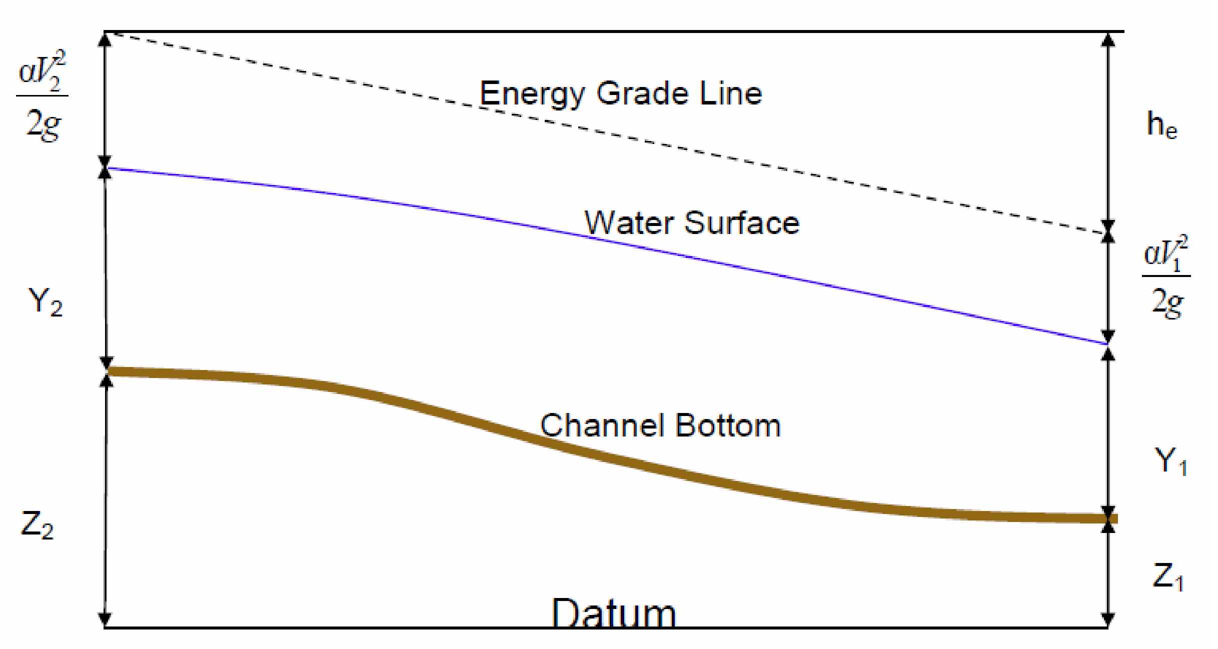


Figure 4.1. Terms of the Energy Equation

The energy head loss (h_e) between two cross sections is comprised of friction losses and contraction or expansion losses. The equation for the energy head loss is as follows:

$$h_e = L\bar{S}_f + C\left|\frac{a_2V_2^2}{2g} - \frac{a_1V_1^2}{2g}\right|$$

Where: L = discharge weighted reach length

$\bar{S}_f$ = representative friction slope between two sections

C = expansion or contraction loss coefficient

The distance weighted reach length, L, is calculated as:

$$L = \frac{L_{lob}\bar{Q}_{lob} + L_{ch}\bar{Q}_{ch} + L_{rob}\bar{Q}_{rob}}{\bar{Q}_{lob} + \bar{Q}_{ch} + \bar{Q}_{rob}}$$

where: L_{lob}, L_{ch}, L_{rob} = cross section reach lengths specified for flow in the left overbank, main channel, and right overbank, respectively

$\bar{Q}_{lob} + \bar{Q}_{ch} + \bar{Q}_{rob}$ = arithmetic average of the flows between sections for the left overbank, main channel, and right overbank, respectively

4.1.3.3. Cross Section Subdivision for Conveyance Calculations

The determination of total conveyance and the velocity coefficient for a cross section require that flow be subdivided into units for which the velocity is uniformly distributed. The approach used in HEC-RAS is to subdivide flow in the overbank areas using the input cross section n-value break points (locations where n-values change) as the basis for subdivision. Conveyance is calculated within each subdivision from the following form of Manning's equation (based on English units):

$$Q = KS_f^{1/2}$$

$$K = \frac{1.486}{n}AR^{2/3}$$

where: K = conveyance for subdivision

n = Manning's roughness coefficient for subdivision

A = flow area for subdivision

R = hydraulic radius for subdivision (area / wetted perimeter)

The program sums up all the incremental conveyances in the overbanks to obtain a conveyance for the left over bank and the right over bank. The main channel conveyance is normally computed as a single conveyance element. The total conveyance for the cross section is obtained by summing the three subdivision conveyances (left, channel, and right).

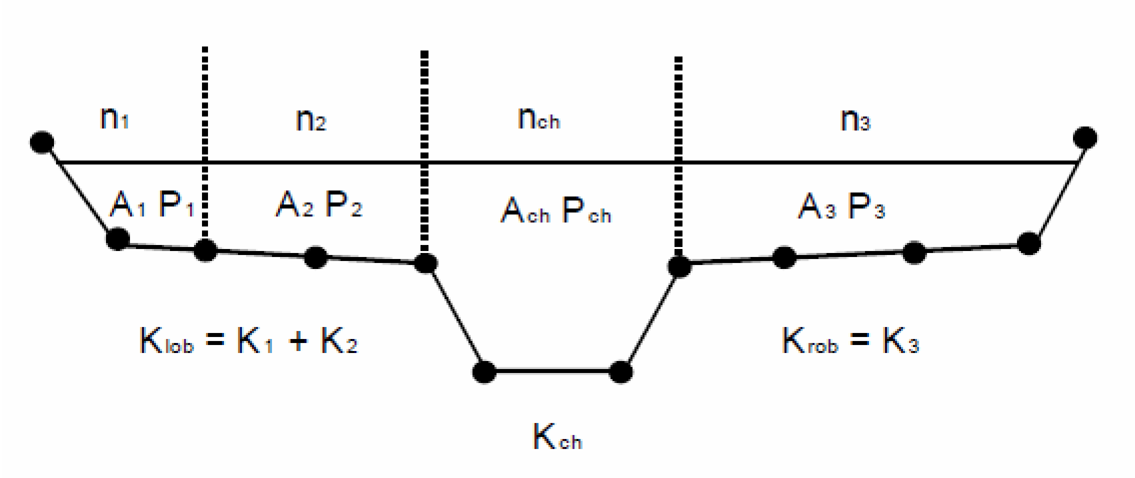


Figure 4.2.

An alternative method available in HEC-RAS is to calculate conveyance between every coordinate point in the overbanks. The conveyance is then summed to get the total left overbank and right overbank values. This method is used in the Corps HEC-2 program. The method has been retained as an option within HEC-RAS in order to reproduce studies that were originally developed with HEC-2.

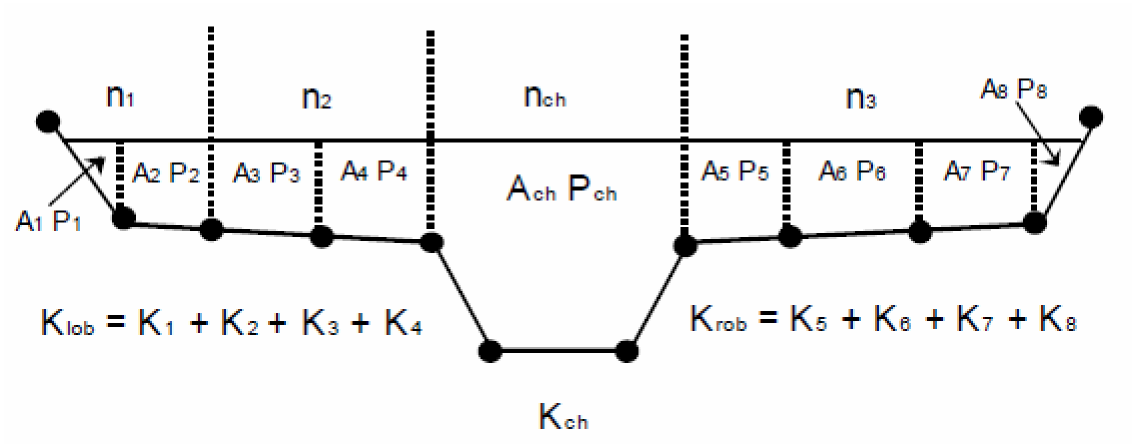


Figure 4.3.

The two methods for computing conveyance will produce different answers whenever portions on the overbank have ground sections with significant vertical slopes. In general, the HEC-RAS default approach will provide a lower total conveyance for the same water surface elevation.

4.1.3.4. Composite Manning's n for the Main Channel

Flow in the main channel is not subdivided, except when the roughness coefficient is changed within the channel area. HEC-RAS tests the applicability of subdivision of roughness within the main channel portion of a cross section, and if it is not applicable, the program will compute a single composite n value for the entire main channel.

For the determination of n_c, the main channel is divided into N parts, each with a known wetted perimeter P_i and roughness coefficient n_i.

$$n_c = \left[\frac{\sum_{i=1}^{N} \left(P_i n_i^{1.5} \right)}{P} \right]^{2/3}$$

Where: n_c = composite or equivalent coefficient of roughness

P = wetted perimeter of entire main channel

P_i = wetted perimeter of subdivision I

n_i = coefficient of roughness for subdivision

4.1.4. HEC-RAS Graphical User Interface Components

When you first start HEC-RAS, you will see the main window like shown in figure below.

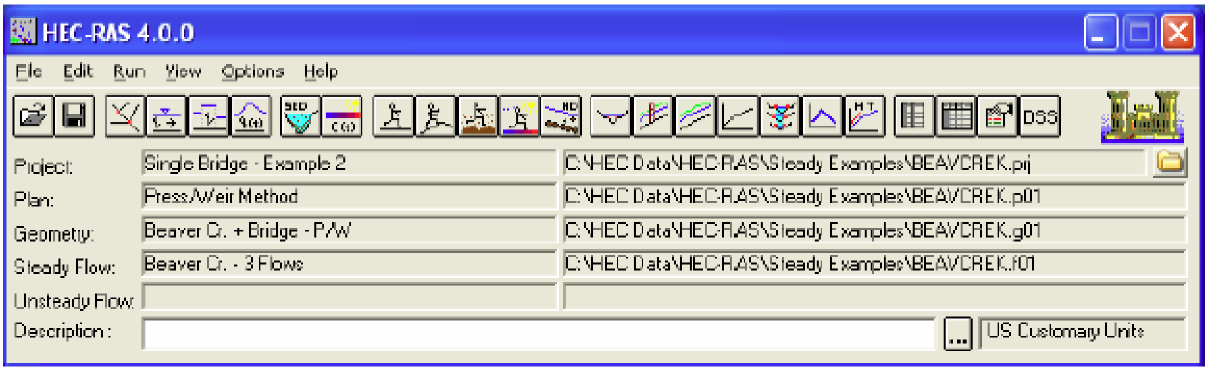


Figure 4.4. HEC-RAS User Interface

At the top of the HEC-RAS main window is a Menu bar with the following options:

File: This option is used for file management.

Edit: This option is used for entering and editing data.

Run: This option is used to perform the hydraulic calculations.

View: This option contains a set of tools that provide for graphical and tabular displays of the model output.

Options: This menu item allows the user to change program setup options.

Help: This option allows the user to get online help and see the HEC-RAS manuals.

Also on the HEC-RAS main window is a Button bar. The button bar provides quick access to the most frequently used options under the HEC-RAS menu bar. A description of each button is shown below.

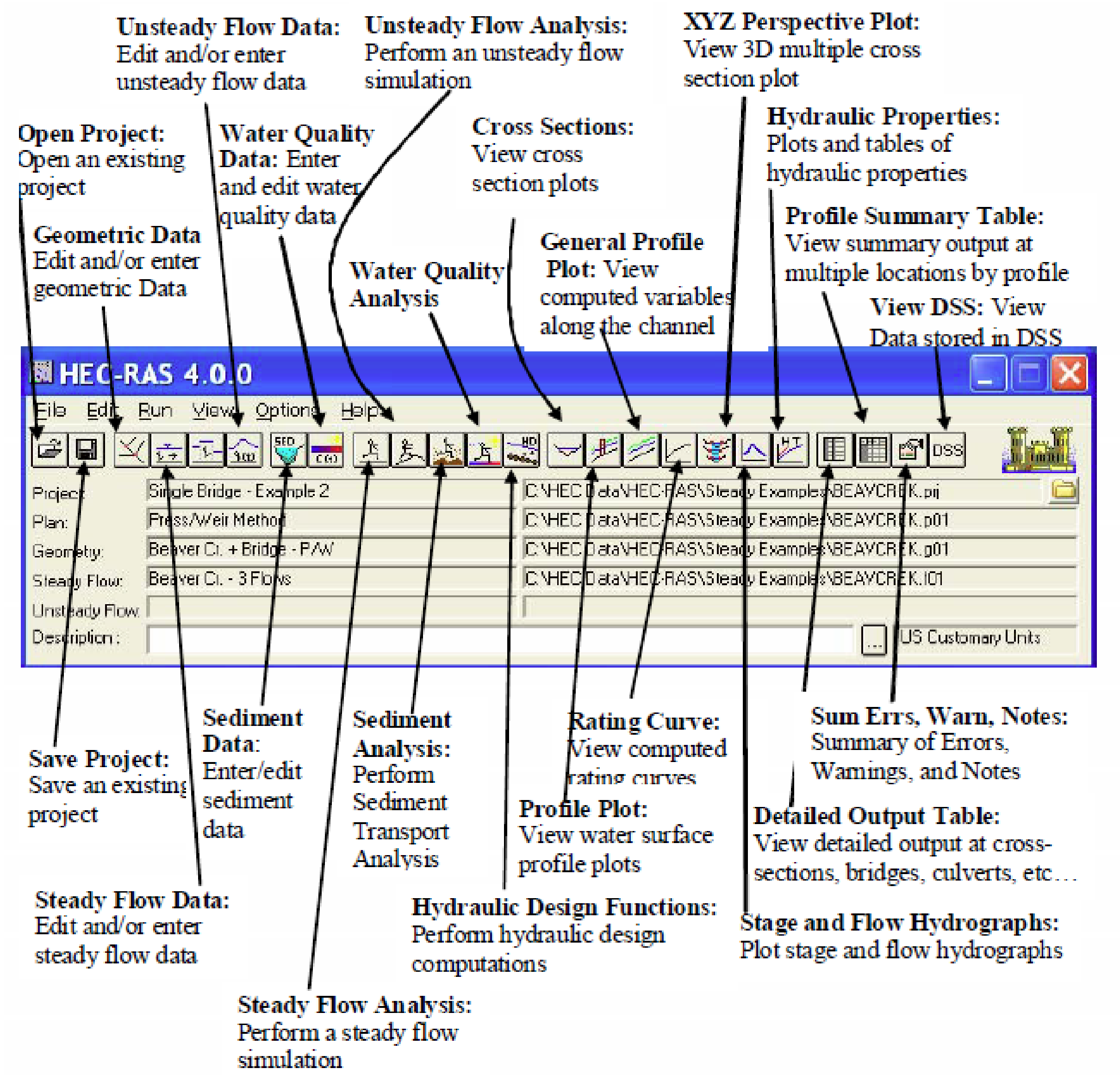


Figure 4.5. HEC-RAS User Interface Componenets

4.2. Literature

4.2.1. Flood Hazard Mapping In Lower Reach of Kelani River, Sri Lanka

4.2.1.1. Introduction

Kelani river is the second longest of Sri Lanka which originates in the central hills and flows mainly to the West till it meets the sea at the northern boundary of the city of Colombo. The river basin is entirely located in the wet zone with an extent of 2230 sq. km with average annual rainfall of about 2400 mm. With the knowledge of historical flood events occurred in the basin, lower reach of Kelani River was selected for this study. (Fowze and friends, 2008)

4.2.1.2. Methodology

The ‘Steady Flow Water Surface Profiles’ component of the Hydrologic Engineering Center’s River Analysis System (HEC-RAS) which is designed for applying in flood plain management and flood insurance studies was utilized in the study by modeling the selected stretch of the Kelani River as a single river reach.

4.2.1.3. Model Inputs

Implementation of HEC-RAS requires inputs which come from three basic categories of data;

a. Geometric data

b. Basin Characteristics

c. Flow Data

4.2.1.4. Geometric Data

A Triangulated Irregular Network (TIN) model of the river system was, therefore, created from topographic maps of scale 1:10,000 and spot levels as of year 2000 collected from the Survey Department of Sri Lanka. The contours were of 10 m interval. Having imported the data into the HEC-RAS system, the cross section data were adjusted to suit the surveyed cross sections (as of year 2007) which were obtained from the Irrigation Department.

4.2.1.5. Basin Characteristics

Manning's n value is highly variable and depends on a number of factors including surface roughness, vegetation, channel irregularities, channel alignment, scour and deposition, obstructions, size and shape of the channel, stage and discharge, seasonal changes, suspended material and bedload.

The contraction and expansion coefficients are used to model the energy loss within a reach due to the contraction or expansion of flow due to the change in cross section. Typical values of 0.1 and 0.3 pertaining to locations where the change in river cross sections is small and the flow is subcritical were adopted based on the variation of selected river reach.

4.2.1.6. Flow Data

Discharge and water level values make the upstream and downstream boundary conditions. In the intention of preparing flood hazard maps corresponding to 10 yr., 20 yr., and 50 yr. return period events, frequency analyses were carried out to determine peak discharges employing the Gumble distribution which has been adopted in Sri Lanka and using annual peak discharge data recorded at Glencourse gauging station for the last 35 years obtained from the Irrigation Department.

4.2.1.7 Flood Simulation

Having completed the setup of the system with the requisite model parameters and variables, a calibration run was performed using the peak discharge value corresponding to the 50 yr. return period flood event. Comparison between the observations and model predictions were found to very satisfactory except at some locations.

4.2.1.8. Results and Discussion

Figures below show the produced flood maps corresponding to 50 year and 10 year return period flood events. As could be seen from the maps flood depths were classed into 4 groups as up to 1 m, 1 – 3 m, 3 – 5 m, and above 5 m. However, these grouping could easily be modified to suit different stakeholder requirements and work out hazard levels.

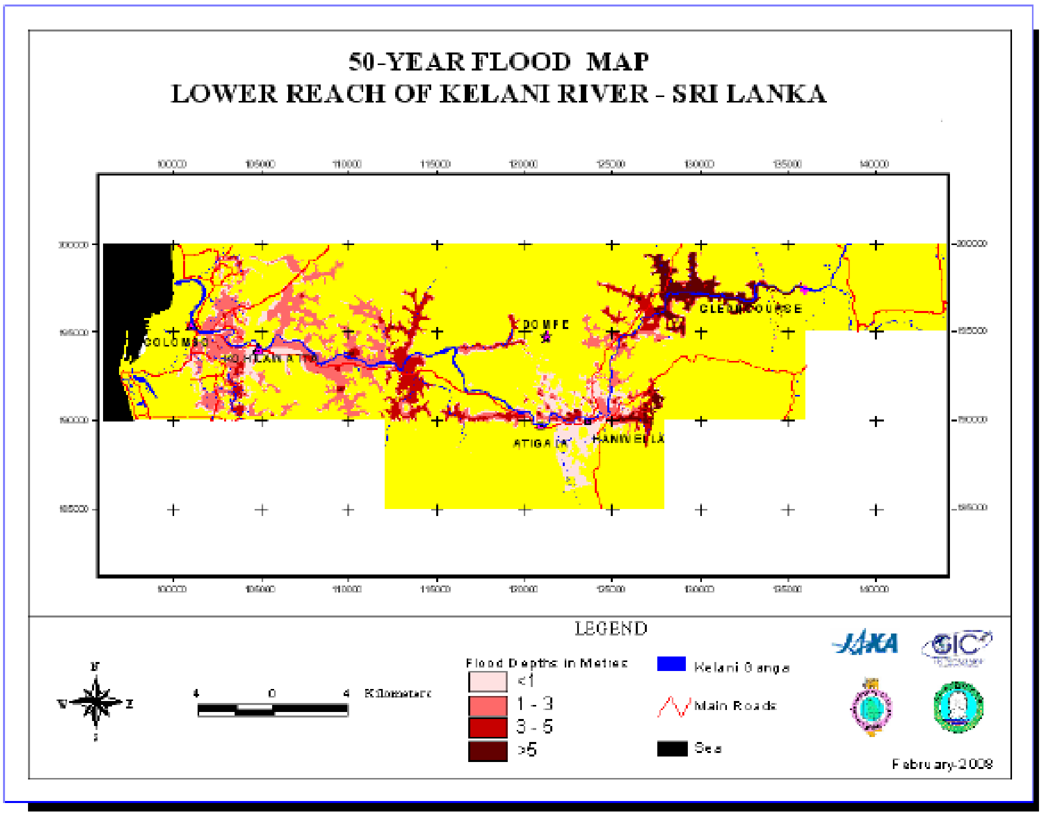


Figure 4.6.

Based on the above classification, flood inundation areas corresponding to the different return periods were determined and given in Table 1. Results of flood simulations, as could be seen in Table below, also indicate that a total of 63, 77, and 94 square kilometers of the study area would be subjected to flood encroachments due to 10 yr., 20 yr., and 50 return period flood events respectively.

4.2.2. Case Study: Flood Mitigation of the Muda River, Malaysia

4.2.2.1. Muda River Study Reach and Database

The Muda River drains mountainous areas of the State of Kedah and the topography of the region is shown in Figure below. The water shed is adjacent to Thailand and covers a drainage area of 4,210 km^2. At the upstream end of the Muda River is Muda Dam, which provides water storage for the Muda irrigation scheme. The upper and middle reaches of the Muda River belong to the State of Kedah, while the lower 30 km of the river delineates the boundary between the States of Kedah and Palau Pinang. There are three major tributaries of the Muda River system, namely, the Ketil River with a drainage area of 868 km^2, the Sedim River with 626 km^2, and the Chepir River covering 335 km^2 (Julien and friends 2010).

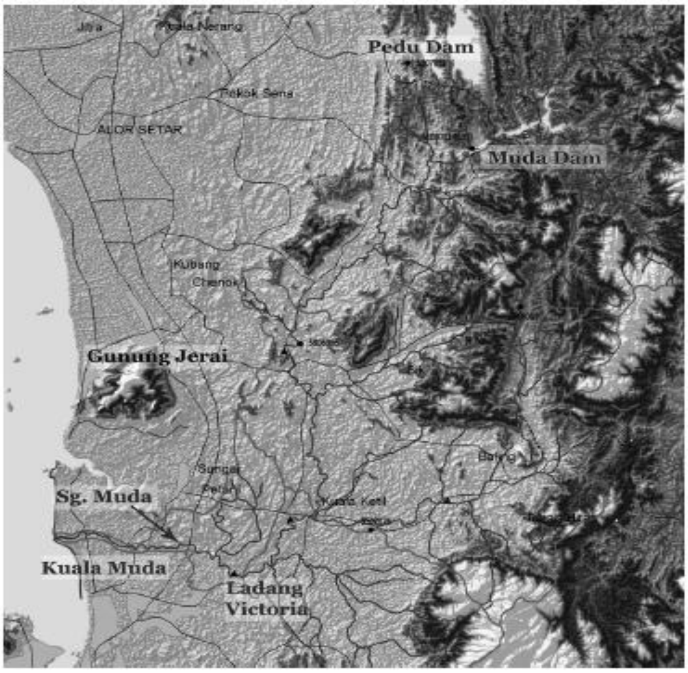


Figure 4.7.

4.2.2.2. River Modeling

The main channel of the Muda River has a length of about 180km with a slope of 1/2.287.9 (or 0.00043) from the river mouth to Muda Dam. The channel is typically around 100-rn wide and widens up to about 287.9 in near the river mouth. The bathymetric surveys in 2000 indicate that the shallowest point in the river is located 2.5-km upstream of the river mouth, which impedes navigation during low tides. A riverbed material survey shows a predominance of sands and gravels on the main stream and tributaries. Bed load transport is the dominant mode of sediment transport in the Muda River. The mean annual bed load discharge of the Muda River was estimated by JICA (1995) about 10,000 m^3/yr. Significant scour of the channel bed is attributed to sand and gravel mining operations, aggravating bank erosion and causing riverbed degradation.

The hydraulic analysis using the HEC-RAS model [United States Army Corps of Engineers (USACE) 2002] provides information on the variations in river stages, discharges, and velocities for the design flood (Julien, 2006). The HEC-RAS model for this study generates the water surface elevation based on the 2000 survey of the existing cross section. The 2000 survey extends 50 m on the flood plain on both banks based on the recommendation by JICA (1995) study that the bunds should be constructed 50 m from the banks. The unsteady flow analysis in the HEC-RAS model was used to replicate the hydrograph data for October 2003. The hourly tidal level data at the Kedah Pier were also used as a downstream boundary condition at the river mouth. The hydrograph at Ladang Victoria from October 2nd to October 19th was used to simulate the 2003 flood. The peak discharge took place on October 6. 2003 at 4 p.m. with a value of 1,340 m^3/s. Fig. 10 shows a few of the 215 cross sections used for the simulation. Hourly water level records at three locations (Ladang Victoria. Bumbong Lima and River Mouth) were used to check the predicted water level by the HEC-RAS model. Different values of Manning n (0.025. 0.030. and 0.035) were tried for calibration, and the best results were obtained with Manning n of 0.03 and 0.05 for the main channel and floodplains, respectively. These results corroborate the calibration done by an earlier study (JICA 1995). The model results are therefore considered sufficiently accurate for the determination of levee heights.

4.2.2.3. Conclusions

This review of the flood control remediation plan for the Muda River highlights several important points in the design of flood remediation countermeasures against the frequent and intense floods during the monsoons of Southeast Asia. Some of the main conclusions include the analysis of measured daily discharge records can produce a more reliable 50-year peak discharge than hydrologic models. i.e., there is a 25% difference between the flood frequency analysis of field measurements (1.34.0 m^3/s) and hydrologic model results (1 .815 rn3/s); various hydrologic models can result in 100% variability in the prediction of peak discharges and design hydrographs; the proposed levee height of the Muda River could have been based on the 2003 flood plus a 1-m freeboard; the sand and gravel mining operations caused major problems associated with river bed degradation including pumping requirements at irrigation canal intakes and structural instability problems at bridge crossings: and it is recommended to replace in stream sand and gravel mining operations with off stream mining operations within the hood plain corridor at a minimum distance of 50 m from the river banks.

4.2.3. Floodplain Mapping: A Case Study of Maçka, Değirmendere River

4.2.3.1. Introduction

In this study, floodplain mapping of Değirmendere River that passes through the town of Maçka, Trabzon and finally connects to the Black Sea has been done using geographical information systems (GIS) and river analysis systems (RAS). Değirmendere River flows inside the boundaries of East Black Sea Basin, which has the highest precipitation rate in Turkey. One of the most important points for this area is that there are detailed maps of the area with a scale of 1/2000. These maps have been updated with the land work in the area. Missing maps of the area have been found as well.

4.2.3.2. Methods and Modeling

First job in this study was to find detailed maps of the study area. For this, maps that has 1/2000 scale with 1m contour interval and 1/25000 scale with 10m contour interval have been found. From combining these maps, another map that has much closer resemblance to the real topography of the area has been developed. Data provided from this map has used in ArcGIS software to receive TIN (Triangulated Irregular Network) data of the area.

Geometric data of the map then transferred to HEC-RAS software using HEC-GeoRAS module in ArcGIS. HEC-RAS also needs discharge values-peak discharge-to run hydraulic model simulation. DSİ has provided these discharge values each branch on the river inside study area. Using statistical methods, discharge values for 100 yr. and 500yr. return periods have been calculated.

The Manning coefficient (n) for natural riverbed has taken as n=0.030, because of the high sediment amount in water. The Manning coefficient for embankments are; n=0.022 for sections with both sides are concrete walls, n=0.026 for sections with one side is concrete wall and other side is natural ground, n=0.045 for sections with both sides are natural ground. For the sections with structures, Manning coefficient has taken as 0.060.

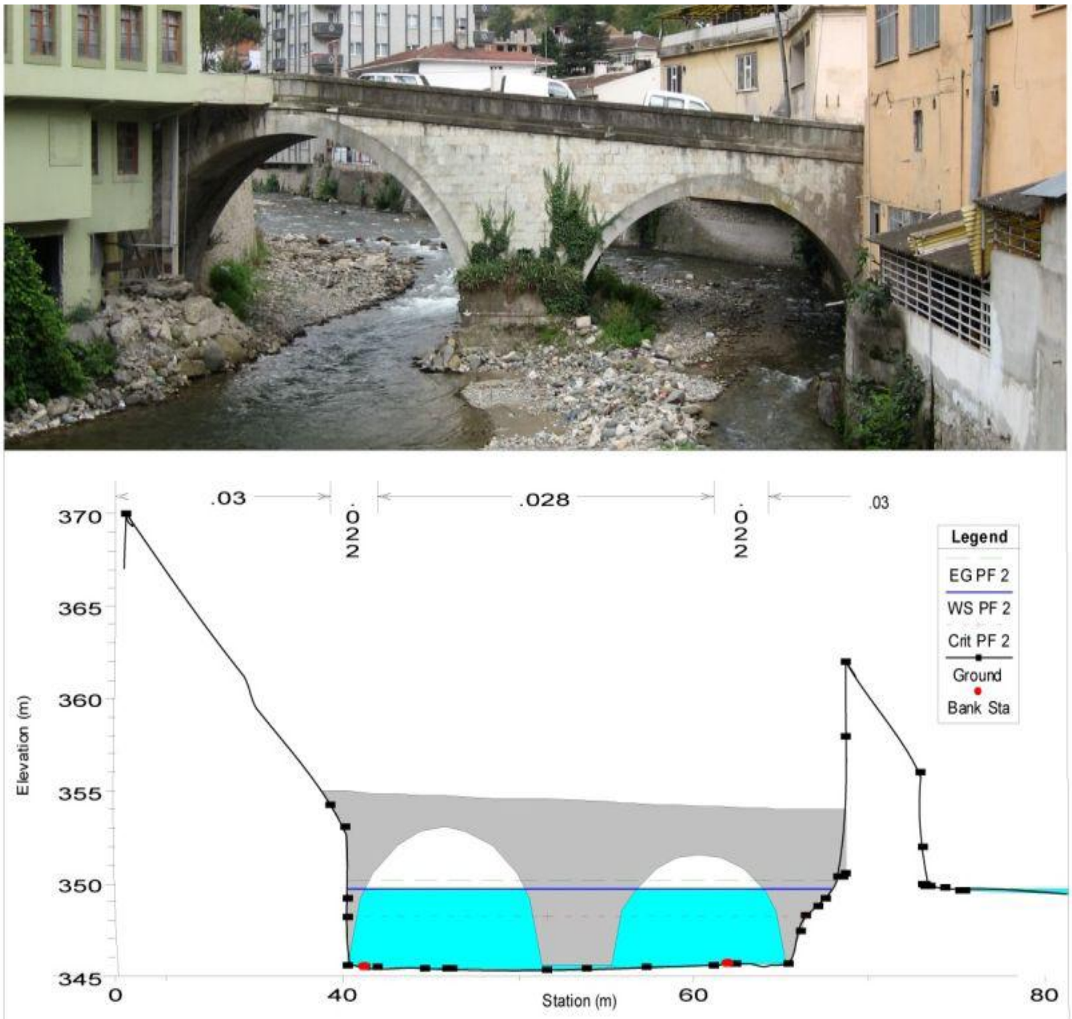


Figure 4.8.

4.2.3.3. Results

After entering geometric data of the area and structures that are on the riverbed and flow data for the river, HEC-RAS simulation has been run and results obtained. These results converted to proper files that can be used in ArcGIS software. As for the reason for transferring results to ArcGIS is that map of the flooded area can be viewed easily and effectively. After investigating these maps, it is found that the measures taken for flood prevention are only enough for a storm event that has 100 yr. return period.

If a storm event that has 500 yr. return period happens, most of the town would be inundated. There is only a small chance that a storm like this could happen but in 1990, discharge rate of Değirmendere River reached over 1000 m^3/sec and this is quite larger than the 500 yr. return period peak discharge value. One of the measures that must be taken immediately is to build water structures to translate peak discharge for flood prevention and to block sediment transportation. Also the building constructed on riverbed must be relocated to somewhere safe.

4.2.4. Floodplain Delineation in Muğla-Dalaman Plain Using Gis Based River Analysis System

4.2.4.1. Study Area

The study area is the Dalaman Plain, which is located in Lower Dalaman river basin. The lower Dalaman river basin is situated at the southwest of Turkey within the Dalaman river basin. The catchment area of the lower Dalaman river basin is about 5250 km2.

4.2.4.2. Aim of the Study

Dalaman plain has been used for agricultural purposes for years. But due to latest touristic and business trends in the area makes the area attractive as a settlement place. In the latest years, there is a big trend for settlement in the floodplain. The idea of this study is to identify flood risk on the Dalaman plain and define the possible flood water level by applying latest hydrologic / hydraulic modeling tools (HEC-RAS and HEC-GeoRAS) and GIS software.

4.2.4.3. Application of the Model

In the modeling with HEC-RAS , Manning roughness coefficient (n) is one of the most input important parameter. Roughness coefficients are an indication of the relative channel roughness. Considering the features of this river reach, the Manning roughness coefficient for main channel and flood plain is taken as 0.023 and 0.028 respectively. The “n” values are found from the calibration the flood event which was happened in 1998.

The other main input for HEC-RAS model is the river cross section. In this study, the contour map of the study areas were digitized from 1:25000 scale topographic maps and 1:5000 scale maps. By using ArcGIS and 3D Analyst software, Triangulated Irregular Network (TIN) surface model were created from contour maps. Another input parameter is the inflow value from the upstream. Several studies were done to find the inflow in the upper reach. In the feasibility study which was done in 1983 a return period of 100 years was used in the analysis by traditional way considering the situation of the plain at that time. But due to recent urbanization, touristic and economic potential of the plain 500 years return period is selected and used in this study. The geometric data was imported into HEC-RAS for model completion and simulation. Data imported into HEC-RAS included the stream network and crosssectional geometry. Station-elevation data, bank stations, downstream reach lengths, Manning's *n* values, and levee information were imported for each cross section.

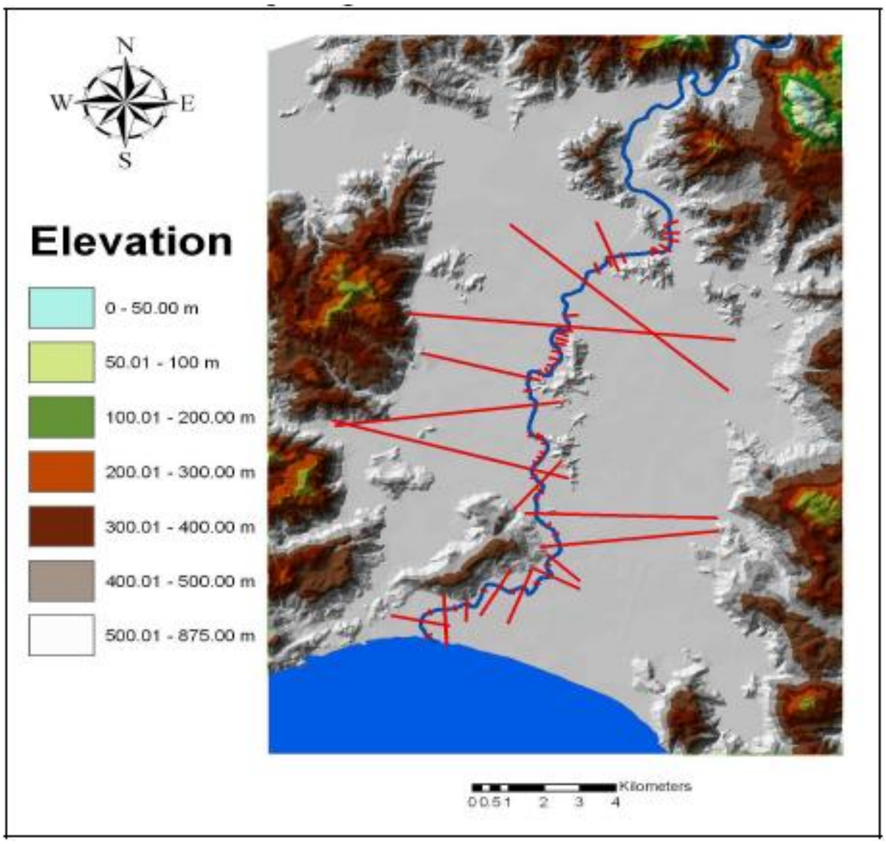


Figure 4.9.

4.2.4.4. Floodplain Delineation

Results exported from HEC-RAS were imported into the GIS using GeoRAS. Data exported from HEC-RAS included water surface elevations at each cross section, velocity information at distributed points along each cross section, and bounding polygon information. Floodplain delineation for each scenario was performed resulting in an inundation depth grid and floodplain polygon. The polygon can be used as boundary region and the inundation depth can be used for the determination of the real flood risk.

4.2.4.5. Conclusion

In this study, a coupled application of HEC-RAS and HEC-GeoRAS is used to delineate the flood plain and identify the flood risk in Dalaman Plain. The old flood plain and the new flood plain which is found by modeling with HEC-RAS and HEC-GeoRAS is shown in figure below. It can be seen from the figure that the use of new model in delineation of the flood plain reduce the flood plain about 60% which also supports the use of new models in flood plain delineation.

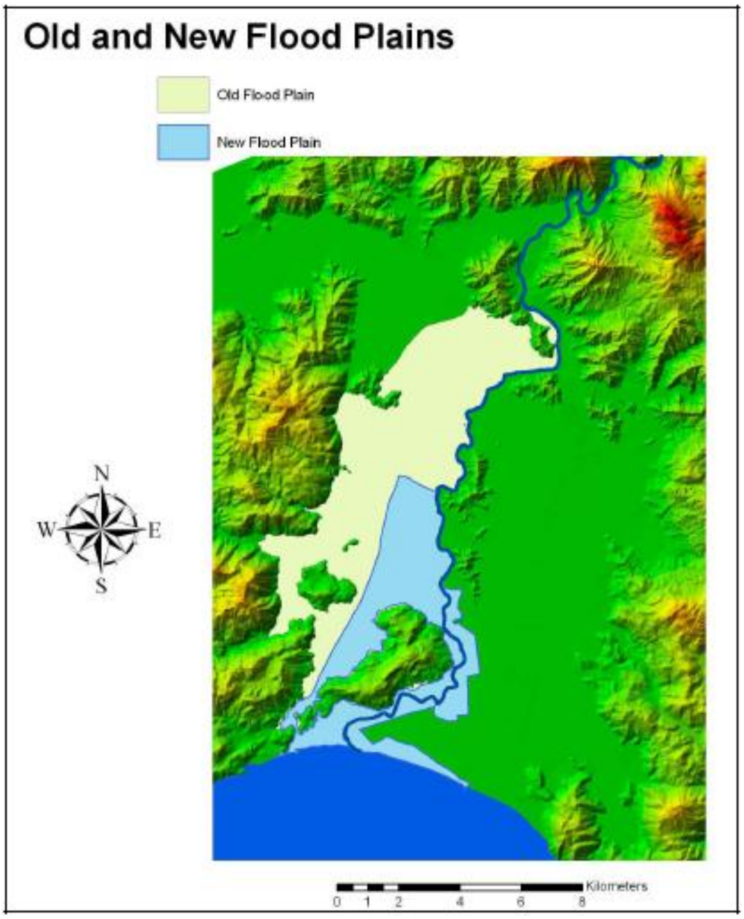


Figure 4.10.

4.3.5. Methodology

4.3.5.1 Scenarios Used In This Study

Three different scenarios have created for this study:

1- Q = 300 m^3/s flood discharge for 100 yrs. return period,

2- Q = 500 m^3/s flood discharge for 1000 yrs. return period,

3- Q = 1000 m^3/s chosen randomly as a third scenario.

These three scenarios are used in HEC-RAS software as a flow input and results are obtained as a water surface profile maps. These results are presented in the following Section 4.4.

4.3.5.2. Geometric Data of the Porsuk Basin

DEM map of the whole Porsuk basin with a 1:25000 scale has acquired and delineation process has been done in ArcGIS software. TIN map of the area also created to use in HECGeo-RAS interface inside the ArcGIS. River network has divided into 5 sections and digitized with HECGeo-RAS. These sections are called Porsuk 1, Porsuk 2, Porsuk 3, Sarısu and Uluçayır. River centerlines have drawn in Google Earth and imported into ArcGIS. Cross-sections are created in ArcGIS with HECGeo-RAS interface tools. For Porsuk 1 section cross-sections are placed with 100m distance between each section. For the remaining sections cross-sections are placed with 50m distance between each section. 1397 cross-sections have created in ArcGIS. Banklines are also created parallel to the river centerlines.

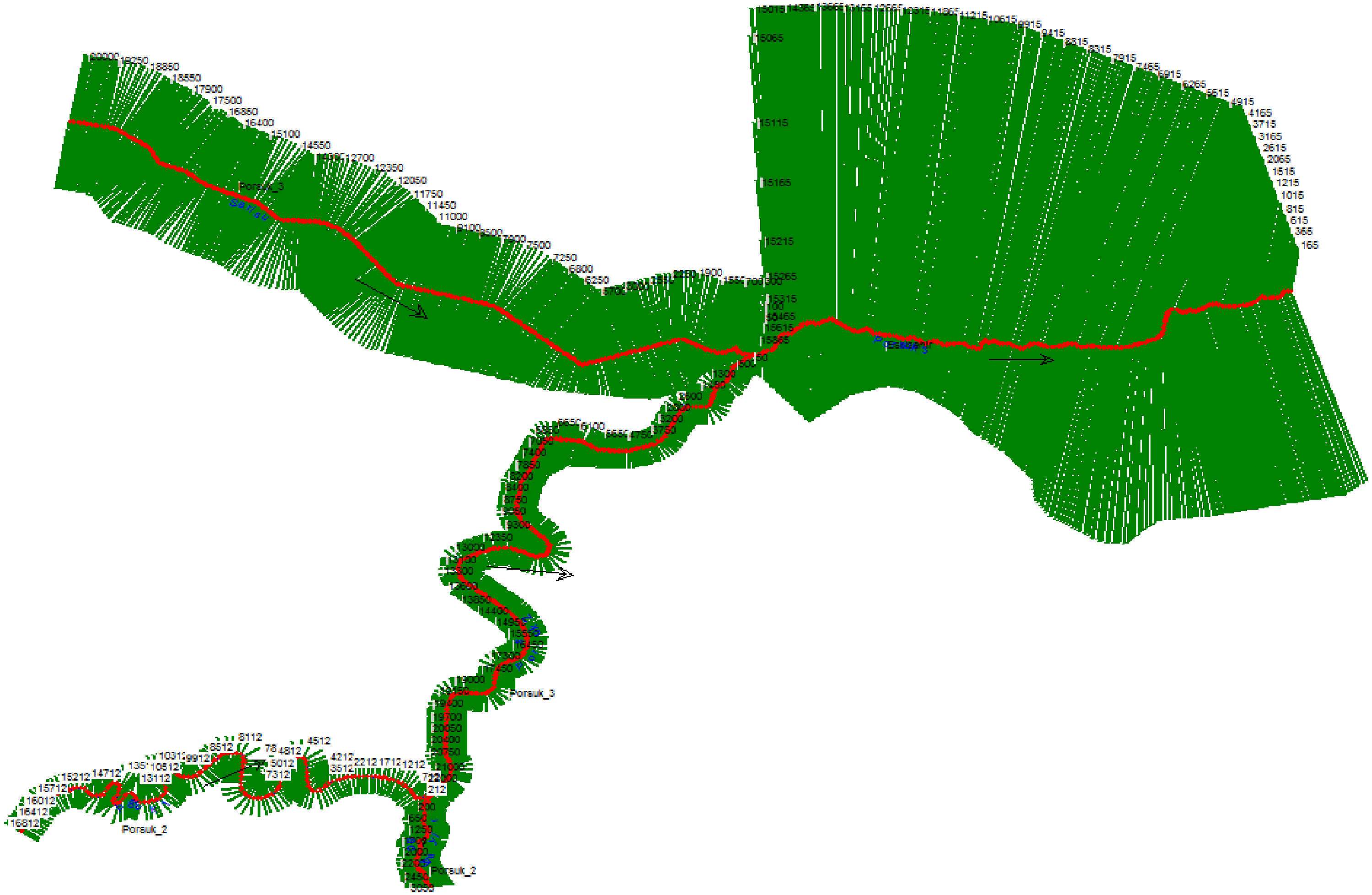


Figure 4.11. Cross-sections for each section

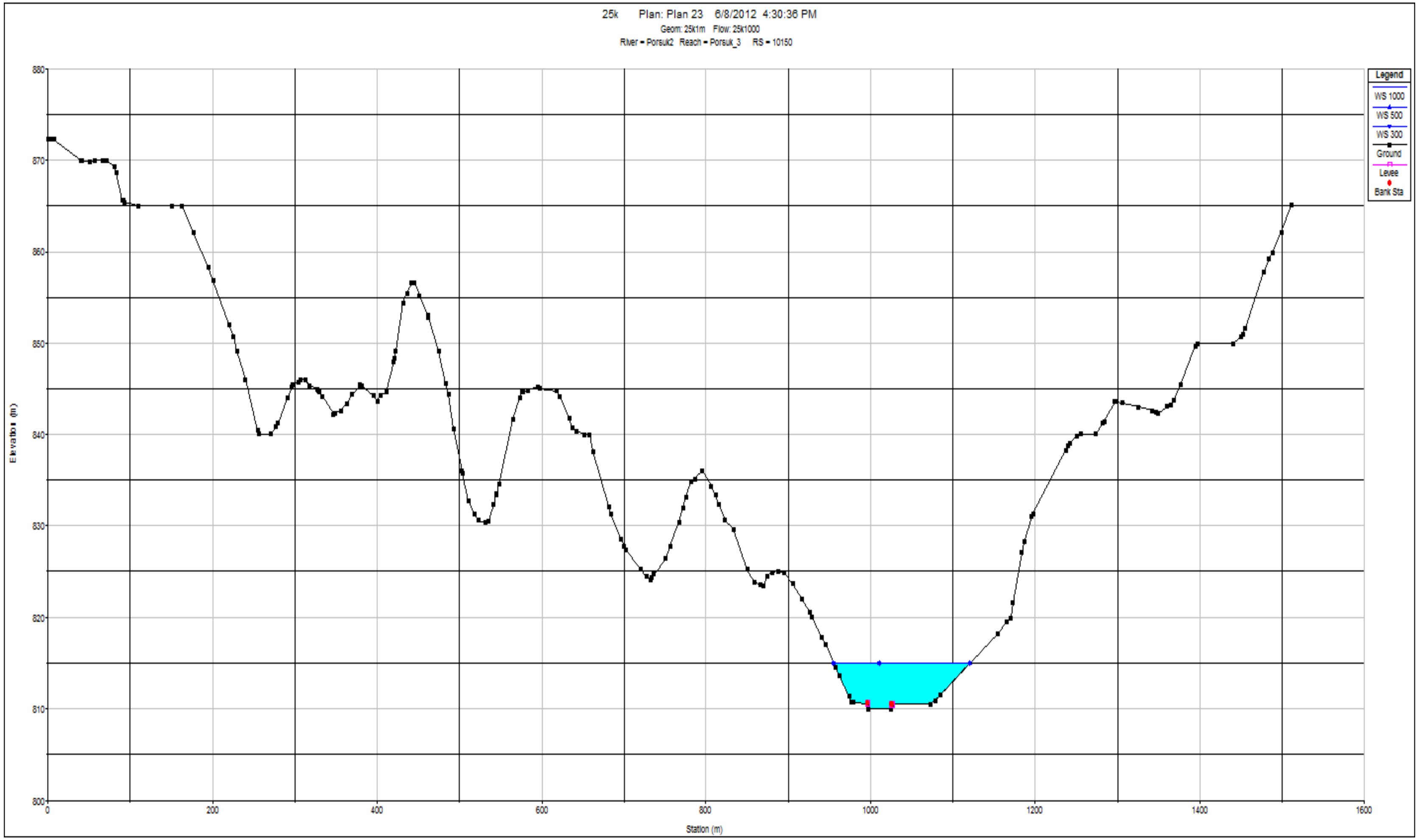
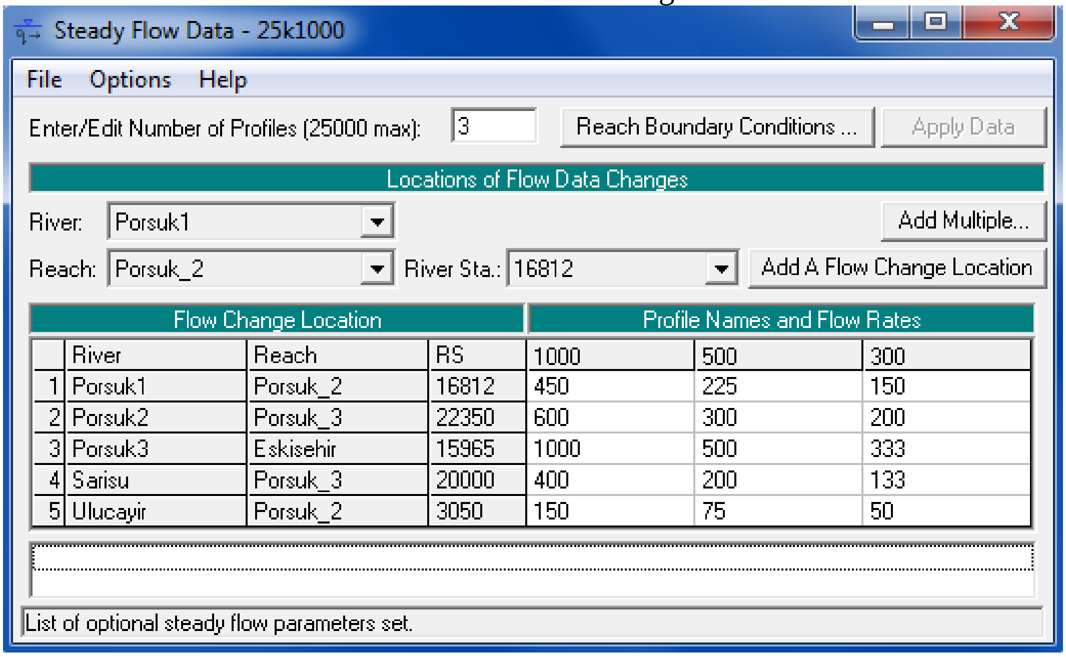


Figure 4.12 A cross-sections of the River Bad

4.3.5.3. Flow Data for Porsuk Basin

Flow data for each section can be seen in Figure 4.13.1 – 4.13.2.



	River	Reach	RS	1000	500	300
1	Porsuk1	Porsuk_2	16812	450	225	150
2	Porsuk2	Porsuk_3	22350	600	300	200
3	Porsuk3	Eskisehir	15965	1000	500	333
4	Sarisu	Porsuk_3	20000	400	200	133
5	Ulucayir	Porsuk_2	3050	150	75	50

Figure 4.13.1. Steady Flow Data

River	Reach	Profile	Upstream	Downstream
Porsuk1	Porsuk_2	all	Normal Depth S = 0.001497	Normal Depth S = 0.001497
Porsuk2	Porsuk_3	all	Normal Depth S = 0.001372	Normal Depth S = 0.001372
Porsuk3	Eskisehir	all	Normal Depth S = 0.001365	Normal Depth S = 0.001365
Sarisu	Porsuk_3	all	Normal Depth S = 0.0007895	Normal Depth S = 0.0007895
Ulucayir	Porsuk_2	all	Normal Depth S = 0.005013	Normal Depth S = 0.005013

Figure 4.13.1. Boundary Conditions

4.4. Results

Results of three different scenarios are given as figures and tables in below sections.

4.4.1. Scenario 1: Q = 300m^3/s:

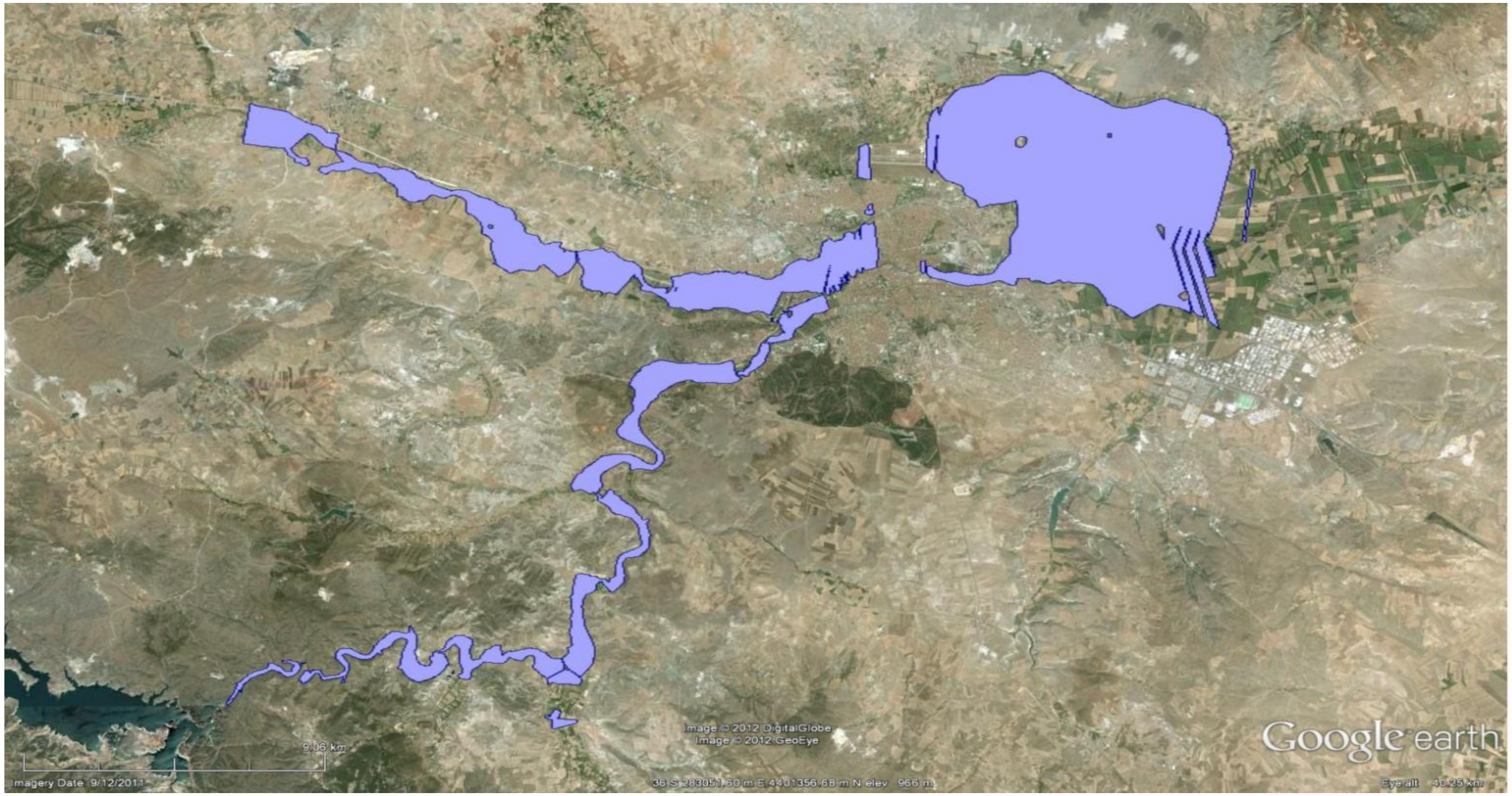


Figure 4.14. Flood Areas for Q = 300 m^3/s

Figure 4.15. Flood Areas and Depths for Q = 300 m^3/s

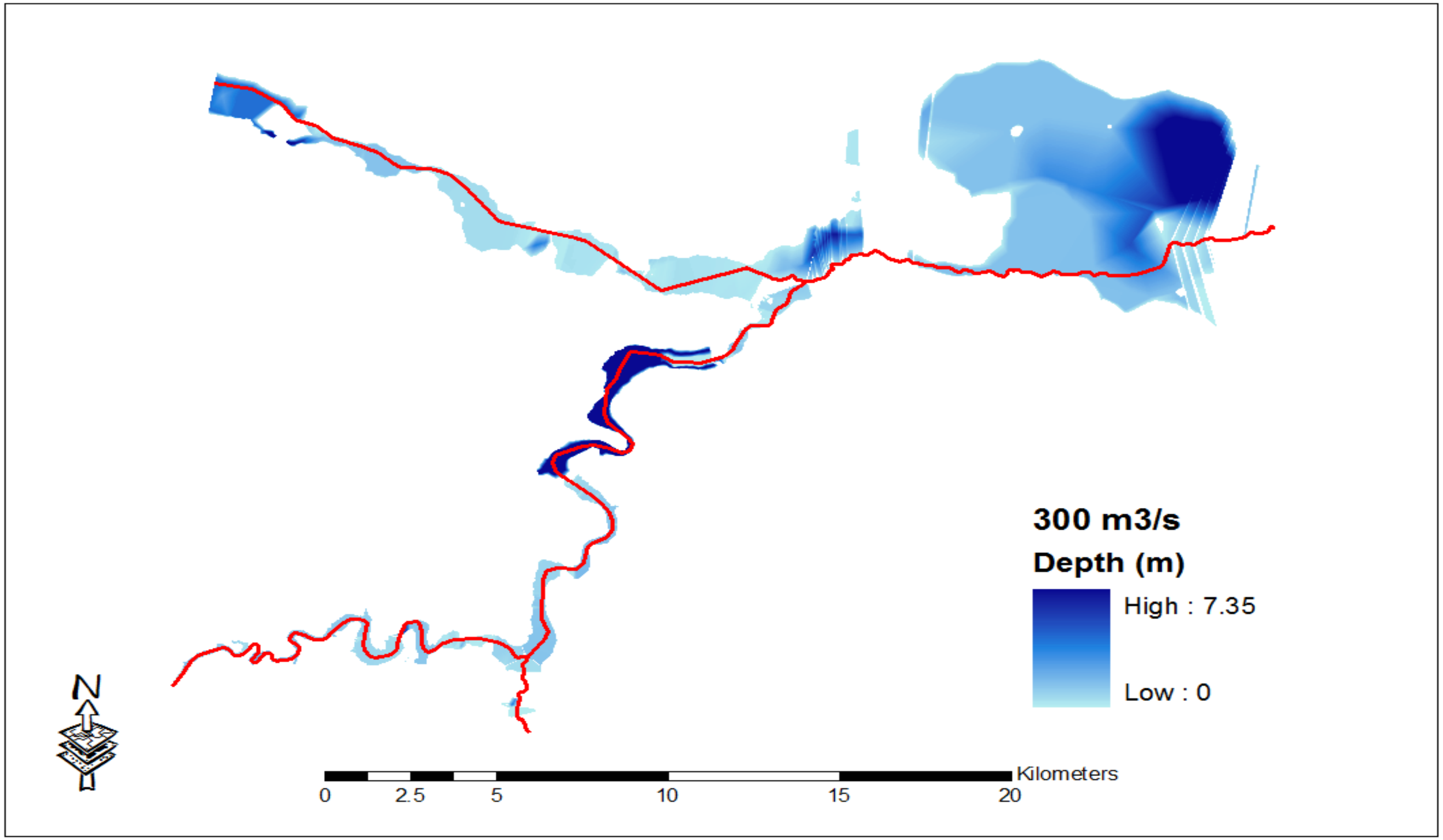


Figure 4.16. Depth values for Q = 300 m^3/s

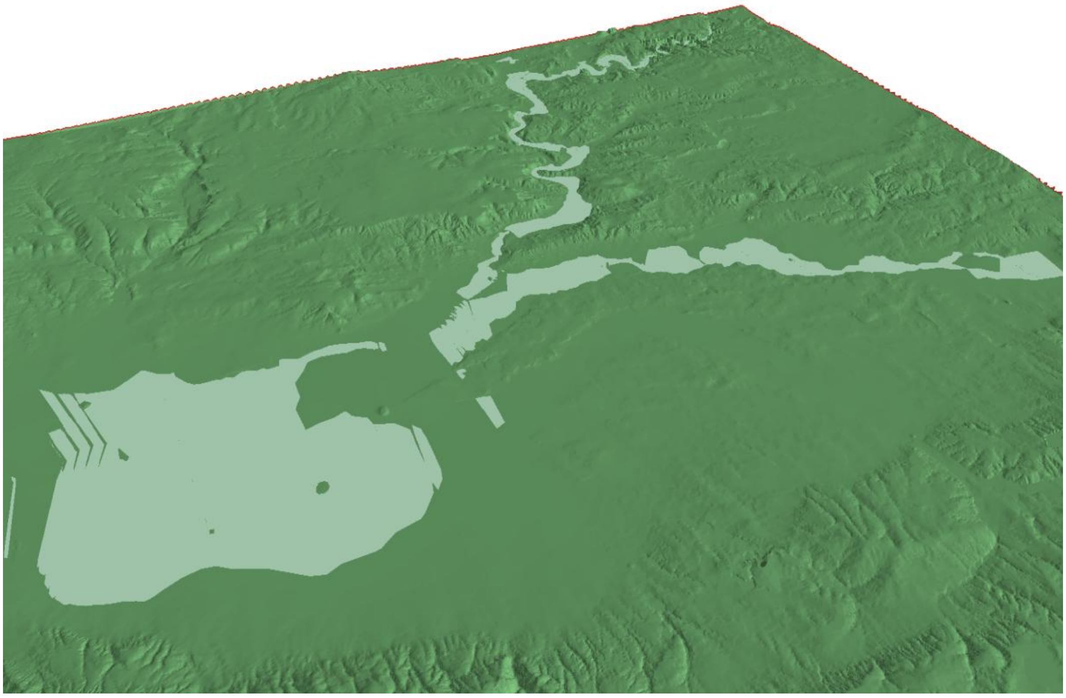


Figure 4.17. TIN and flood areas for Q = 300 m^3/s taken from ArcScene software

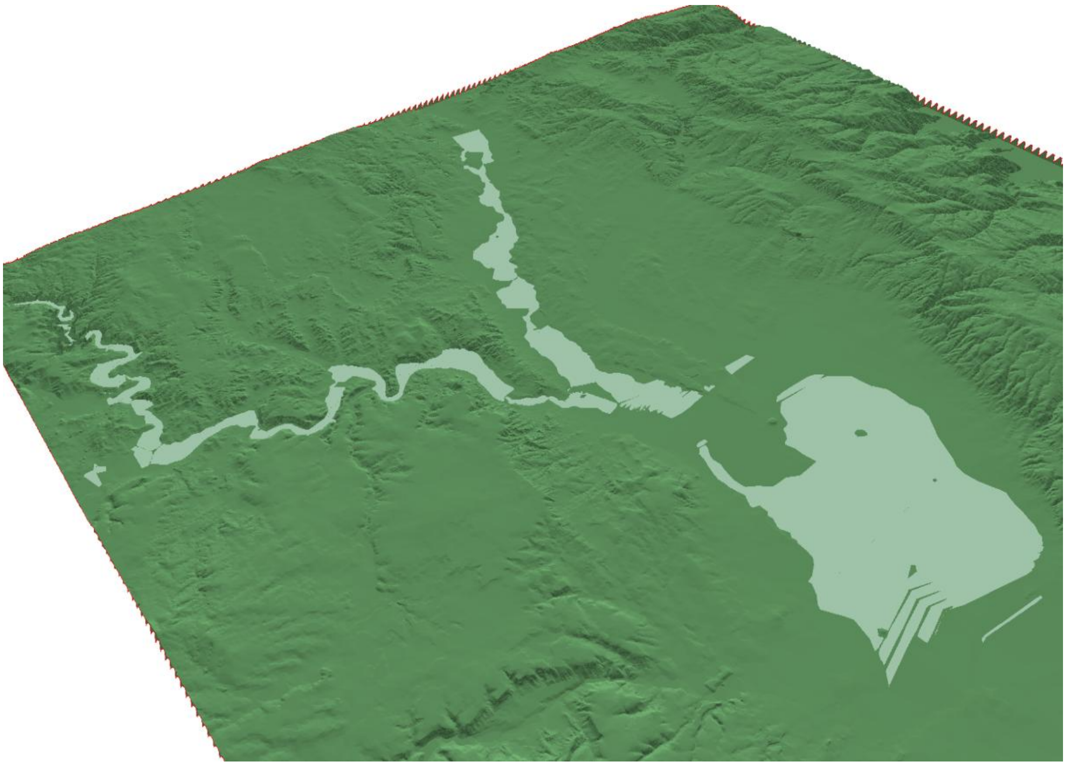


Figure 4.18. TIN and flood areas for Q = 300 m^3/s taken from ArcScene software

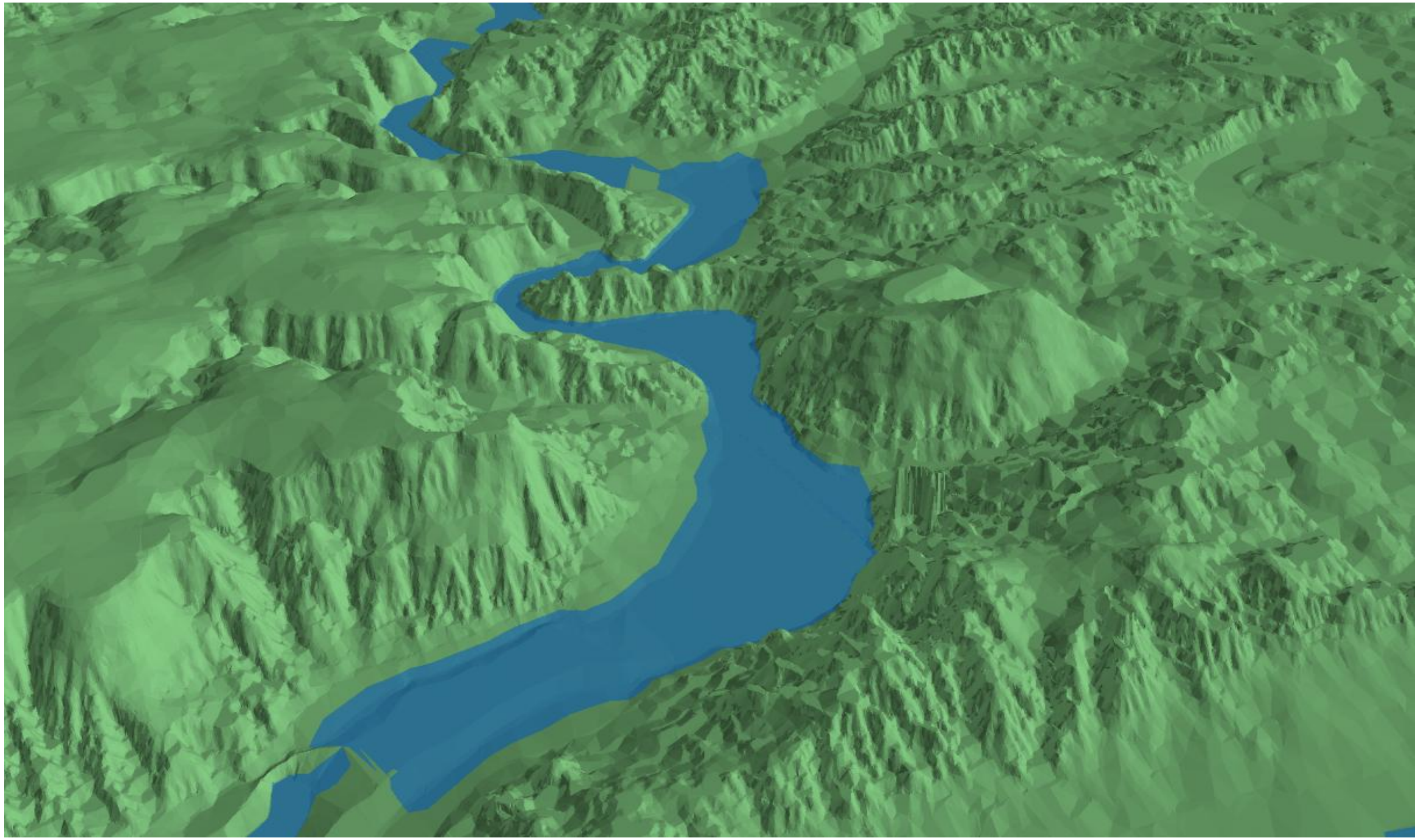


Figure 4.19. TIN and flood areas for Q = 300 m^3/s taken from ArcScene software

4.4.2. Scenario 2: Q = 500m^3/s:

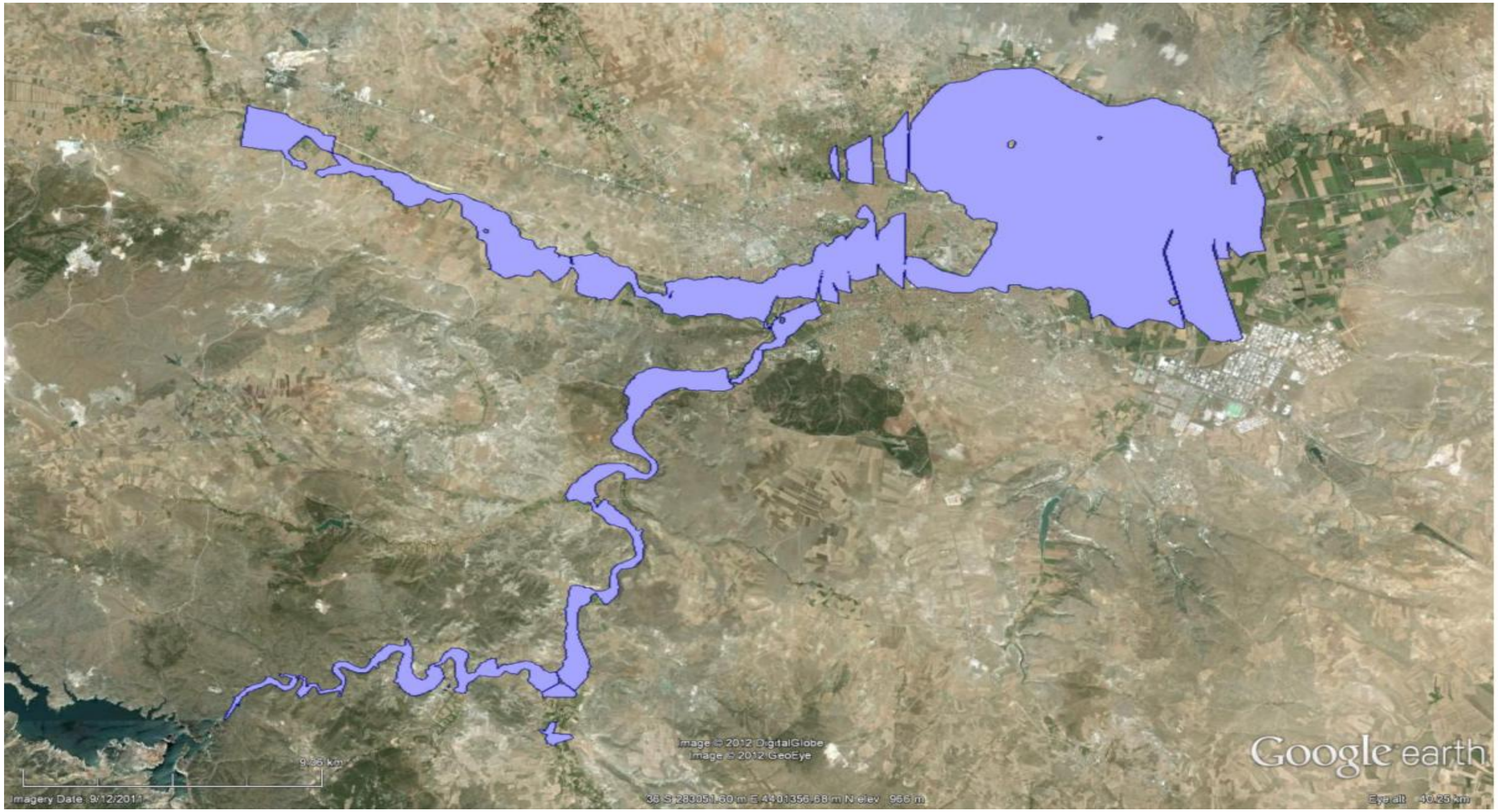


Figure 4.20. Flood Areas for Q = 500 m^3/s

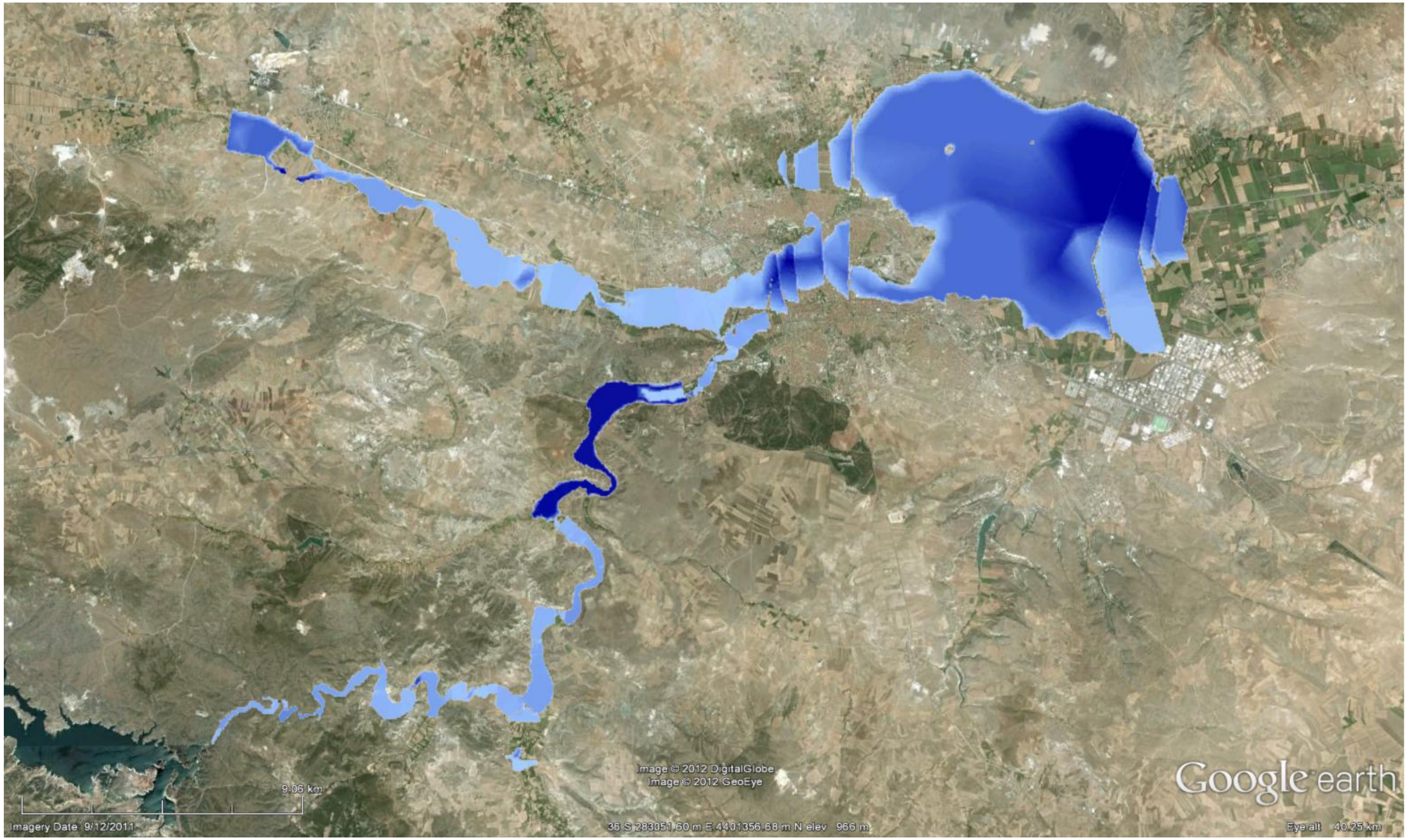


Figure 4.21. Flood Areas and Depths for Q = 500 m^3/s

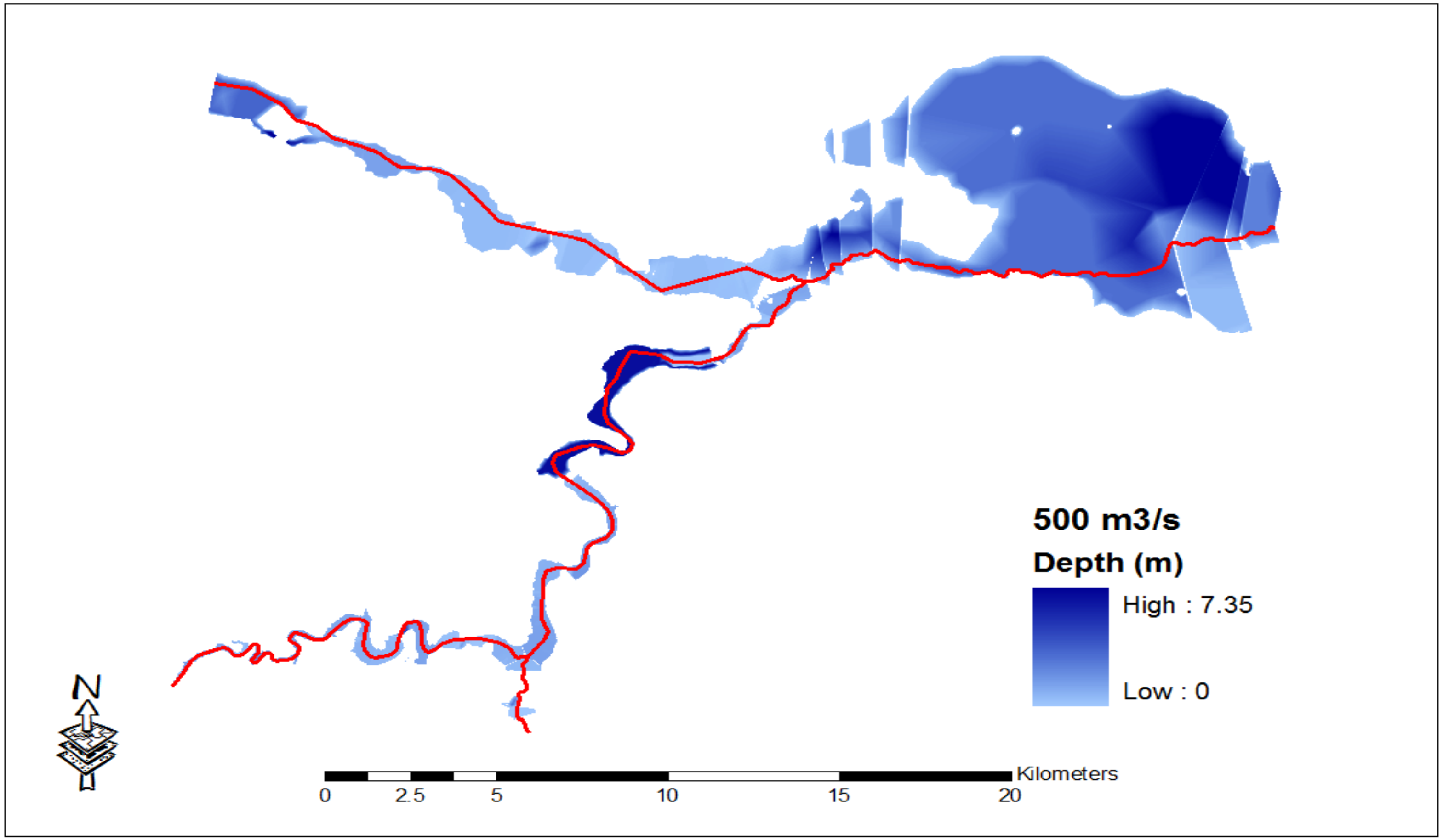


Figure 4.22. Depth values for Q = 500 m^3/s

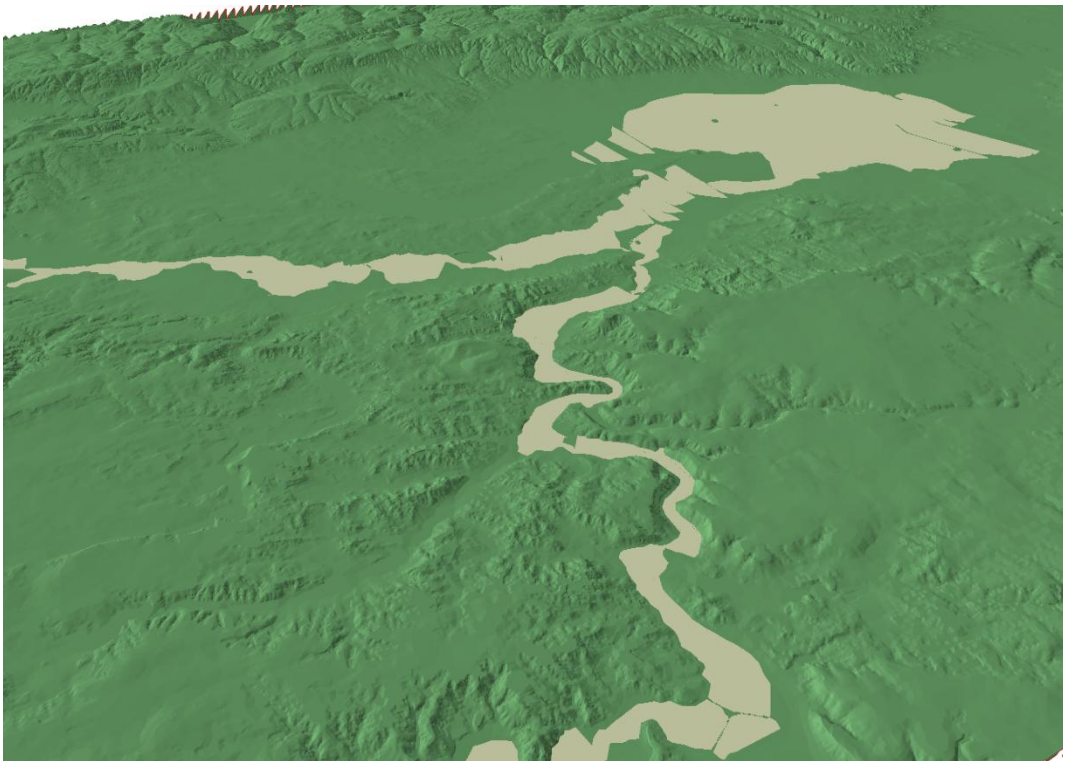


Figure 4.23. TIN and flood areas for Q = 500 m^3/s taken from ArcScene software

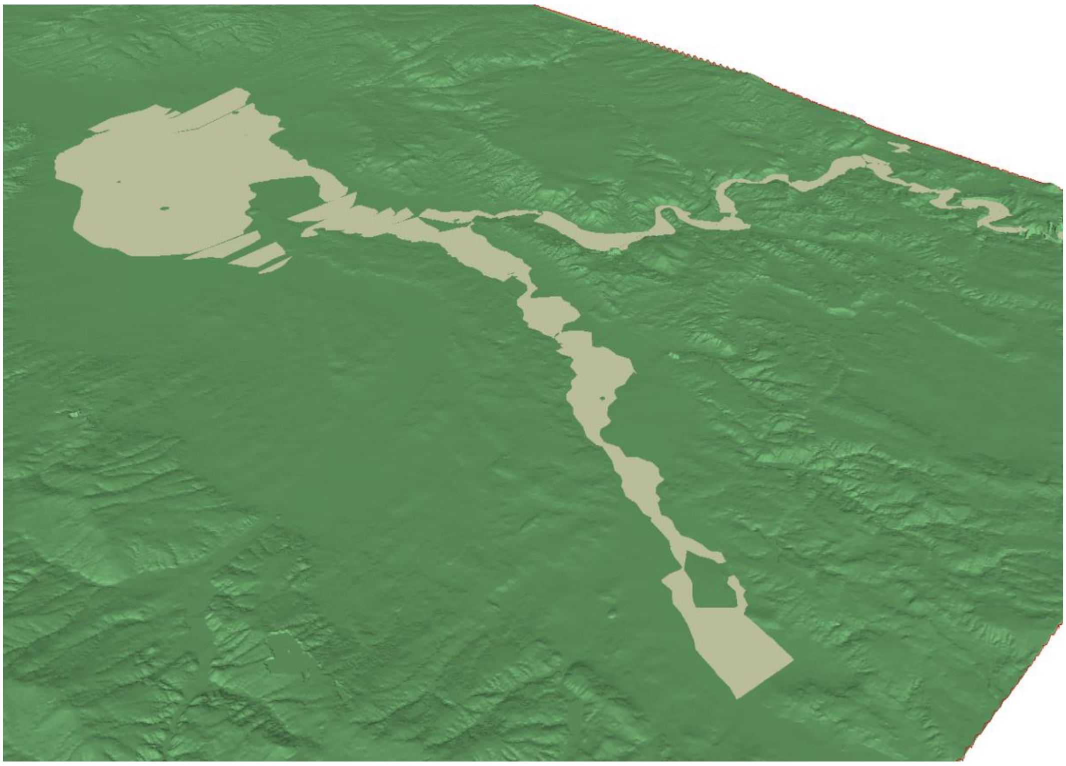


Figure 4.24. TIN and flood areas for Q = 500 m^3/s taken from ArcScene software

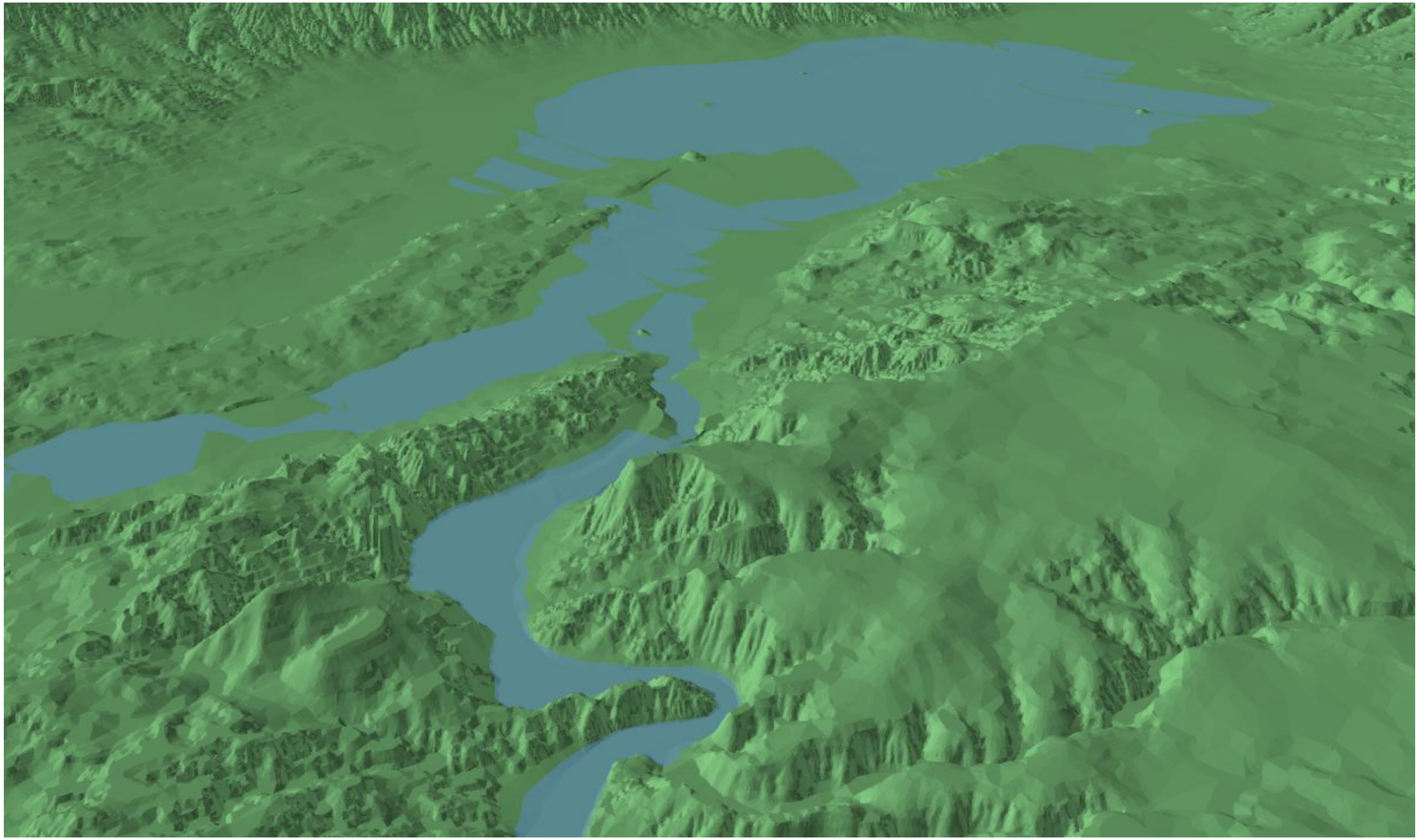


Figure 4.25. TIN and flood areas for Q = 500 m^3/s taken from ArcScene software

4.4.3. Scenario 3: Q = 1000m^3/s:

Figure 4.26. Flood Areas for Q = 1000 m^3/s

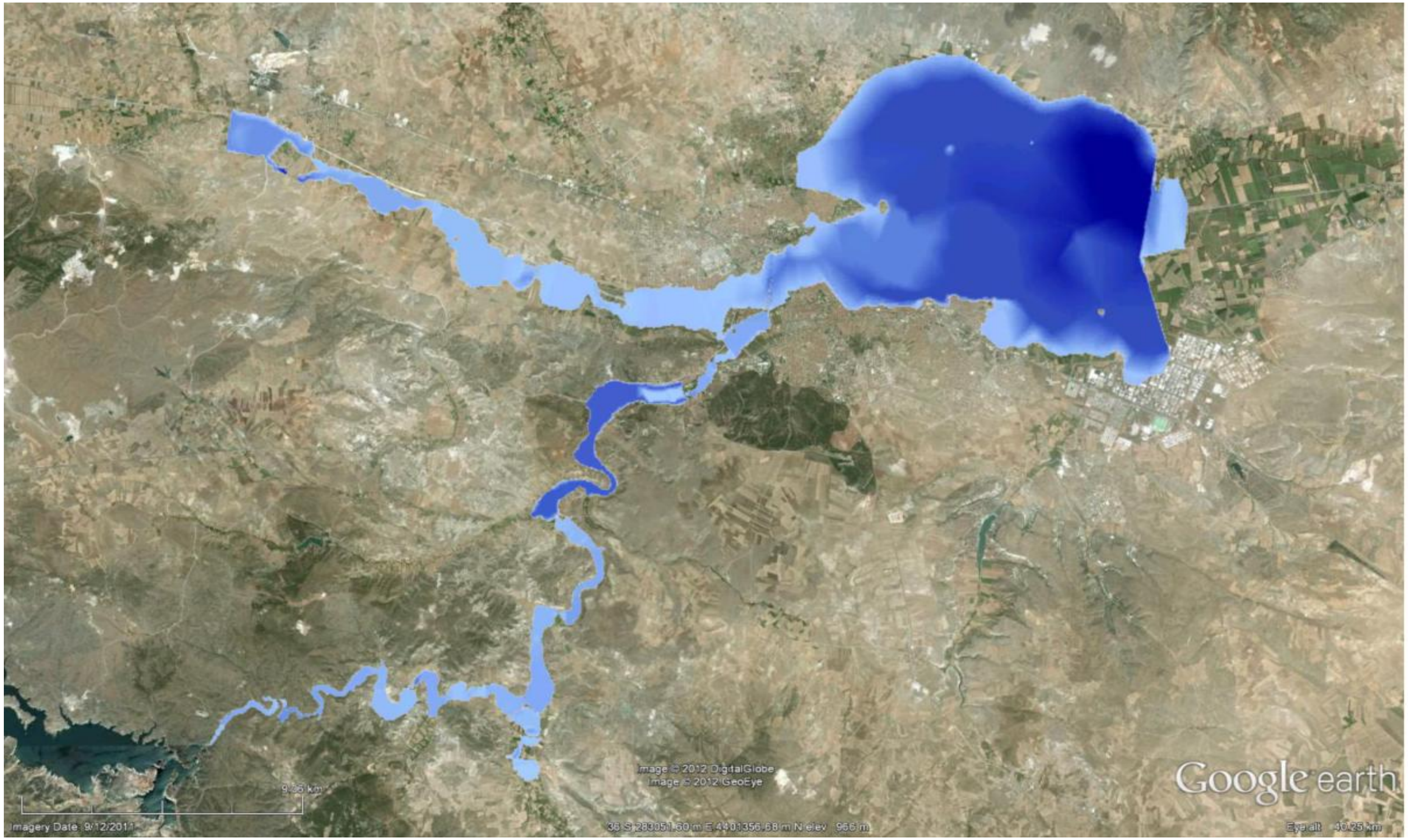


Figure 4.27. Flood Areas and Depths for Q = 1000 m^3/s

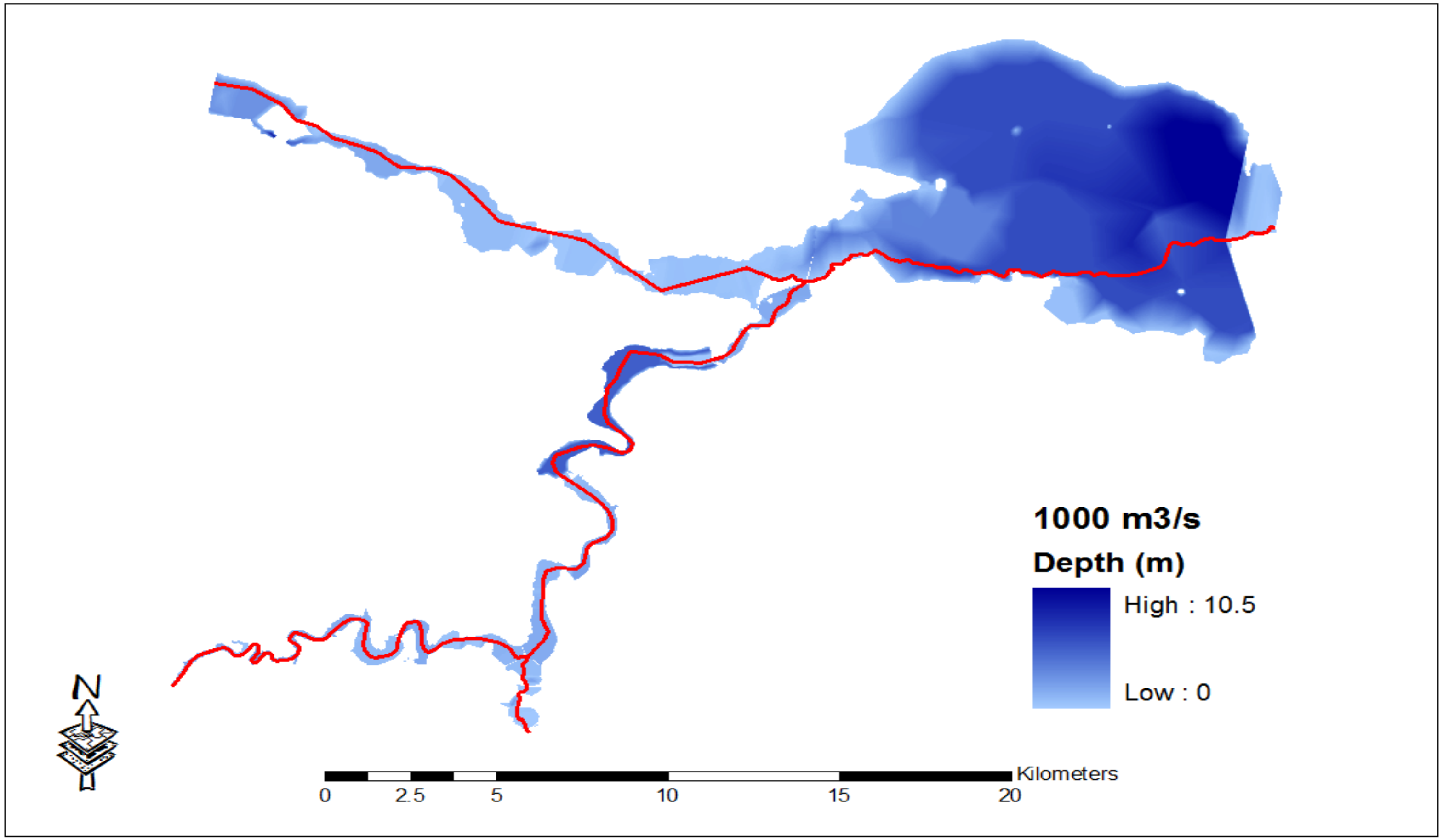


Figure 4.28. Depth Values for Q = 1000 m^3/s

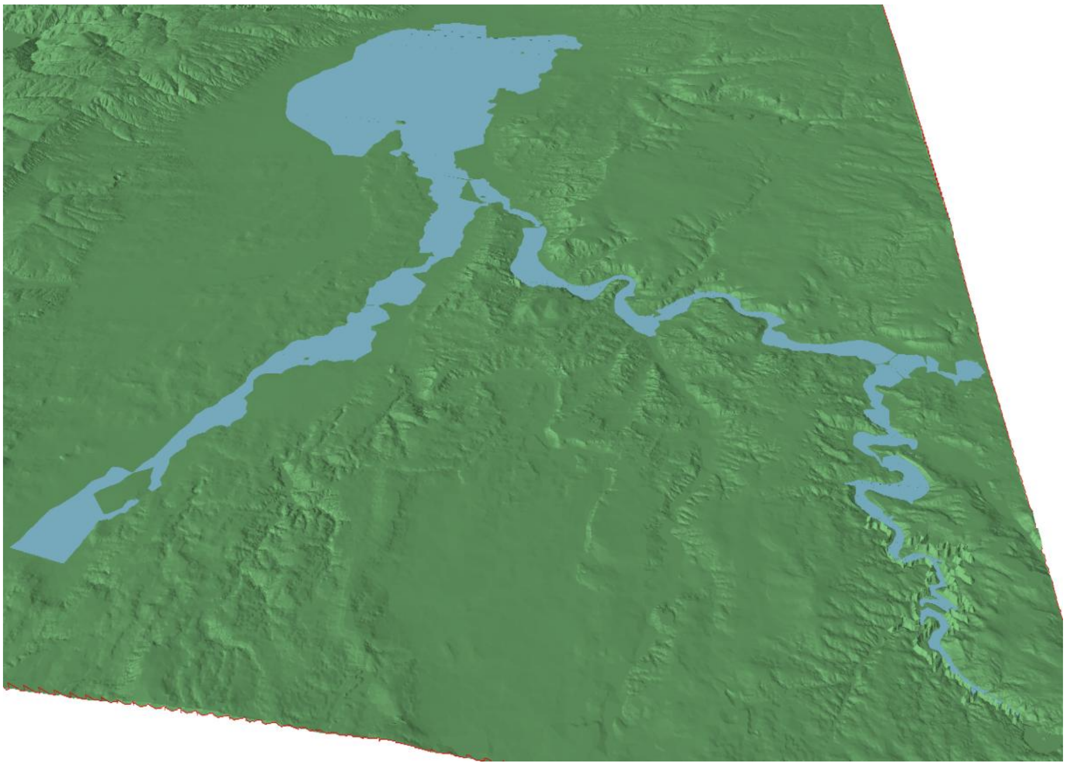


Figure 4.29. TIN and flood areas for Q = 1000 m^3/s taken from ArcScene software

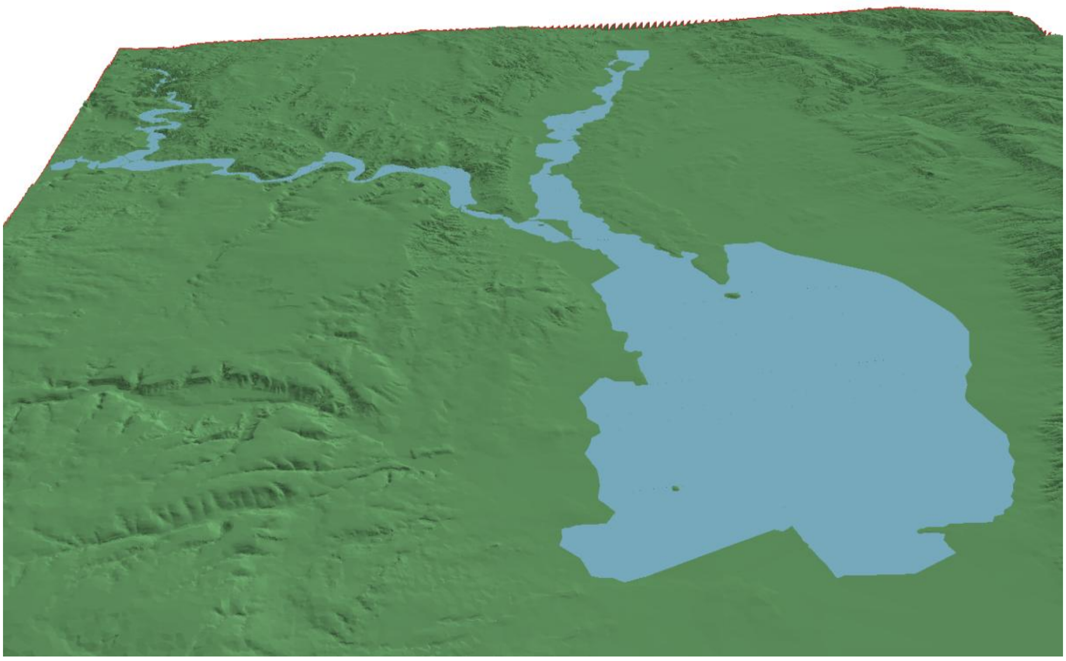


Figure 4.30. TIN and flood areas for Q = 1000 m^3/s taken from ArcScene software

Figure 4.31. TIN and flood areas for Q = 1000 m^3/s taken from ArcScene software

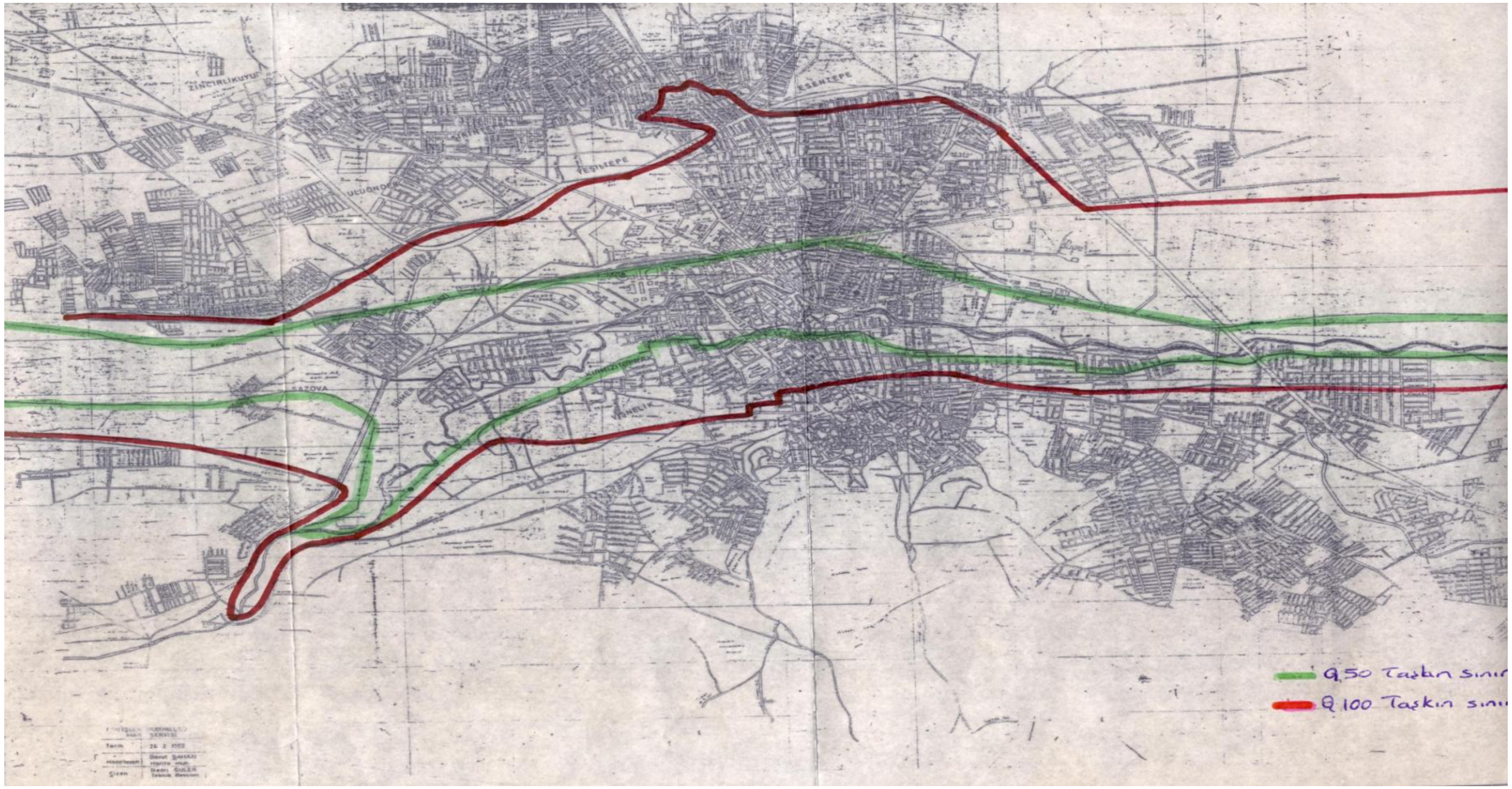


Figure 4.32. Flood maps taken from DSİ (State Hydraulic Works)

4.5. Conclusions and Recommendations

Inundation areas for Eskişehir city center has created for this study to see which areas will be flooded and warn the authorities for the effects of these situations if possible. We know that this study is not sufficient enough to consider it as a serious study but it can be seen as a first step in this field of work. Better results can be obtained by using maps with scale less than 1:5000 so that the topography of the area can be represented more closely to real topography of the area. More flow data for different past events can also be useful to calibrate and compare the results obtained.

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