MODELING AND DEVELOPMENT OF A GROUNDWATER MANAGEMENT PLAN FOR ULUBEY AQUIFER SYSTEM, UŞAK - TURKEY

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Approval of the thesis:

MODELING AND DEVELOPMENT OF A GROUNDWATER MANAGEMENT PLAN FOR ULUBEY AQUIFER SYSTEM, UŞAK – TURKEY

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ABSTRACT

MODELING AND DEVELOPMENT OF A GROUNDWATER MANAGEMENT PLAN FOR ULUBEY AQUIFER SYSTEM, UŞAK – TURKEY

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The purpose of this study is the characterization and modeling of Ulubey aquifer system which serves as an important water supply for Uşak province located in inner parts of the Aegean Region in Turkey. In recent years, growing population, accelarating industrial activities and on the contrary decreasing rainfall and contamination of the surface water resources made groundwater indispensable to meet domestic, agricultural and industrial water demands of Uşak province. All these facts necessitate the development of a groundwater management plan, which this study aims to end up with. For this purpose, every single component of the recharge/discharge mechanisms of the groundwater budget of the aquifer system should conceptually be comprehended. However, due to lack of data, all of the components can not be precisely determined. Hence, a mathematical groundwater flow model successfully calibrated under steady state conditions, is utilized to calculate the missing components of the groundwater budget and also to test the effects of increased pumping rates for irrigational and domestic uses to supply the increasing demand in the future. For this purpose, three management scenarios are set up under transient conditions over a planning period of 20 years. Drawdown maps, groundwater budgets and groundwater level hydrographs are utilized to observe the effects. The results of these simulations proved that neither of the tested management scenarios creates significant drawdowns or change in groundwater reserve of the Ulubey aquifer system.

Keywords: Ulubey Aquifer System, Groundwater Budget, Numerical Modeling, Calibration, Groundwater Management

ÖZ

ULUBEY AKİFER SİSTEMİNİN (UŞAK - TÜRKİYE) MODELLENMESİ VE YERALTISULARI YÖNETİM PLANI GELİŞTİRİLMESİ

Ünsal Erdemli, Burcu

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Tez Yöneticisi : Prof. Dr. Hasan Yazıcıgil

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Bu çalışmanın amacı Türkiye'de Ege Bölgesinin iç kesimlerinde yeralan Uşak ilinin önemli su kaynaklarından biri olan Ulubey akifer sisteminin karakterize edilmesi ve modellenmesidir. Son yıllarda nüfus artışı, hızlanan endüstriyel aktiviteler ve bunların yanında yağışların azalması, yüzey suyu kaynaklarının hızla kirlenmesi Uşak ilinde yeraltısuyunun içme, kullanma, tarımsal sulama ve endüstriyel amaçlarla kullanılmasını zorunlu kılmıştır. Bütün bu koşullar, bu çalışmanın da amaçladığı gibi, bir yeraltısuları yönetim planının oluşturulmasını gerektirmektedir. Bunun için öncelikle akifer sisteminin yeraltısuyu bütçesinin oluşturan her bir beslenim/boşalım mekanizmasının kavramsal olarak anlaşılması gerekmektedir. Ancak, veri yetersizliği sebebiyle yeraltısuyu bütçesinin tüm bileşenleri net olarak belirlenememiştir. Dolayısıyla, matematiksel bir yeraltısuyu akım modeli oluşturularak kararlı akım koşulları altında başarılı bir şekilde kalibre edilmiştir. Oluşturulan bu model, yeraltısuyu bütçesindeki eksik bileşenlerin hesaplanmasının yanısıra gelecekte artması

öngörülen sulama ve kullanma suyu taleplerini karşılamak amacıyla yapılacak ek çekimlerin sisteme olan etkilerini test etmek amacıyla da kullanılmıştır. Bu amaçla 20 yıllık bir planlama dönemi için kararsız akım koşullarında üç adet yönetim senaryosu oluşturulmuştur. Oluşturulan senaryoların etkilerini gözlemlemek amacıyla senaryolara ait düşüm haritaları, yeraltısuyu bütçeleri ve yeraltısuyu seviye değişimlerini gösteren hidrograflar kullanılmıştır. Yapılan simülasyonların sonuçları, test edilen hiçbir senaryonun Ulubey akifer sisteminin su seviyelerinde ve yeraltısuyu rezervinde önemli değişikliklere sebep olmadığını ortaya koymuştur.

Anahtar Kelimeler: Ulubey Akifer Sistemi, Yeraltısuyu Bütçesi, Numerik Modelleme, Kalibrasyon, Yeraltısuyu Yönetimi

TO MY BELOVED FAMILY...

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CHAPTER 1

INTRODUCTION

1.1 Purpose and Scope

Fresh water has always been an indispensable natural resource for humans throughout the course of history. The most primitive societies evolved and founded modern civilizations along the banks of major rivers, such as Tigris, Euphrates, Nile, Indus and Yellow River. As populations increased and borders expanded, people had to search for the ways to survive far from the rivers, they constructed ducts and reservoirs; and finally when these were also insufficient, they discovered a new fresh water resource “groundwater”. Since then groundwater has served as an important source of fresh water required for domestic, agricultural and industrial uses. Demand on groundwater has grown continuously as a consequence of population increase and industrialization. These facts lead to the concern that groundwater, like any other scarce resource, has to be managed.

The purpose of this study is the characterization and modeling of Ulubey aquifer system which serves as an important water supply for Uşak province located in inner parts of the Aegean Region in Turkey. In recent years, growing population, accelerating industrial activities and on the contrary decreasing rainfall and contamination of the surface water resources made groundwater indispensable to meet domestic, agricultural and industrial water demands of Uşak province. All these facts necessitate the development of a groundwater management plan, which this study aims to end up with. In order to develop a groundwater management plan, a conceptual groundwater budget has to be set up and every single component of the recharge/discharge mechanisms constituting the groundwater budget of the aquifer system should conceptually be comprehended. However, due to lack of data, all of the components can not be precisely determined. Consequently, a mathematical groundwater flow model is utilized to determine the missing components of groundwater budget and also to test alternative management scenarios. After calibrating the model under steady state conditions, alternative management scenarios are tested under transient conditions. The alternative management scenarios examine the effects of increased pumping rates for irrigational and domestic uses to supply the increasing demand in the future. This case study provides an example demonstrating how mathematical flow models can be utilized to develop and test groundwater management scenarios. Furthermore, outcomes of this study, providing recommendations on management of Ulubey aquifer system, will hopefully serve as a guide for decision-makers to set up a groundwater management plan.

1.2 Location and Extent of the Study Area

The study area is located in inlands of the Aegean region and it is situated within the provincial boundaries of Uşak, Denizli and Kütahya cities. It lies between 38°07'30" - 38°55'11" north latitudes (UTM 4221650 – 4312200 N) and 28°59'35" - 30°00'04" east longitudes (UTM 674700 - 760200 E) (Figure 1.1).

The study area of 3972 km^2 completely encloses the Banaz Stream Basin. Banaz Stream drains an area of 3475 km^2 corresponding to 87% of the study area.

1.3 Previous Studies

Geological maps of scales 1/50,000 and 1/25,000 including several parts of the study area were produced by the General Directorate of Mineral Research and Exploration (MTA).

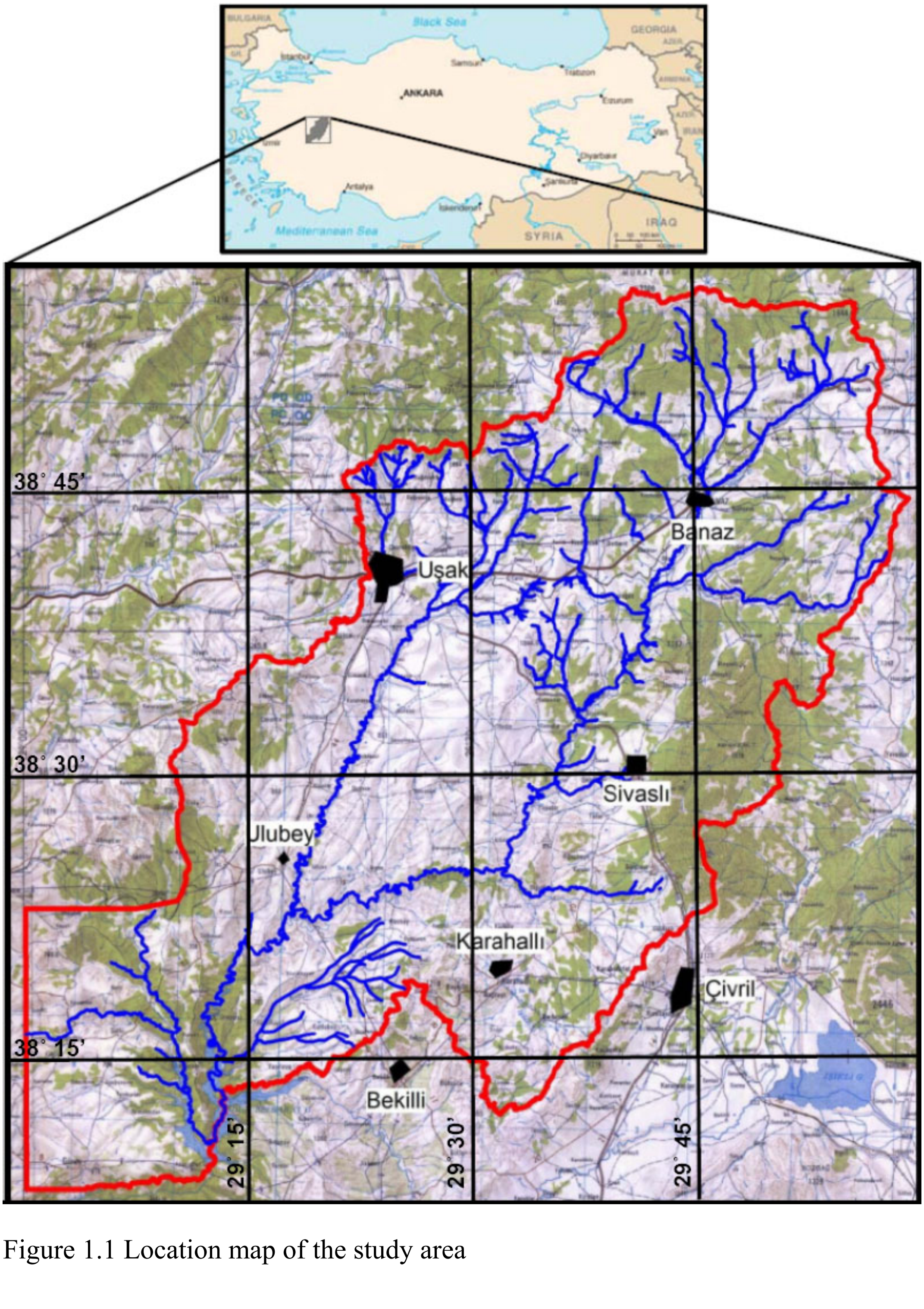


Figure 1.1 Location map of the study area

First geological study within and around the study area was the "Geology of the region between Kütahya and Gediz" (Akkuş, 1962). In 1969 "Geology of the Aegean Region – Babadağ Locality" was studied by Akarsu (1969). Gördes migmatites around the study area were studied by Ayan, in 1973 (Ayan, 1973). In 1973, a study on "Important Problems along the Southern Boundary of Menderes Massive and Possible Solutions" was published (Boray et al., 1973). Bingöl studied "Geotectonic Evolution of West Anatolia" in 1975 and "Geology of Murat Mountain and Petrology of Main Lithological Units" in 1977 (Bingöl, 1975 and Bingöl, 1977). Ercan et al. (1978) conducted a study on "Geology of the Neogene Basins in the Locality of Uşak". "Geology of Simav, Emet, Tavşanlı, Dursunbey, Demirci, Kütahya Localities" were studied by MTA in 1979 (Akdeniz and Konak, 1979). "Geology, Mineralogy and Petrography of Uşak- Banaz-Sivaslı Region" was studied by Caran in 1999 (Caran, 1999). The recent geological study on "The Mineralogical Investigation of Some Mineralizations Related to Ophiolite, Granite and Volcanism around Murat Dağı Massive" was conducted by Dokuz Eylül University in 2005 (Minareci, 2005).

Although gology of the region including the Banaz Stream Basin was studied by many researchers for several purposes, there are no hydrogeological investigations except those performed by the State Hydraulic Works (DSİ) and the İller Bankası (Bank of Provinces). Hydrogeological investigations conducted by the Bank of Provinces focus on the localities around the municipalities. The most comprehensive study performed by Teksan Temel A.Ş. for the Bank of Provinces was the feasibility study for drinking water supply for the city of Uşak (TEKSAN, 1996). Within the scope of this study, water demand of Uşak province over a period of 35 years and existing water resources were determined and also additional sources of water were recommended.

The first study conducted by DSİ in this locality dealt with the hydrogeological investigations to supply drinking water to some villages in Karahallı and Ulubey towns, in 1955. Studies on hydrogeological investigations of Uşak, Banaz and Sivaslı Plains were initiated in 1960 and according to the results of this study 13 exploration wells were drilled. “The Hydrogeological Investigation Report for Uşak, Banaz and Sivaslı Plains” was published by DSİ in 1976 (Koç et al., 1976). “The Hydrogeological Investigation Report for Uşak Springs” was prepared by DSİ 2nd District Office in 1979 (Aysan, 1979). In 1985, a more detailed hydrogeological investigation including a broader area was performed by 2nd District Office of DSİ and in 1986 “A Preliminary Hydrogeological Investigation Report for Banaz Plain (Uşak-Banaz-Sivaslı-Ulubey-Karahallı Plains)” was prepared (Bilgisu and Çil, 1986). Based on the recommendations presented in this report, 9 exploration wells were drilled by DSİ between 1987 and 1990. After 1990, 6 more exploration wells were drilled and the study performed in 1985 were extended southwards and results were published as “Uşak-Banaz-Ulubey-Sivaslı and Karahallı Plains Hydrogeological Investigation Report”, in 1993 (Kadıoğlu, 1993). Another study conducted in the area dealt with the hydrogeological investigations for a part of the area near Uşak and Susuzören Village (Vaytaş, 2006).

The latest study in the area was conducted by Yazıcıgil et al. in 2008 in order to develop a management plan for the Ulubey aquifer system in the Banaz Stream Basin. This thesis was completed within the scope of the study conducted by Yazıcıgil et al (2008).

There are two geophysical resistivity investigations performed by MTA and DSİ within the study area. In 1990, MTA performed 132 vertical electrical soundings along 4 profiles having a total length of 130 km in order to determine the geoelectrical characteristics and structures of the Neogene units in the locality of Uşak-Ulubey-Eşme (Tok, 1990). The second geophysical investigation was performed by DSİ in Ulubey plain with 19 vertical resistivity soundings, in 1992 (DSİ, 1992).

CHAPTER 2

DESCRIPTION OF THE STUDY AREA

2.1 Physiography

The study area is located in inlands of the Aegean region and completely encloses the Banaz Stream Basin (Figure 1.1). The basin is surrounded by Murat Mountain (2309 m) and ridges with altitudes ranging between 2218 m and 1515 m in the north, by Ahır Mountain (1940 m) and ridges with altitudes ranging between 1870 m and 1040 m in the east, by Büyükmenderes River and ridges with altitudes ranging between 1282 m and 1030 m in the south and finally by Elmadağ (1805 m), Kışladağ (1298 m) and ridges with altitudes ranging between 700 m and 1760 m in the west.

2.2 Climate and Meteorology

The Banaz Stream Basin has continental type of climate, where it is hot and dry in summer, and cold and wet in winter. There are 15 meteorological stations in and around the study area. Seven of these stations are located within the Banaz Stream Basin and eight of them are located around the basin. Locations of the stations are presented in Figure 2.1; and information about these stations such as; coordinates, elevations, operation period and operating institution, are presented in Table 2.1. Only three of these stations (Uşak, Gediz and Kışladağ) are currently active.

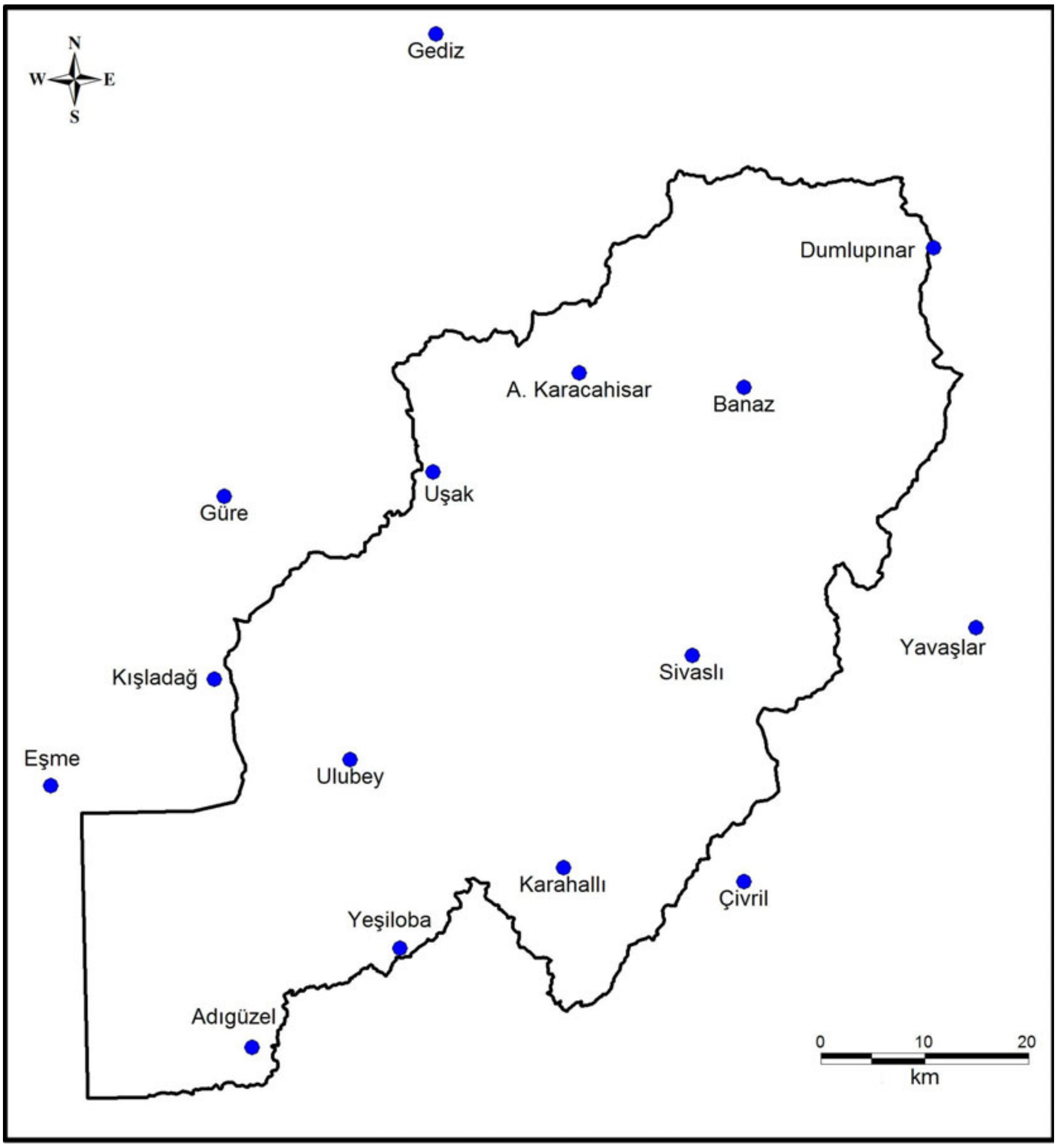


Figure 2.1 Meteorological stations within and around the study area

Table 2.1 Information about the meteorological stations

Station Name	Coordinates		Elevation	Operation Period	Operating Institution
	Easting	Northing			
Banaz	739049	4290847	925	1964-1995	DMİ
Güre	688554	4280236	650	1988-1995	DMİ
Sivaslı	734010	4264777	1050	1984-1994	DMİ
Eşme	671741	4252099	810	1984-1994	DMİ
Ulubey	700807	4254622	725	1984-1997	DMİ
Karahallı	721486	4244058	990	1988-1992	DMİ
Uşak	708814	4282592	919	1929-	DMİ
A. Karacahisar	723058	4292234	1190	1963-2005	DSİ
Adıgüzel	691276	4226630	765	1992-2004	DSİ
Yavaşlar	761572	4267481	1050	1964-2001	DSİ
Yeşiloba	705644	4236236	710	1968-2005	DSİ
Kışladağ	687615	4262435	991	2001-	Tüprag
Dumlupınar	757467	4304387	1250	1988-1994	DMİ
Çivril	739030	4242707	840	1975-2003	DMİ
Gediz	709138	4325178	825	1975-	DMİ

Average monthly and annual precipitation data recorded at meteorological stations located within and around the Banaz Stream Basin are presented in Table 2.2. Seasonal average and seasonal distribution of precipitation data for the stations located within the Banaz Stream Basin are presented in Table 2.3. The seasonal distribution of precipitation data given in Figure 2.2 shows that 37% of the total annual precipitation is recorded in winter (December, January, February), 31% is recorded in spring (March, April, May), 10% is recorded in summer (June, July, August) and remaining 22% is recorded in fall (September, October, November).

Table 2.2 Monthly and annual precipitation values recorded at meteorological stations within and around the Banaz Stream Basin (mm)

Station Name	Months												Total
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
Banaz	67.2	62.1	61.5	52.4	47.0	25.1	17.4	9.5	14.4	36.6	61.0	84.9	539.0
Güre	25.1	26.2	43.2	42.3	39.4	22.1	10.7	14.9	7.2	32.8	55.5	60.8	380.1
Sivaslı	51.7	35.8	45.7	38.2	64.9	21.0	18.2	21.0	0.0	38.9	63.5	71.8	470.7
Eşme	40.1	39.0	52.8	44.2	35.7	16.0	18.7	22.0	15.9	27.1	61.0	71.4	443.7
Ulubey	38.2	34.4	48.4	40.1	36.3	13.3	8.3	15.2	7.2	29.9	60.2	57.2	388.7
Karahallı	18.6	38.9	42.9	55.3	53.0	7.3	8.5	3.8	6.4	41.3	61.0	71.1	408.1
Uşak	71.4	64.3	58.8	49.0	49.3	23.8	17.7	12.3	17.6	38.1	59.2	79.7	541.0
A.Karacahisar	87.7	81.3	67.3	65.8	48.1	24.2	22.0	16.9	20.4	42.5	77.3	106.3	659.7
Adıgüzel	51.5	64.0	55.2	55.4	45.4	20.0	17.8	27.4	12.4	28.4	59.1	71.8	508.5
Yavaşlar	60.5	53.8	52.8	47.8	38.1	26.4	19.4	17.6	22.0	29.5	51.0	79.9	498.9
Yeşiloba	71.7	64.6	54.4	53.8	39.1	23.4	23.4	17.6	22.5	39.8	54.9	73.2	538.3
Kışladağ	47.6	60.5	52.6	59.6	20.0	24.9	16.9	18.1	30.2	32.7	60.1	56.2	479.5
Dumlupınar	27.2	40.8	52.4	63.6	57.7	23.2	22.1	15.0	8.3	51.4	79.1	81.1	522.0
Çivril	57.8	47.0	41.0	45.0	43.7	21.4	12.7	5.8	15.9	31.1	56.7	65.6	443.7
Gediz	76.2	62.0	58.4	60.5	42.0	21.7	18.9	12.4	18.9	44.0	69.0	87.2	571.1
Average	52.8	51.7	52.5	51.5	44.0	20.9	16.8	15.3	14.6	36.3	61.9	74.5	492.9

Table 2.3 Seasonal average (mm) and seasonal distribution (%) of precipitation data for the stations located within the Banaz Stream Basin

Station Name	Winter		Spring		Summer		Fall		Total Annual Precipitation
	Total	%	Total	%	Total	%	Total	%	
Banaz	214.2	39.7	160.8	29.8	52.0	9.6	112.0	20.8	539.0
Sivaslı	159.3	33.8	148.8	31.6	60.2	12.8	102.4	21.8	470.7
Ulubey	129.8	33.4	124.8	32.1	36.7	9.5	97.4	25.0	388.7
Karahallı	128.6	31.5	151.3	37.1	19.6	4.8	108.7	26.6	408.1
Uşak	215.4	39.8	157.0	29.0	53.8	9.9	114.8	21.2	541.0
A. Karacahisar	275.3	41.7	181.1	27.5	63.1	9.6	140.2	21.3	659.7
Yeşiloba	209.5	38.9	147.3	27.4	64.4	12.0	117.1	21.7	538.3
Average	190.3	37.0	153.0	30.6	50.0	9.7	113.2	22.6	506.5

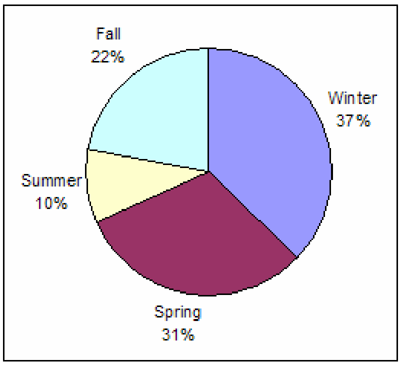


Figure 2.2 Seasonal distribution of average annual of precipitation for the stations located within the Banaz Stream Basin

Using the long term (1929-2006) precipitation data recorded at Uşak meteorological station located within the Banaz Stream Basin, a cumulative deviation from mean annual precipitation graph is developed as shown on Figure 2.3. According to this graph, wet and dry periods are determined as follows: period between 1929 and 1934 is dry, period between 1935 and 1955 is wet, period between 1956 and 1961 is dry, period between 1962 and 1981 is wet, period between 1982 and 1996 is dry, period between 1997 and 2003 is wet and finally period since 2004 to present is dry.

Within the wet periods between 1935-1955 and 1962-1981, there are two dry sub-periods. The cumulative deviation from mean annual precipitation graph based on long term data demonstrates the fact that dry periods lasted longer and wet periods lasted shorter in recent years probably as a result of global warming.

As it is presented in Table 2.1, operation periods of Güre, Sivaslı, Eşme, Ulubey, Karahallı and Dumlupınar stations are very short and correspond to the dry period between the years 1984 and 1995. Due to this fact, meteorological stations are classified into two groups; one group represents the data of only dry period of 1984-1995 and the other group represents a broader range of years including both dry and wet periods. Isohyetal maps for average and dry years are

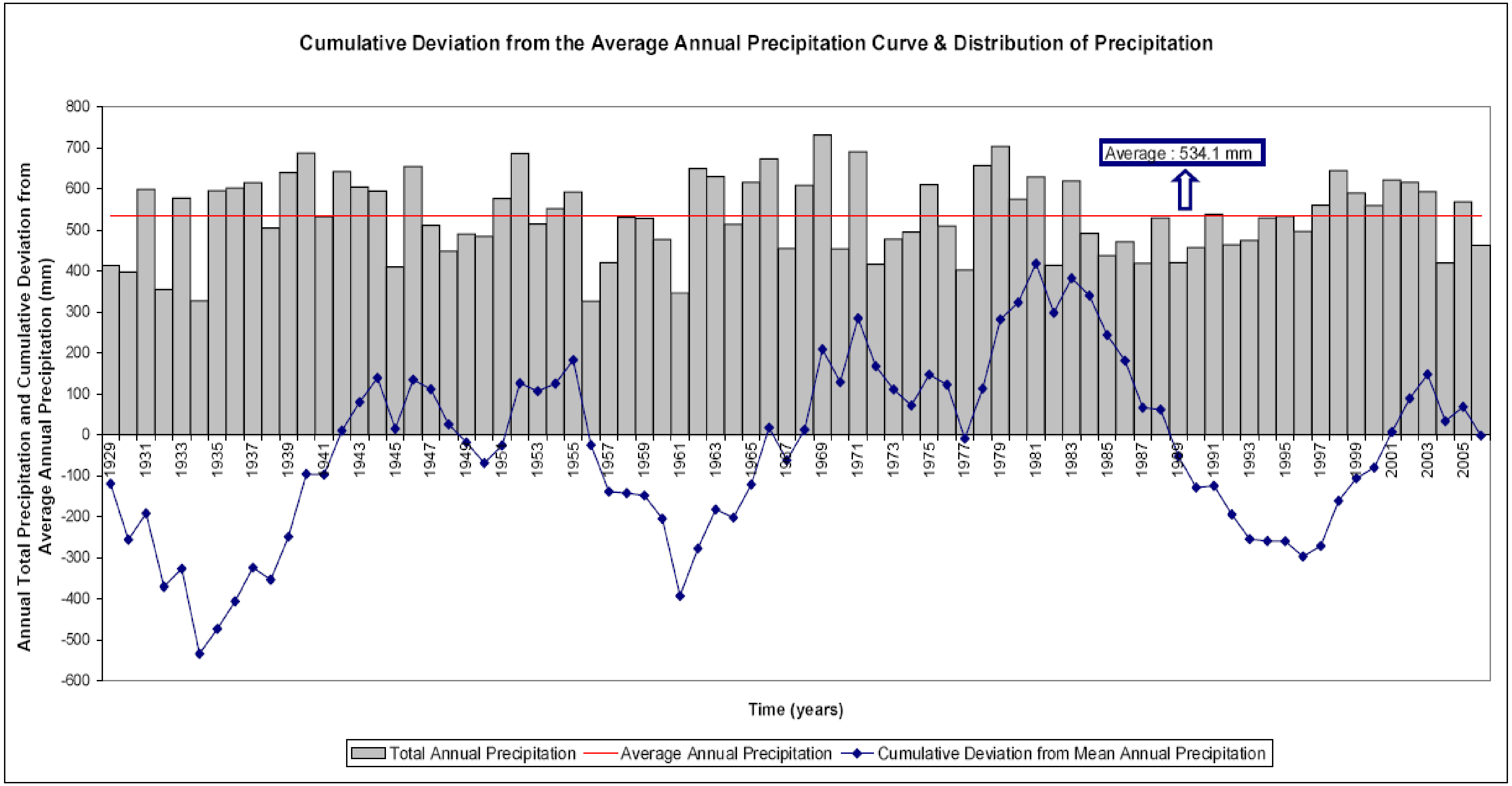


Figure 2.3 Cumulative deviation from mean annual precipitation and distribution of precipitation recorded at Uşak meteorological station

shown in Figures 2.4 ad 2.5, respectively. According to Figure 2.4, average year's precipitation value ranges between 640 mm/year in the north and 440 mm/year in southeast (around Çivril) and southwest (around Kışladağ). Using isohyetal method, average year's precipitation value for the basin is calculated as 516 mm. The average annual precipitation value for Turkey is around 650 mm. So, average annual precipitation value calculated for the basin is 20% less than that of Turkey. According to Figure 2.4, dry year's precipitation value ranges between 620 mm/year in the north and 380 mm/year in the southwest (around Ulubey). Using isohyetal method, dry year's precipitation value for the basin is calculated as 460 mm/year, which is 56 mm/year or 10.9% less than average year's precipitation value.

According to the data recorded at Uşak meteorological station between the years 1967 and 2006, the average monthly temperature value ranges between 2.5°C in January and 23.4°C in July. The average annual temperature is calculated as 12.4°C. The average monthly relative humidity value ranges between 54.1% in August and 77.4% in December. The average annual relative humidity is calculated as 65.4% for the monitoring period. West, east and northwest are the dominant directions from which wind blows in Uşak. Among these, west winds can reach the highest speed (29.6 m/s). In city centrum, average wind speed is 2.8 m/s.

According to the data recorded at Uşak meteorological station between the years 1975 and 2006, the annual total evaporation value ranges between 1003 mm and 1558 mm. Average annual evaporation value is calculated as 1228.6 mm. Figure 2.6 demonstrates the distribution of the annual total evaporation on yearly basis.

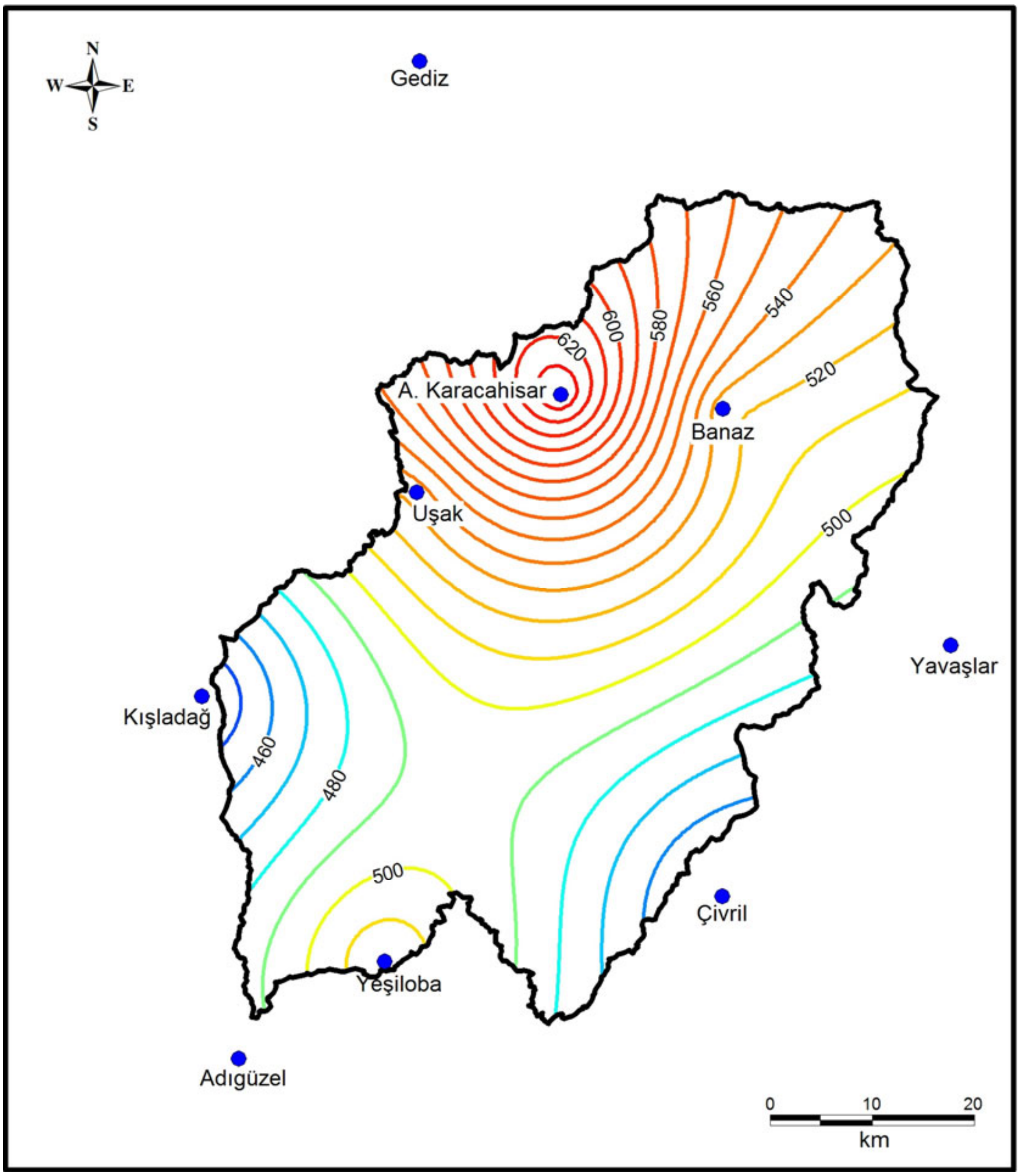


Figure 2.4 Isohyetal map of Banaz Stream Basin for average years (mm)

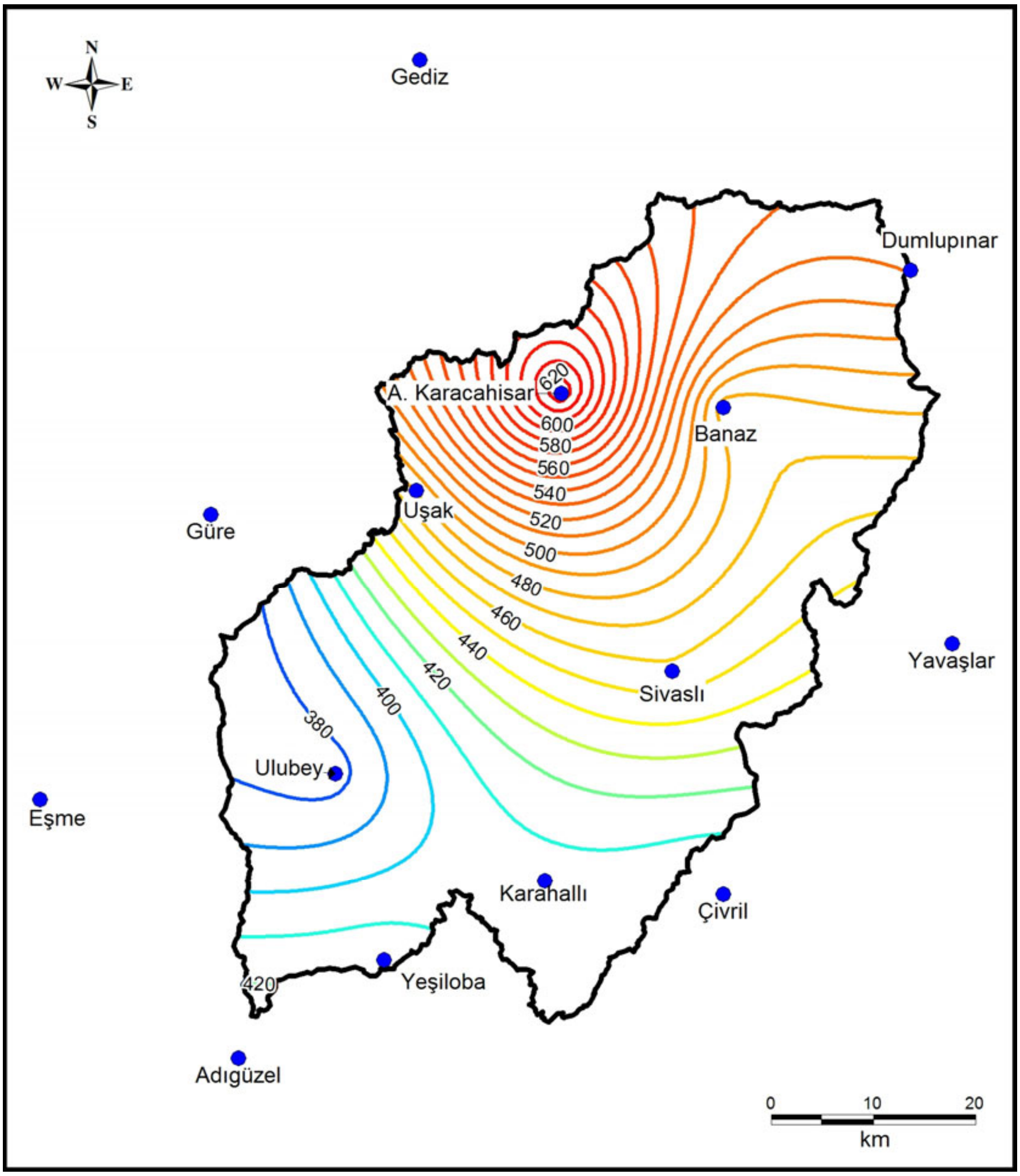


Figure 2.5 Isohyetal map of Banaz Stream Basin for dry years (mm)

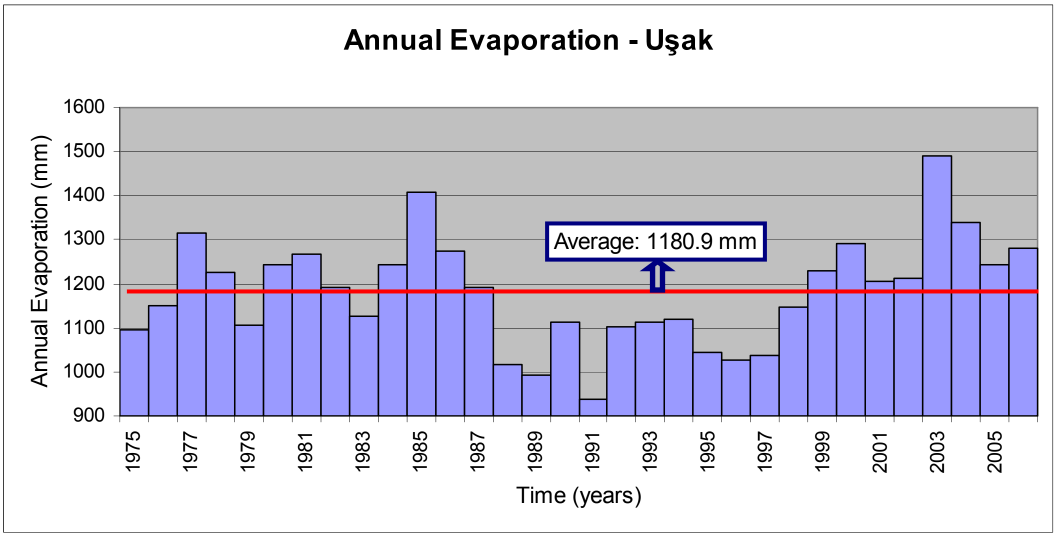


Figure 2.6 Total annual evaporation recorded at Uşak meteorological station

2.3 Geology

2.3.1 Stratigraphy

All lithological units cropping out within the study area range in age between Paleozoic and Quaternary. These are Eşme Formation (Paleozoic), Musadağı Marbles (Paleozoic), Kırkbudak Formation (Upper Triassic), Kızılcasöğüt Formation (Jurassic), Özbeyli Metaophiolite (Upper Cretaceous), Vezirler Mélange (Upper Cretaceous), Baklan granite, Kürtköy Formation (Miocene), Yeniköy Formation (Miocene), Karacahisar volcanics, Ahmetler Formation (Pliocene), Beydağı volcanics, Ulubey Formation (Pliocene), Asartepe Formation (Pliocene) and Quaternary deposits. Schists and gneisses of Eşme Formation form the crystalline basement of the basin (Yazıcıgil et al., 2008). Ercan et al. (1978) describes the lihtology of Musadağı Marbles as in general white colored and locally dolomitic marbles. Kırkbudak Formation is a fining upward sequence which is made up of the alternation of sandstone, siltstone and claystone (Akdeniz and Konak, 1979). Kızılcasöğüt Formation is made up of grey, blue and white colored dolomitic limestones (Ercan et al., 1978) having a thickness of maximum 100 m (Caran, 1999). Özbeyli Metaophiolite composes three major lithologies such as metagabbro, serpantinite and schists (Caran, 1999). Vezirler Mélange is basically made up of blocks of several lithologies including ultramafic rocks, radiolarian chert, cherty limestone, spilitic masses and marbles (Ercan et al., 1978). Vezirler Mélange tectonically overlies the older units (Eşme, Musadağı, Kırkbudak ve Kızılcasöğüt) and it is unconformably overlain by Kürtköy Formation of Miocene age (Yazıcıgil et al., 2008). Baklan granite is made up of quartz, plagioclase, K-feldspar, amphibole and biotite (Minareci, 2005). Kürtköy Formation is a fining upward sedimantary sequence including conglomerates, sandstones and siltstones (Yazıcıgil et al., 2008). Yeniköy Formation is in general made up of fluvial sedimets and locally lacustrial sediments of sandstone, claystone, siltstone and limestone (Yazıcıgil et al., 2008). Ahmetler Formation, which is composed of three Merdivenlikuyu, Balçıklıdere and Gedikler Members ((Ercan et al., 1978) is a fining upward sequence made up of conglomerates, sandstone, tuffite, claystone and marn (Yazıcıgil et al., 2008). Ulubey Formation is made up of lacustrial limestones, locally intercalated by marn. Thickness of Ulubey Formation is defined as 250 m in the locality of Ulubey by Ercan et al. (1978) and it is defined as 50 m in the northeast of Sivaslı by Caran (1999), which implies that thickness of this unit is thinner along the basin boundaries (Yazıcıgil et al., 2008). Asartepe Formation is made up of alternating conglomerates and sandstones having a maximum thickness of 200 m which can be observed along the boundaries of the basin (Yazıcıgil et al., 2008). Quaternary deposits include older alluvium, talus-fan deposits, travertine and present alluvium. There are two volcanic activities, Karacahisar volcanics are the products of the older volcanism, whereas Beydağı volcanics are the products of the younger one. The geological map of the study area showing the areal distribution of these units is shown in Figure 2.7. The stratigraphic sequence of the basin is shown in the generalized columnar section given in Figure 2.8. Six geological cross-sections are produced combining data from surface geology and well logs (Figure 2.9). Alignments of these cross-sections are shown in Figure 2.7.

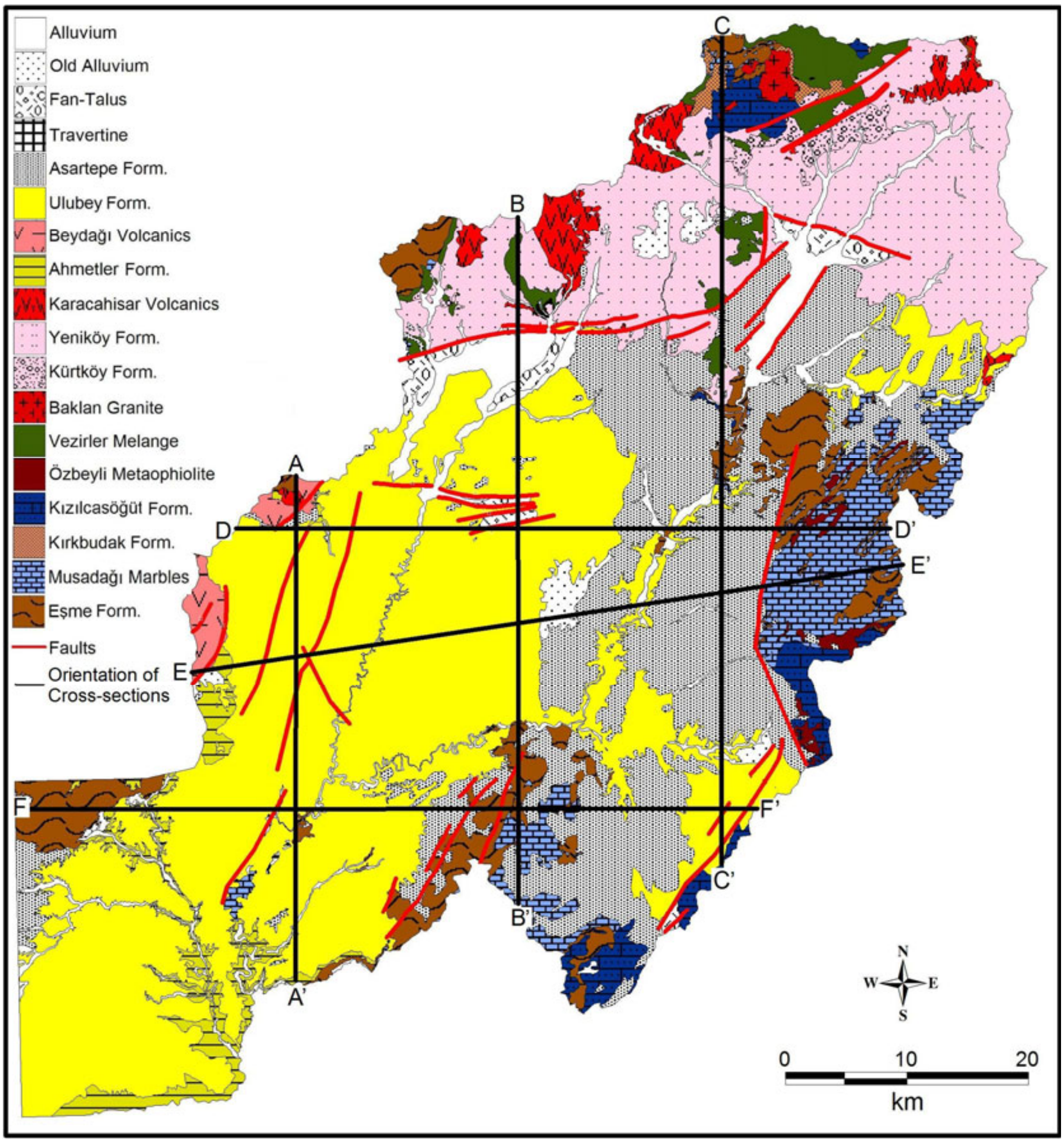


Figure 2.7 Geological map of the study area (Yazıcıgil et al., 2008)

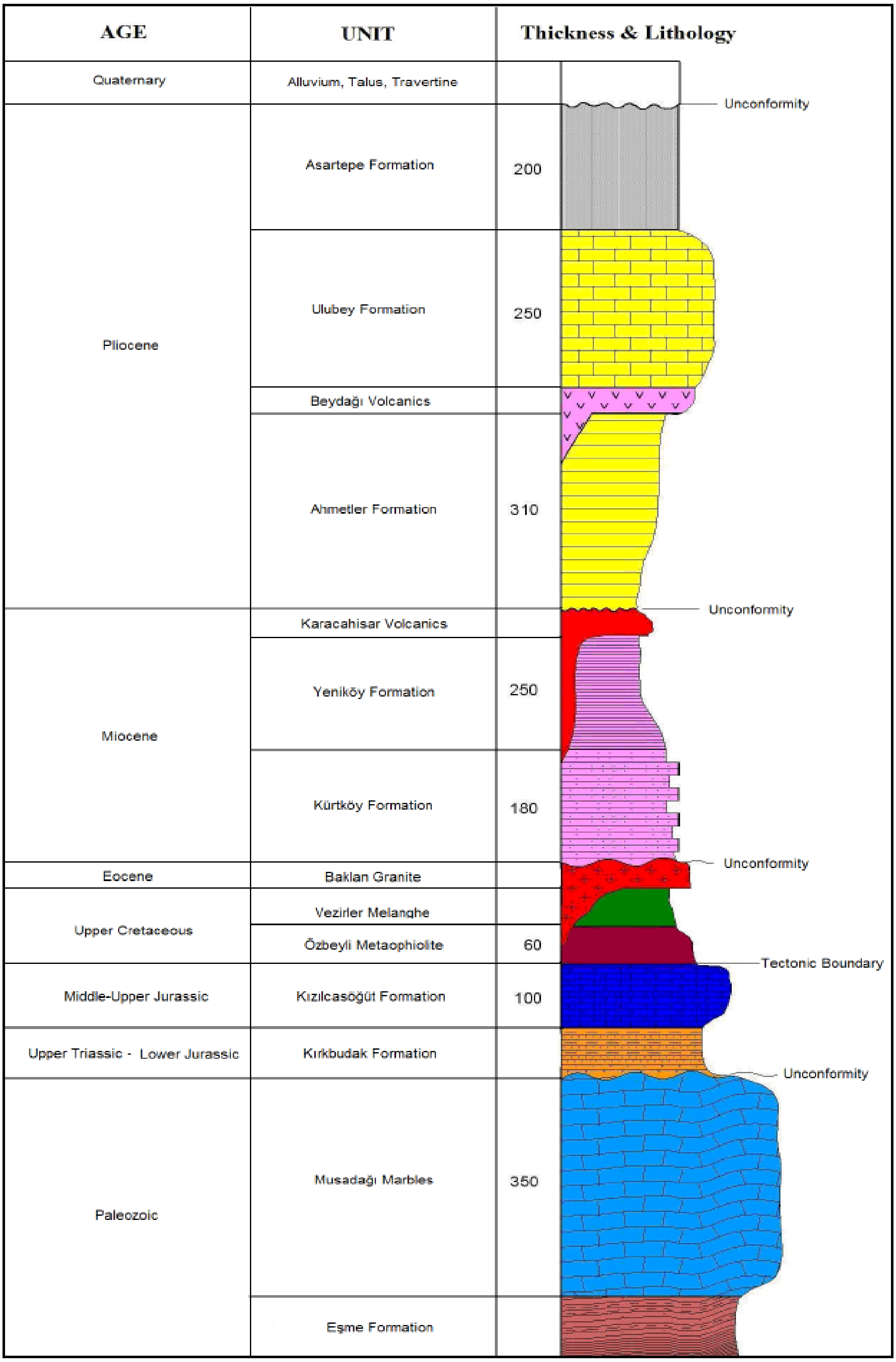


Figure 2.8 Generalized columnar section of the study area (Yazıcıgil et al., 2008)

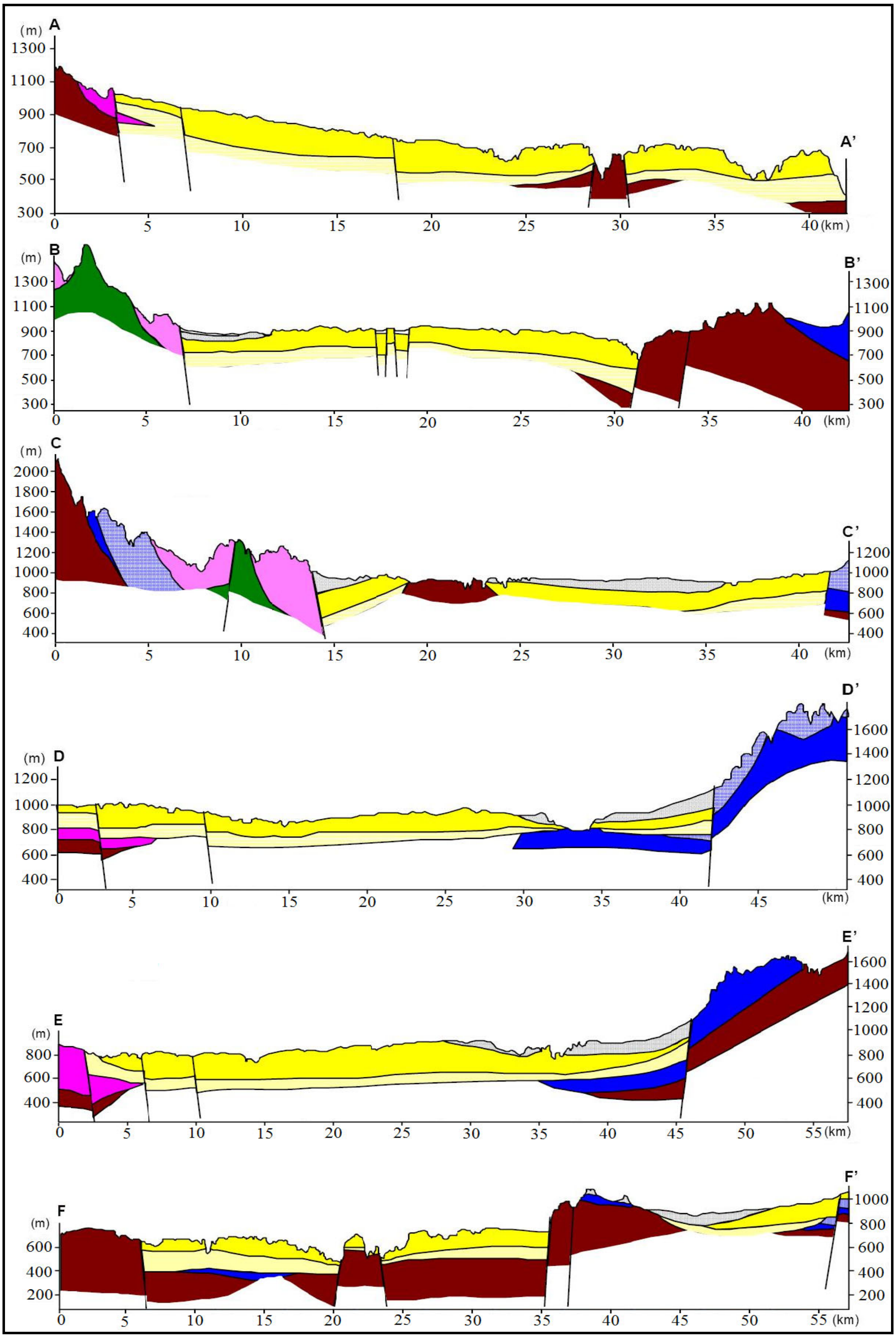


Figure 2.9 Geological cross-sections of the study area (Yazıcıgil et al., 2008)

2.3.2 Structural Geology

The most important structural elements within the study area are faults, which can be classified into two groups according to their alignments as NE-SW and E-W. The locations of these faults are shown on the geological map given in Figure 2.7.

İnay and Karin Faults are the major NE-SW aligned faults, which were also recognized in the previous studies (Kadıoğlu, 1993). These faults are located in the west of Ulubey and they are oriented parallel to each other with a distance of approximately 3 km. Significant amount of groundwater discharge along these faults. Both of these faults can partially be observed on the surface and they are predicted to be buried under Ulubey Formation (Yazıcıgil et al., 2008).

The rest of the faults aligned NE-SW are clustered in three localities. First of these clusters is observed in the eastern parts of the study area between Sivaslı and Çivril. This cluster of faults forms the boundary between units older than Pliocene (metamorphics and metaophiolites) and Pliocene aged units (Ahmetler, Ulubey, and Asartepe Formations). Eastern blocks of these faults are uplifted. It is known that this cluster had an important role in the evolution of the Banaz Stream Basin (Yazıcıgil et al., 2008). However, it is not certain if this cluster is currently active or not. Alluvial fans in the northeast of Sivaslı indicate that activity of these faults might have continued even after Pliocene. Second fault cluster is located in the west of Karahallı. This cluster has almost the same alignment and similar characteristics with the first cluster. Third fault cluster is located in the west of İnay Fault, generally along Beydağı volcanics. These faults form the western boundary of study area, and eastern blocks of them are descended downward (Yazıcıgil et al., 2008).

These three fault clusters produce a graben structure in the Banaz Stream Basin. This graben, in which Ahmetler, Ulubey, Asartepe Formations deposited, started to evolve in Pliocene. There are minor horst-graben structures within this large graben. Outcrops of Eşme Formation and Musadağı marbles in the south of

Ulubey might belong to such a horst structure. However, as these structures do not cross-cut Ulubey Formation, it can be implied that they are buried and recently inactive (Yazıcıgil et al., 2008).

E-W aligned faults, which are structurally significant, have not been recognized in the previous studies. This fault cluster outcropping along Uşak-Banaz line is younger than the other structures within the study area. Only a part of this fault cluster forming a belt could be mapped within the scope of project conducted by Yazıcıgil et al., (2008). Two grabens between Uşak and Ulubey formed by four E-W aligned faults, which have an approximate length of 4 km, provide the best example of this group. These four faults cross cut Ulubey formation and produce two grabens that are filled with Quaternary clastics (Yazıcıgil et al., 2008).

CHAPTER 3

HYDROGEOLOGY

3.1 Water Resources

3.1.1 Surface Water Resources

The major surface water resources within the study area are Banaz Stream which joins Büyük Menderes River on the south of the study area, Yavu Stream which joins Banaz Stream on the south of Ulubey and their tributaries: Kusura, Dokuzsele, Gürlek, Bulkaz, Değirmenönü and Çimenli Creeks (Figure 3.1). There are also a number of perennial streams which flows only in rainy seasons.

In order to determine groundwater potential of the basin, flow measurements are performed at critical locations on Banaz and Yavu Streams by DSİ. Monitoring studies were carried out during the period of 1986-1992 within the framework of the study "Hydrogeological Survey of Uşak, Banaz, Ulubey, Sivaslı and Karahallı Plains" (Kadıoğlu, 1993). There are also flow measurements performed by EİEİ (General Directorate of Electrical Power Resources Survey and Development Administration) in different time periods. Within the framework of the project "Hydrogeological Investigation and Groundwater Management Plan for Ulubey Aquifer, Uşak" (Yazıcıgil et al., 2008), flow measurements were performed at predetermined locations on a monthly-basis between May and December, 2007. Locations of these monitoring stations are shown on Figure 3.2. Information about these stations such as; coordinates, elevations, operation period and operating institution, are presented in Table 3.1.

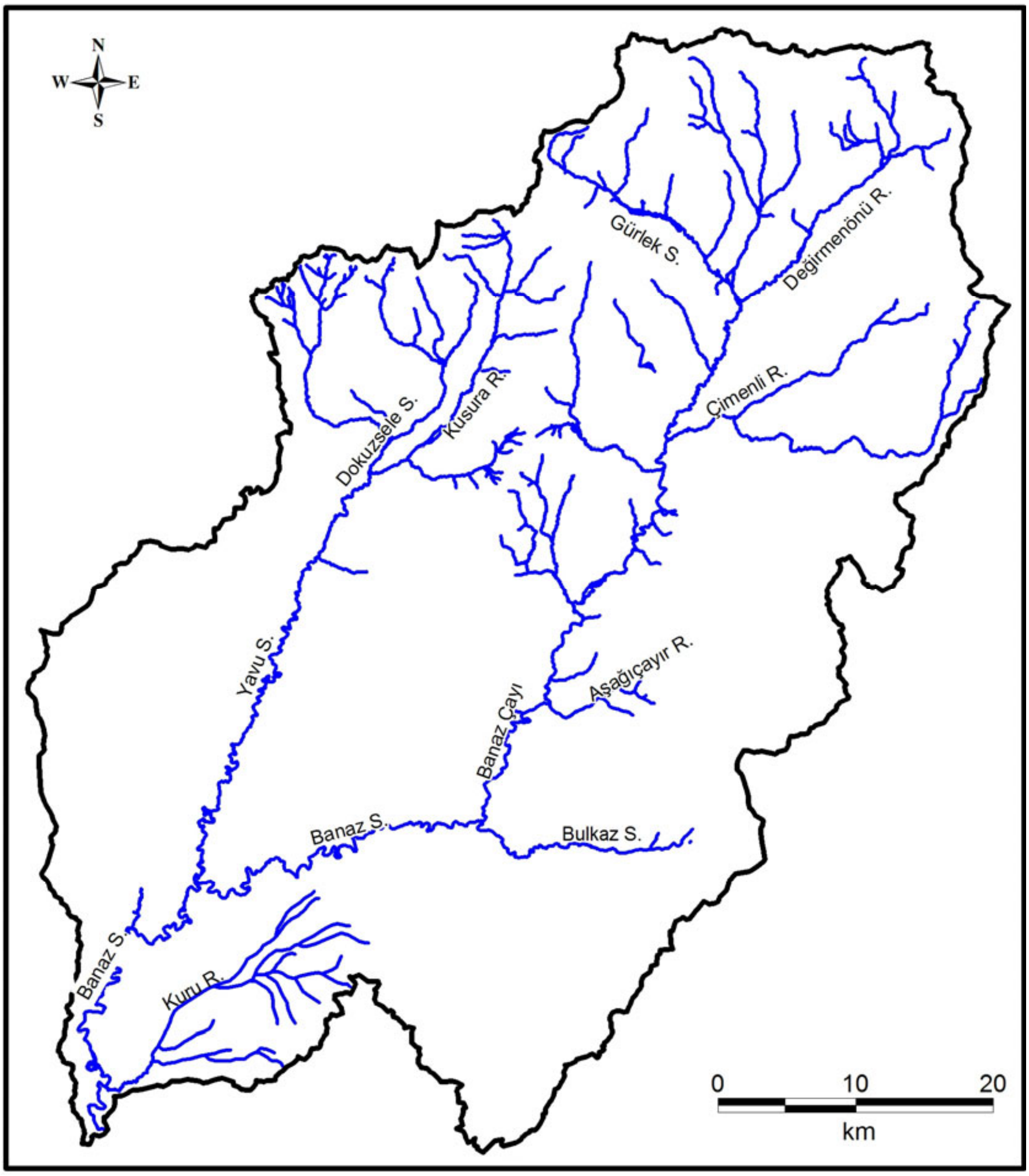


Figure 3.1 Drainage pattern and major surface waters of Banaz Stream Basin

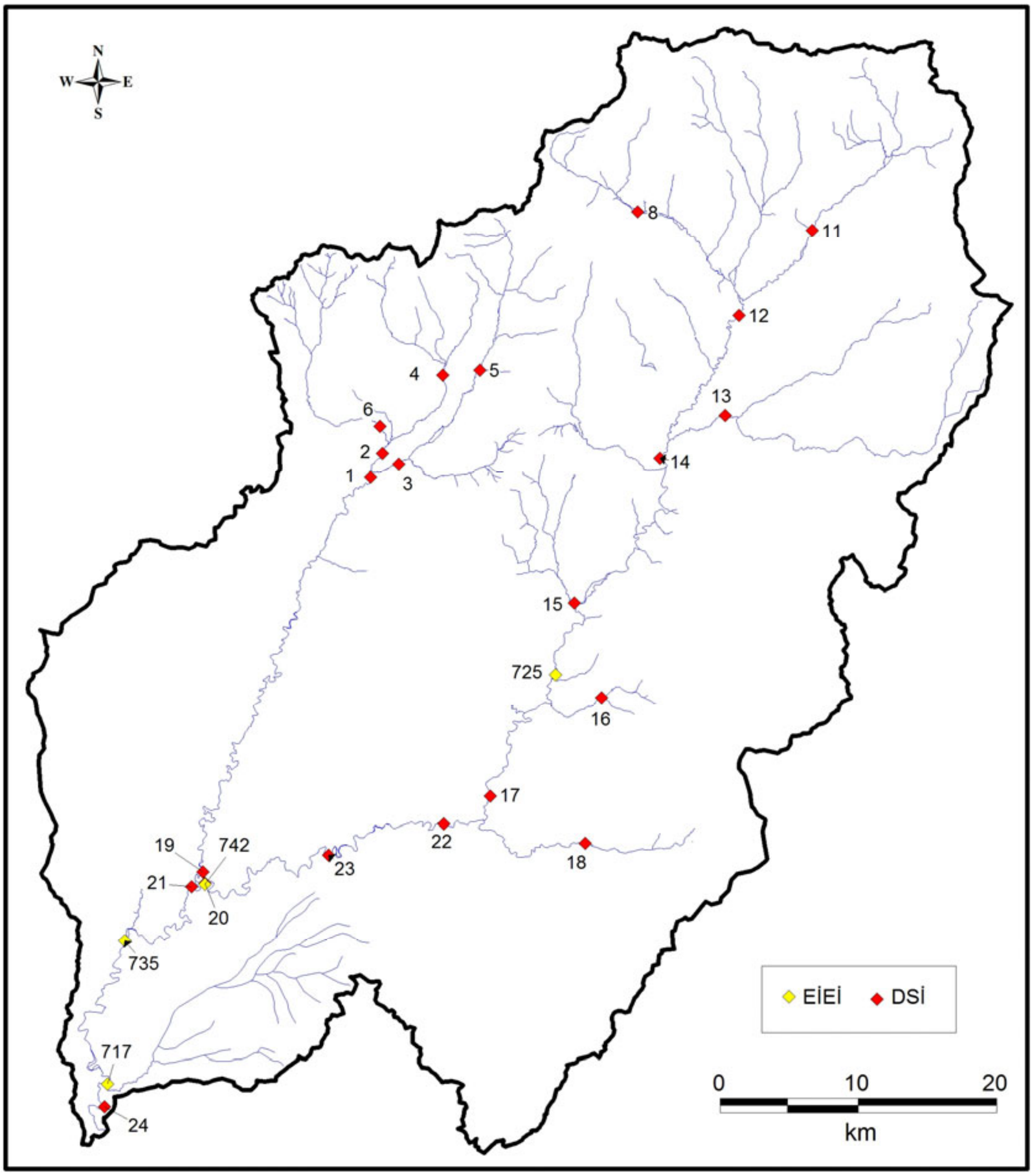


Figure 3.2 Flow monitoring stations within Banaz Stream Basin

Table 3.1 Information about the flow monitoring stations

Station No.	Coordinates		Elevation	Operation Period	Operating Institution
	Easting	Northing			
1	713540	4279460	854	1986-1992, 2007	DSİ
2	714430	4281220	861	1986-1992	DSİ
3	715590	4280440	864	1986-1992	DSİ
4	718820	4286940	889	1986-1992	DSİ
5	721497	4287320	913	1986-1992	DSİ
6	714250	4283200	869	1986-1992	DSİ
8	733000	4298850	1009	1986-1992	DSİ
11	745700	4297500	960	1986-1992	DSİ
12	740380	4291280	902	1986-1992	DSİ
13	739370	4283980	907	1986-1992	DSİ
14	734600	4280850	863	1986-1992, 2007	DSİ
15	728400	4270280	782	1986-1992, 2007	DSİ
16	730360	4263340	879	1986-1992	DSİ
17	722280	4256150	711	1986-1992, 2007	DSİ
18	729160	4252700	829	1986-1992	DSİ
19	701350	4250620	519	1986-1992, 2007	DSİ
20	701480	4249800	518	1986-1992, 2007	DSİ
21	700540	4249550	519	1986-1992, 2007	DSİ
22	718900	4254130	679	1986-1992, 2007	DSİ
23	710500	4251850	589	1986-1992, 2007	DSİ
24	694200	4233500	385	1986-1996	DSİ
717	694407	4235156	395	1963-1972	EİEİ
725	727019	4265039	760	1972-2002	EİEİ
735	695663	4245581	475	1988-2000	EİEİ
742	701487	4249735	531	2000-2004	EİEİ

Long term average monthly and annual flow rates recorded at these stations are presented in Table 3.2. Figure 3.3 represents the hydrograph of station number 735, which has a drainage area of 3226.6 km^2 and has an operation period 1988-2000. The average flow rate recorded at this station is 5.39 m^3/s or 169.9 hm^3/year.

Table 3.2 Average monthly flow rates recorded at the flow monitoring stations within Banaz Stream Basin (m^3/s)

Station Number	Months											
	X	XI	XII	I	II	III	IV	V	VI	VII	VIII	IX
1	0.241	0.304	0.259				0.700	0.486	0.388	0.331	0.185	0.149
2	0.182	0.238	0.325				0.757	0.631	0.318	0.281	0.128	0.105
3	0.001	0.177	0.000				0.345	0.094	0.023	0.009	0.007	0.000
4	0.000	0.000	0.037				0.231	0.126	0.033	0.000	0.000	0.000
5	0.028	0.301	0.039				0.135	0.111	0.020	0.028	0.040	0.039
6	0.173	0.235	0.181				0.324	0.368	0.252	0.157	0.137	0.121
8	0.330	0.342	0.478				1.012	0.593	0.447	0.242	0.166	0.196
11	0.025	0.042	0.044				0.624	0.482	0.228	0.050	0.002	0.002
12	0.330	0.870					3.506	1.843	0.865	0.078	0.017	0.014
13	0.257	0.287	0.384				1.322	1.062	0.139	0.011	0.009	0.048
14	0.471	0.820	1.604				2.582	1.481	0.926	0.092	0.028	0.043
15	0.394	1.159	2.307				3.053	1.594	0.910	0.052	0.000	0.005
16	0.109	0.228					0.231	0.150	0.077	0.041	0.018	0.044
17	0.929	1.861	2.762				4.127	2.217	1.280	0.655	0.652	0.717
18	0.012	0.015	0.000				0.097	0.051	0.000	0.000	0.001	0.000
19	0.489	0.627	0.622				1.047	0.618	0.501	0.297	0.265	0.343
20	2.658	3.736	4.306				4.984	3.488	3.468	2.597	2.231	2.738
21	2.759	4.351	4.988				6.021	4.124	4.205	2.803	2.524	2.925
22	1.970	2.019	3.096				3.975	2.524	1.807	1.193	1.153	1.666
23	2.087	2.473	3.383				4.587	2.789	2.390	1.560	1.828	1.828
24	3.108	4.606	5.589			9.006	6.014	5.118	4.728	3.042	3.228	3.387
717	7.379	7.902	14.432	20.728	23.379	27.191	21.641	17.807	10.929	6.830	5.701	6.242
725	0.488	1.400	2.992	4.062	5.683	6.264	7.683	4.334	1.742	0.325	0.052	0.092
735	2.878	3.974	5.477	5.329	7.910	8.548	11.819	7.658	3.909	2.498	2.275	2.365
742	2.535	2.838	4.023	4.458	4.618	5.680	8.455	6.065	3.435	2.468	2.308	2.412

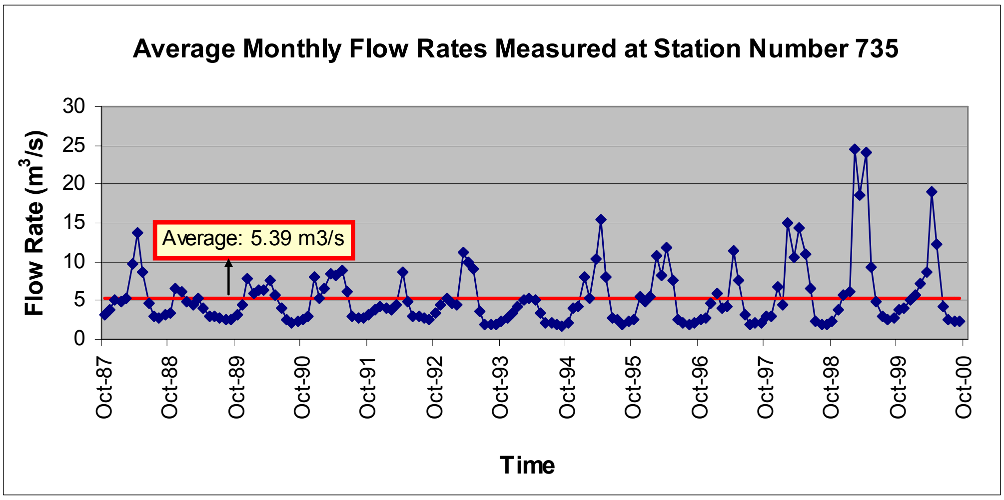


Figure 3.3 Hydrograph of station number 735

3.1.2 Springs

Groundwater in the basin is drained by a number of springs. Some of these springs are located along Banaz and Yavu Streams (Avgan, Cabar, Uyuz, Kocapınar, Hasköy); and some of them are located on the plains (Gürpınar, Evren, Pınarbaşı1, Pınarbaşı2, Sazak, Sarıkız, İnay, Sivaslı1, Sivaslı2). Information about these springs such as; coordinates, elevations, units they emerge and average discharge rates are presented in Table 3.3. The distribution of these springs within the Banaz Stream Basin is shown on Figure 3.4. Figure 3.5 shows the distribution of groundwater discharge from springs based on their locations.

Table 3.3 Information about the springs

Spring Name	Coordinates		Elevation	Unit	Average Discharge (L/s)
	Easting	Northing			
Gürpınar	737634	4255019	949	Alluvium	260
Pınarbaşı 1	734562	4262878	939	Alluvium	21
Pınarbaşı 2	736470	4262483	1092	Alluvium	22
Evren	736148	4263813	1030	Asartepe	34
Sazak	729850	4265520	880	Asartepe	8
Avgan	702109	4249863	521	Ulubey	243
Sarıkız	696824	4249181	539	Ulubey	172
Cabar	722500	4257500	715	Ulubey	493
İnay	693574	4255946	705	Ulubey	8
Kocapınar	701363	4254525	572	Ulubey	12
Uyuz	717690	4254230	689	Ulubey	70
Hasköy	715667	4253917	647	Ulubey	15
Sivaslı 1	733606	4272004	883	Ulubey	1
Sivaslı 2	734007	4271898	895	Ulubey	10

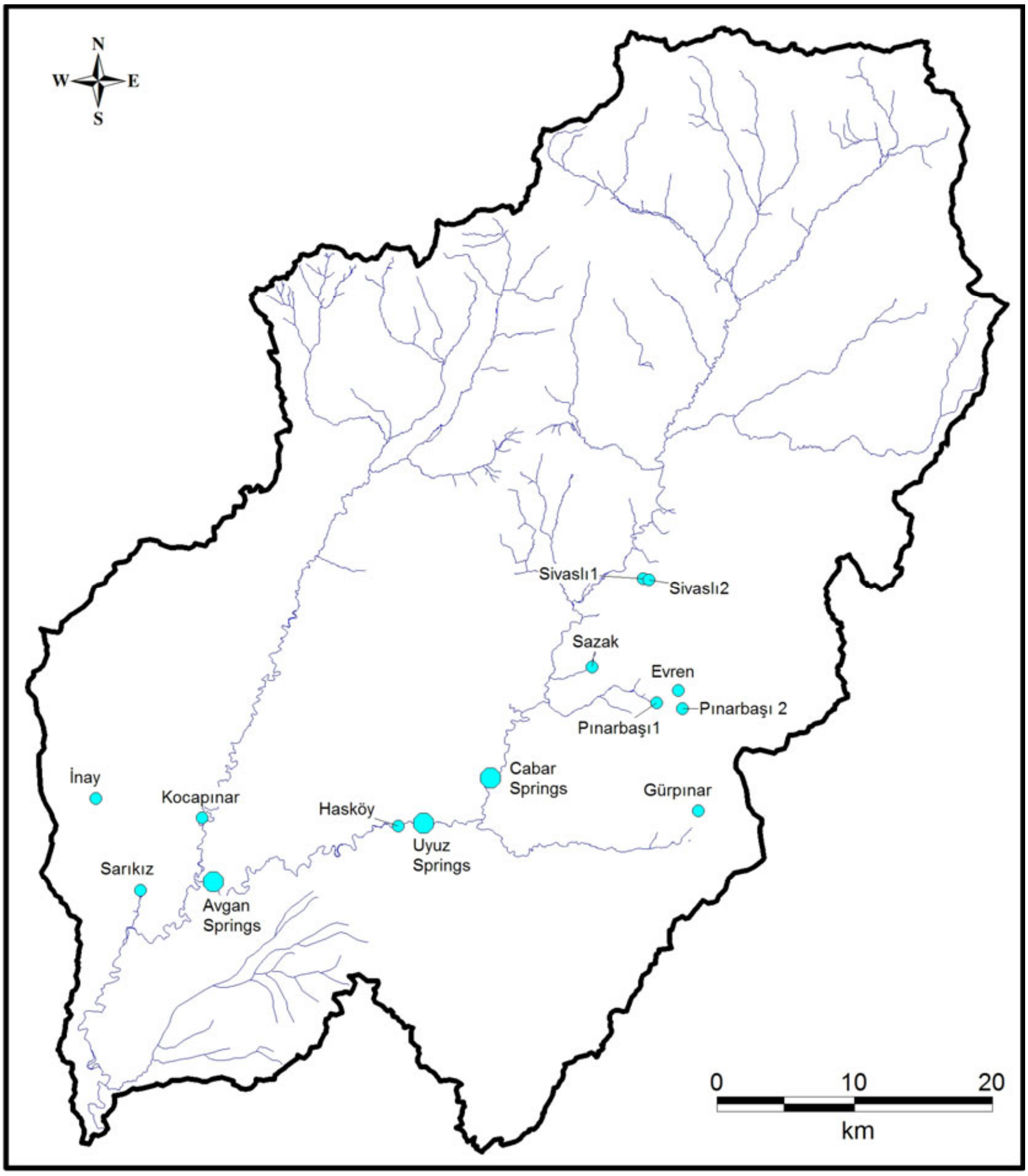


Figure 3.4 Springs within Banaz Stream Basin

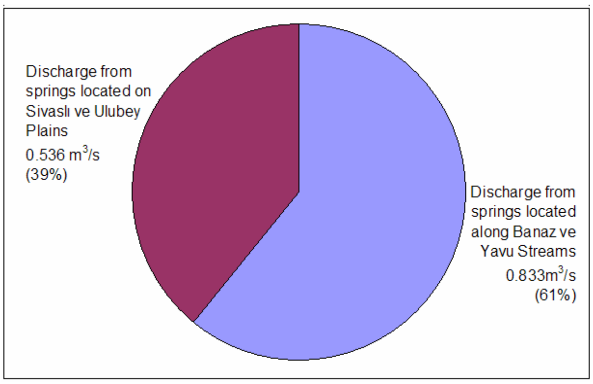


Figure 3.5 Distribution of groundwater discharge from springs based on their locations

As it is shown on Table 3.3 and Figure 3.5, most of the groundwater in the basin is discharged through the springs that are located along Banaz and Yavu Streams, and remaining part is discharged through the springs that are located on Sivaslı and Ulubey Plains. Avgan and Cabar Springs have high discharge rates and they discharge groundwater from several points along Banaz Stream instead of single point. Springs located on Sivaslı Plain (Gürpınar, Sivaslı1, Sivaslı2, Evren, Sazak, Pınarbaşı1, Pınarbaşı2) are formed by the intersection of topography and clayey layers below conglomerates. On the other hand, springs located on Ulubey Plain (İnay, Sarıkız) are formed by fault-controlled karstification (Yazıcıgil et al, 2000).

Within the scope of hydrogeological investigation study of Uşak, Banaz, Ulubey, Sivaslı and Karahallı Plains, springs that are thought to be important were included in monitoring program by DSİ. Discharge rates of Gürpınar, Evren, Pınarbaşı1, Pınarbaşı2 and Sazak Springs were recorded in the period 1985-1988. In 1986, İnay and Sarıkız Springs were also included in the monitoring program and their discharge rates were recorded in the period 1986-1988. According to the results of this monitoring program, Gürpınar (352 L/s) and Sarıkız (188 L/s) Springs were determined to have the highest discharge rates within the basin and since 1989, discharge rates of these springs have been measured twice a year, one in wet season (April) and one in dry season (October). Moreover, within the scope of project “Hydrogeological Investigation and Groundwater Management Plan for Ulubey Aquifer, Uşak” discharge rates of İnay and Sarıkız Springs were measured between May-October 2007 (Yazıcıgil et al., 2008).

Total amount of groundwater discharged by all springs within the basin is 43.17 hm^3 annually on the average. Around 75% of this discharge is from Ulubey aquifer and remaining 25% is from Asartepe Formation and alluvium (Figure 3.6).

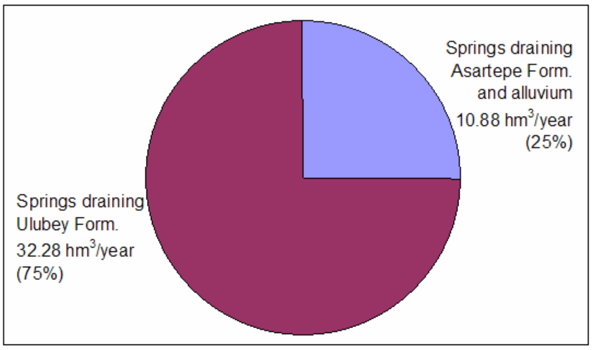


Figure 3.6 Distribution of groundwater discharge on the base of units drained

3.1.3 Surface Water Reservoirs

Adıgüzel Dam, constructed by DSİ, is the largest reservoir in the study area. It is located in the south of the study area where Banaz Stream joins Büyük Menderes River (Figure 3.7). Construction of this dam started in 1976 and completed in 1989. It has a water volume of 1076 million m^3 and capable of irrigating an area of 89600 hectares. Annual energy potential of the dam is 280 GWh. There are also many small dams within and around the study area constructed by DSİ and Rural Services (Rural Services) for irrigational purposes. Areas irrigated by these small dams constructed by DSİ and Rural Services are listed on Table 3.4. Locations of the small dams that could be detected from satellite images are shown on Figure 3.7.

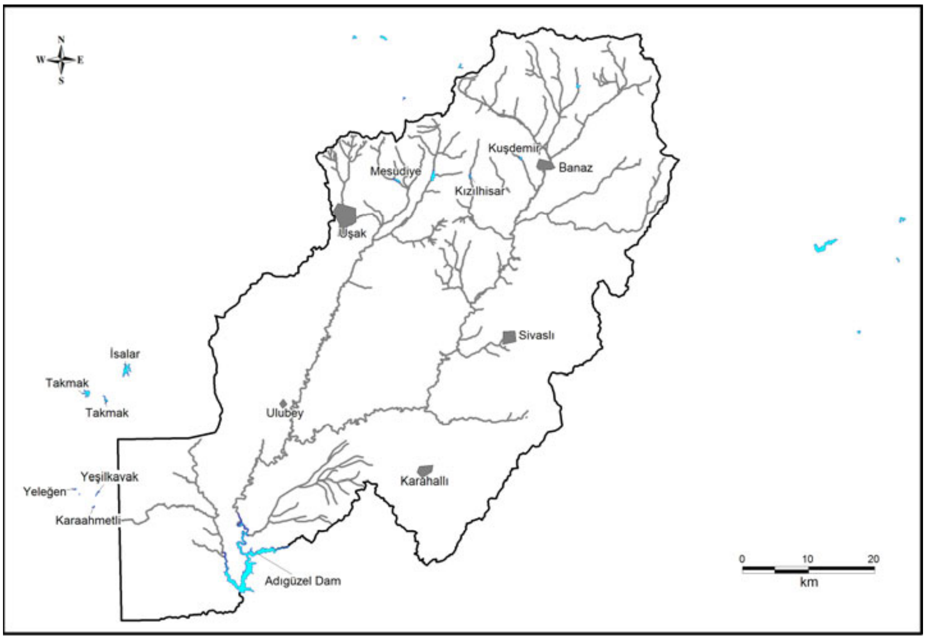


Figure 3.7 Locations of surface water reservoirs

Table 3.4 Information on small dams for irrigation

Name	Constructed by	Irrigated Area (ha)
Eşme - Takmak	DSİ	237
Eşme - Üçpınar	DSİ	205
Eşme - Karaahmetli	DSİ	15
Eşme - Karaağaç	DSİ	139
Eşme - Güneyköy	DSİ	42
Mesudiye	DSİ	315
Eşme - Ahmetler	DSİ	63
Kozviran	DSİ	565
İsalar	DSİ	114
Banaz Ahat	DSİ	557
Kuşdemir	Rural Services	132
Güven	Rural Services	708
Yeniceköy	Rural Services	135
Baltak	Rural Services	165
Takmak	Rural Services	164
Yeşilkavak	Rural Services	97
Yeleğen	Rural Services	180
Kızılhisar	Rural Services	124

3.1.4 Wells

There are more than 800 wells within and around the Banaz Stream Basin which are drilled by DSİ, Bank of Provinces, Rural Services, municipalities and individuals for various purposes.

Logs of 71 wells, which have been drilled since 1960's for exploration, drinking-domestic supply and irrigational purposes, are acquired from DSİ. Logs of 64 wells, which are drilled to meet drinking-domestic water needs of municipalities within and around the study area, are obtained from Bank of Provinces. There are 123 wells by General Directorate of Rural Services to meet drinking water needs of the villages but only logs of 64 of these could be obtained. Finally, a groundwater data base including information on 197 wells have been developed.

There exist many wells drilled by individuals, municipalities and private institutions to meet irrigational, drinking and domestic water needs. By April 2007, 611 registered wells were determined in records of 2nd District Office of DSİ. 372 of these wells, whose coordinates could be determined and which are located within the study area, are shown in Figure 3.8.

Location of the wells drilled by DSİ, Bank of Provinces and Rural Services are also shown in Figure 3.8. Among these wells, the ones that are not dry are classified according to two criteria: unit(s) which the well takes water and institution which drilled the well (Table 3.5). Figures 3.9 through 3.13 represent the distribution of wells according to the year they were drilled. There is a rapid increase in the number of wells drilled after the year 1990. This is probably a consequence of declining groundwater levels and increasing demand on groundwater for irrigational purpose due to drought.

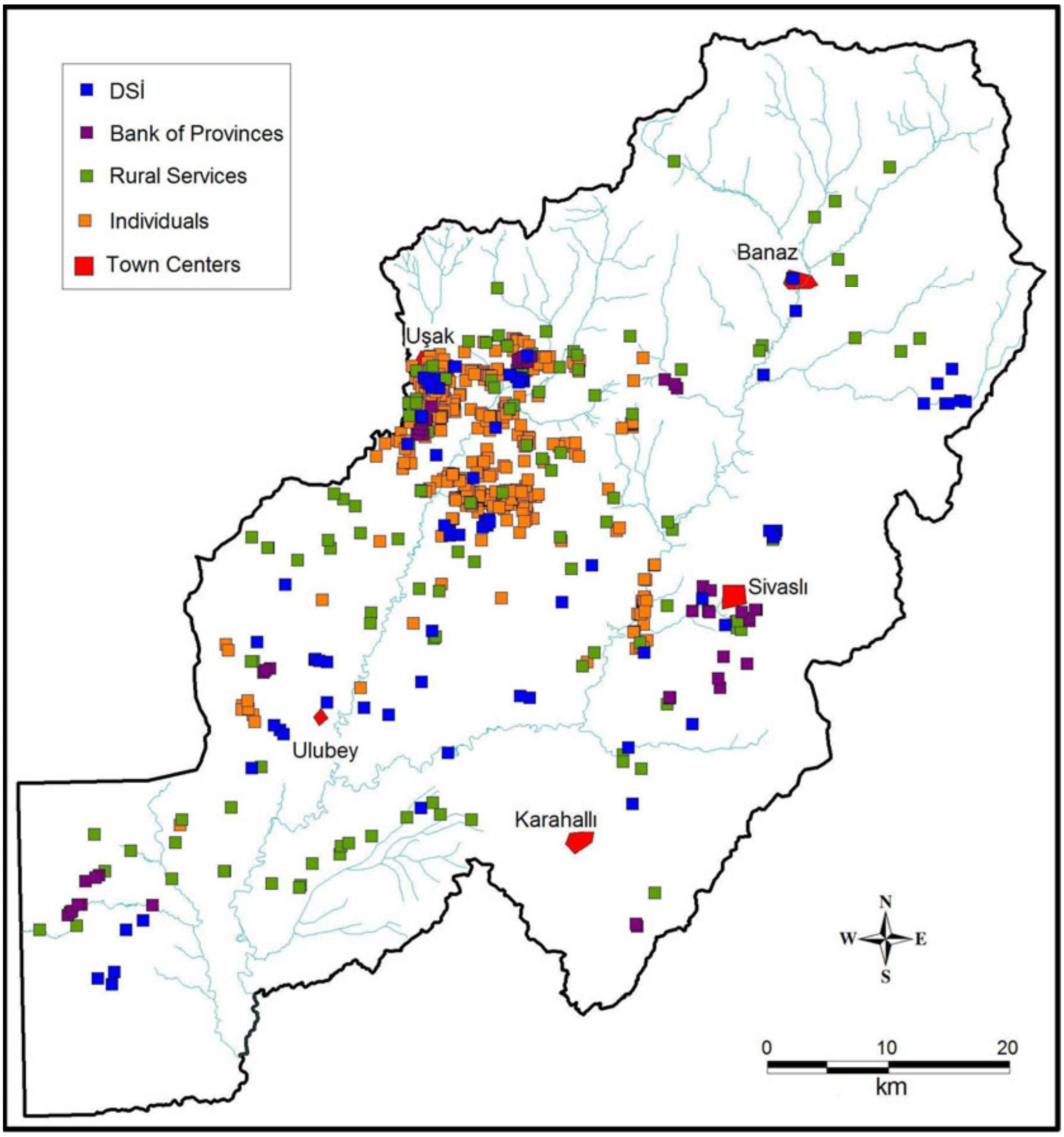


Figure 3.8 Wells located within the study area

Table 3.5 Information about wells within the study area

Unit	DSİ	Bank of Provinces	Rural Services	Total
Alluvium	6	14	0	20
Asartepe	6	13	0	19
Ulubey	29	8	20	57
Ahmetler	0	5	4	9
Musadağı	7	2	1	10
Eşme	1	1	0	2
Ulubey - Ahmetler	6	1	5	12
Alluvium - Ulubey	0	1	0	1
Alluvium - Eşme	0	0	1	1
Asartepe - Ulubey	2	2	0	4
Asartepe - Musadağı	0	1	0	1
TOTAL	57	48	31	136

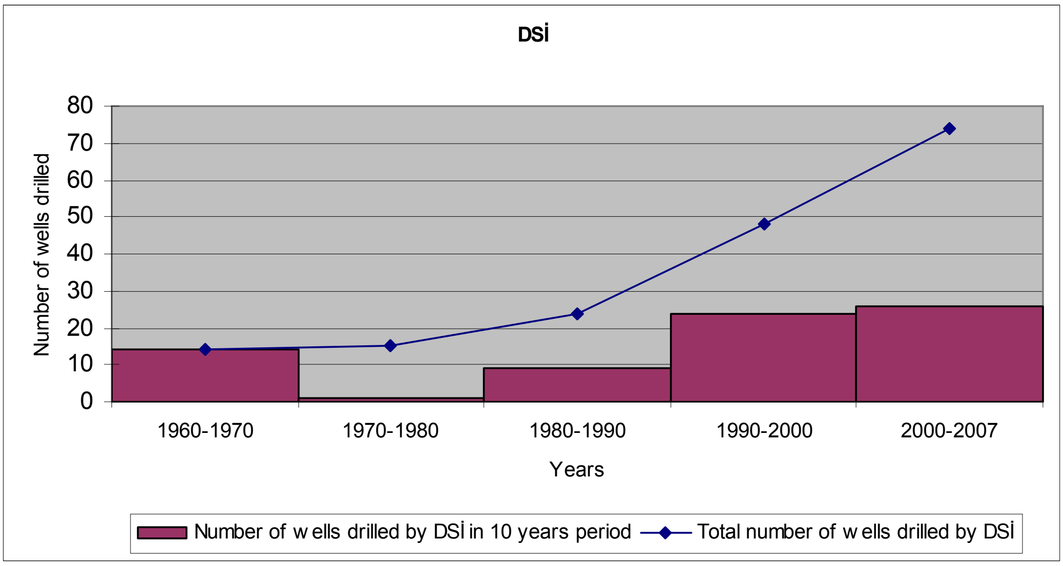


Figure 3.9 Number of wells drilled by DSİ

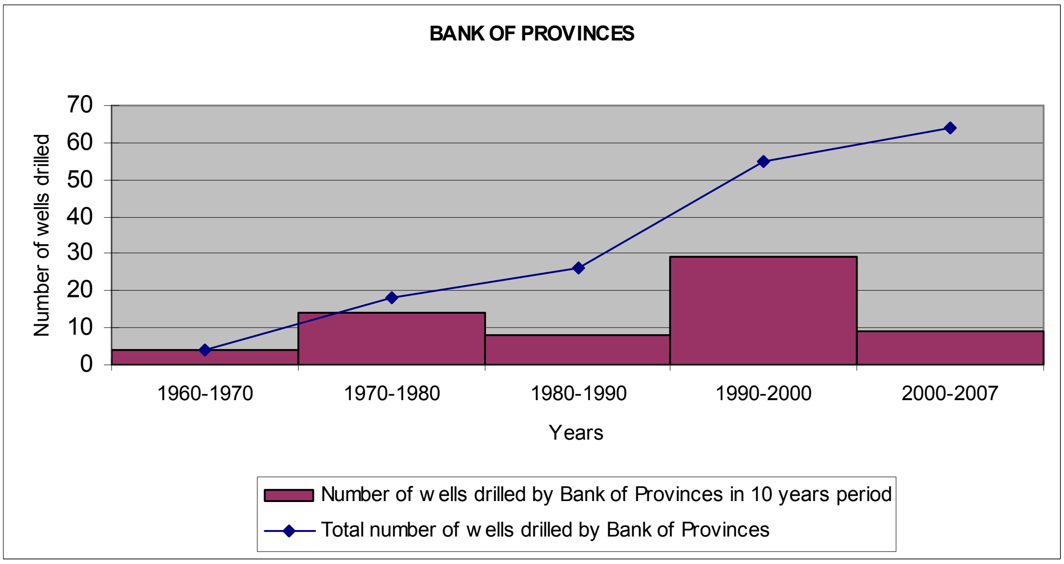


Figure 3.10 Number of wells drilled by Bank of Provinces

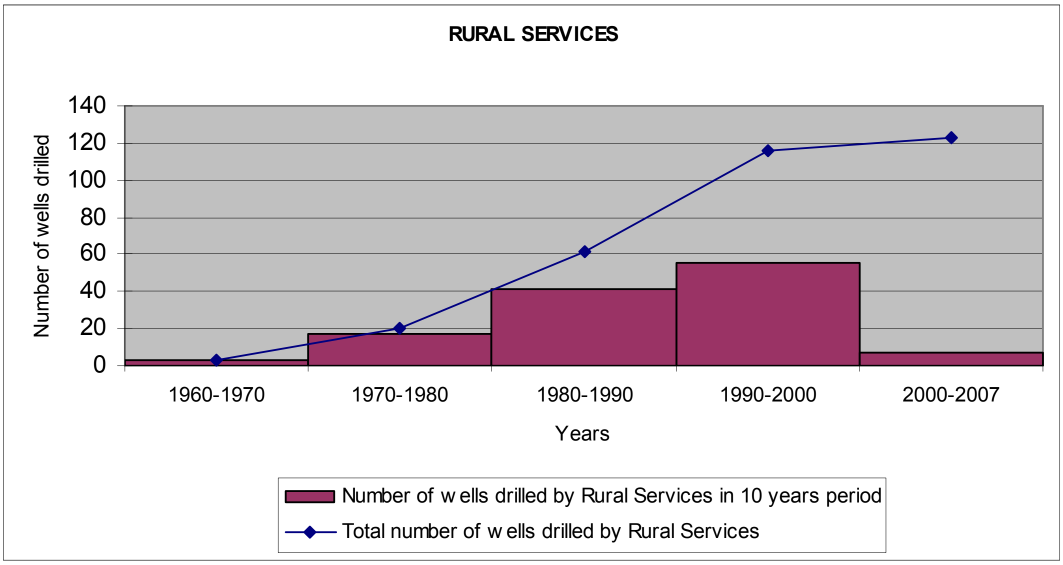


Figure 3.11 Number of wells drilled by Rural Services

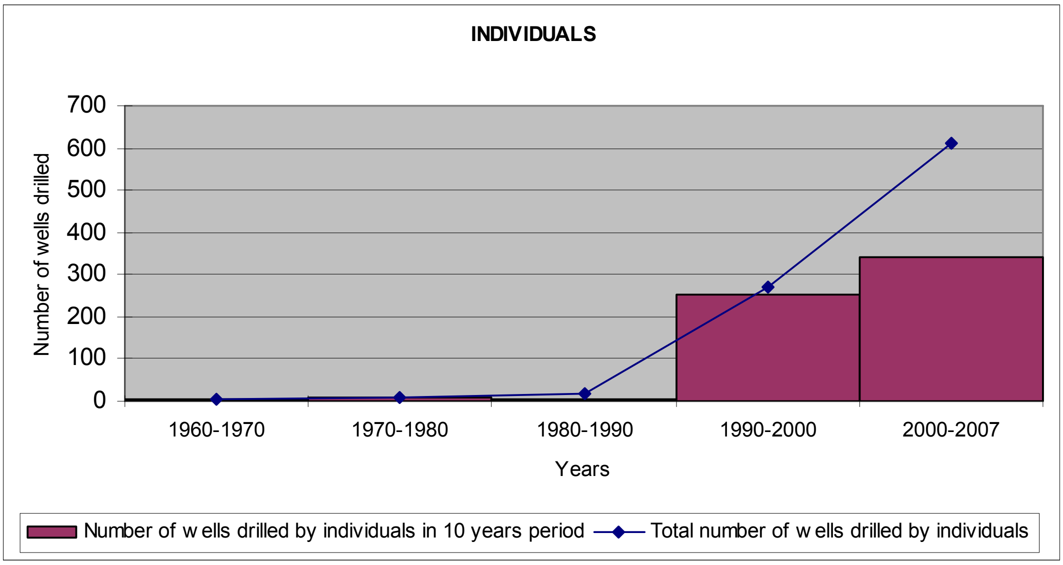


Figure 3.12 Number of wells drilled by individuals

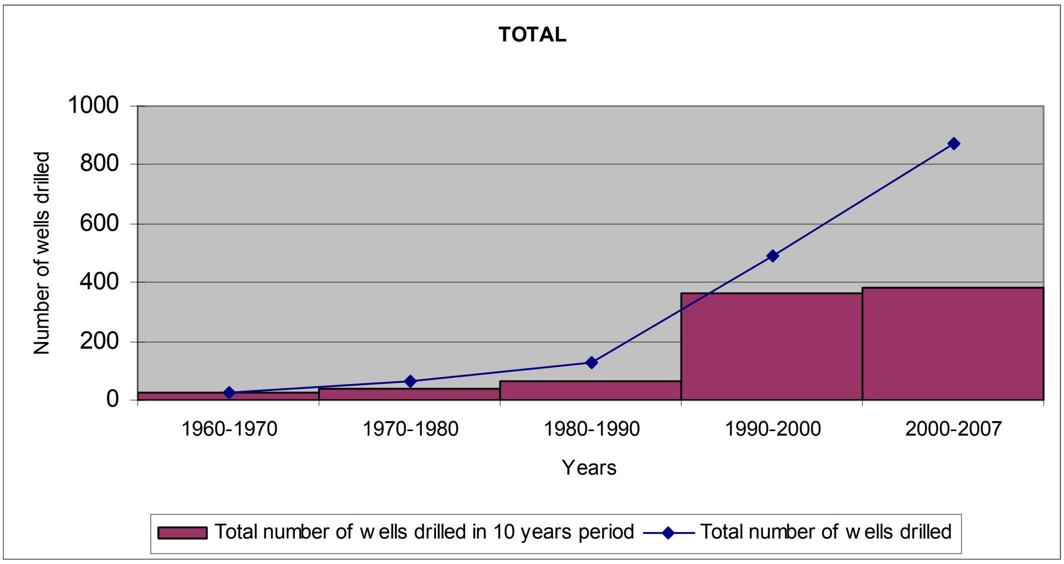


Figure 3.13 Total number of wells

3.1.4.1 Irrigational Cooperatives

Within the basin, there are 11 irrigational cooperatives planned by DSİ. Only one of them is functioning currently and the rest is in different stages of development. Areas and development stages of these cooperatives by April 2007 are presented in Table 3.6. Figure 3.14 shows the distribution of these cooperatives within the basin. Examining the feasibility reports and well data obtained from DSİ, it is determined that 4 wells in Yazıtepe (52724-B, 52725, 52726, 40017-C), 4 wells in İkisaray (52727, 52728, 52729, 52730), 4 wells in Selikler (55074, 55075, 55076, 35071), 5 wells in Susuzören (58156, 58908, 58909, 58910, 58911), 1 well in Çoğuplu (58912), 3 wells in Eldeniz (58279, 58280, 58282) were drilled by DSİ for irrigational purposes. Among these wells 40017-C, 35071 and 58156 were drilled initially for exploration but later they have been utilized for irrigational purposes.

Table 3.6 Information about irrigational cooperatives within the basin

Name	Area(ha)	Development Stage
Yazıtepe	80	Functioning.
İkisaray	40	Wells are drilled. Electrification is completed. Pumps are inserted. Irrigational system will be constructed.
Selikler	100	Wells are drilled. Electrification is completed. Pumps are inserted. Irrigational system will be constructed.
Susuzören	200	Wells are drilled. Electrification, pumps and irrigational system are to be completed.
Çoğuplu	40	Wells are drilled. Electrification, pumps and irrigational system are to be completed.
Eldeniz	80	Wells are drilled. One additional well will be drilled. Electrification, pumps and irrigational system are to be completed.
Budaklar	100	Area to be irrigated is determined. Wells, electrification, pumps and irrigational system are to be completed.
Yayalar	100	Area to be irrigated is determined. Wells, electrification, pumps and irrigational system are to be completed.
Şaban	80	Area to be irrigated is determined. Wells, electrification, pumps and irrigational system are to be completed.
Ovademirler	100	Area to be irrigated is determined. Wells, electrification, pumps and irrigational system are to be completed.
Yavu	100	Area to be irrigated is determined. Wells, electrification, pumps and irrigational system are to be completed.

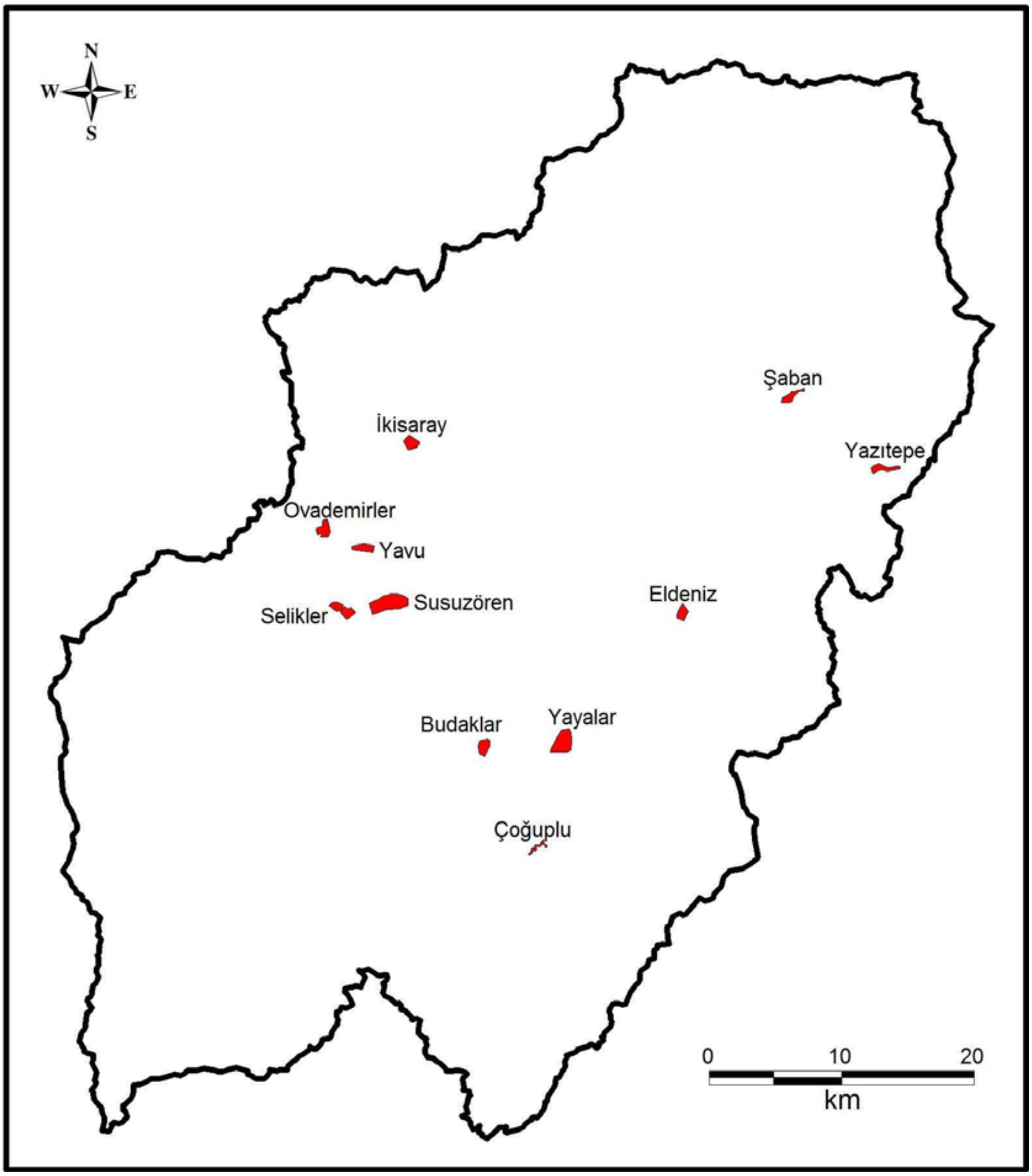


Figure 3.14 Irrigational cooperatives within the basin

3.2 Characterization of Groundwater Bearing Units

In order to determine and characterize groundwater bearing formations within the Banaz Stream Basin, a database is set up comprising of the selected wells drilled by DSİ, Bank of Provinces and Rural Services.

All lithological units within the Banaz Stream Basin are classified into 8 major hydrogeological units according to their groundwater bearing capabilities. Hydrogeological map of the basin is presented in Figure 3.15.

3.2.1 Hydrogeologic Classification of Groundwater Bearing Units

3.2.1.1 Schists and Gneisses (Eşme Formation)

Eşme Formation forms the crystalline basement in the basin. It dominantly outcrops in the north and east of Sivaslı, in the vicinity of Karahallı, in the west of Ulubey and in the north and northeast of Uşak. This unit is classified as poor aquifer because of very low well yields. Yields of the two wells drilled in this formation are 4.0 and 1.0 L/s and their specific capacities are 0.18 and 0.03 L/s/m, respectively. Transmissivity of the unit is calculated as 23.0 m^2/day by examining the results of pumping test performed by DSİ at the well having a yield of 4.0 L/s. Average hydraulic conductivity is determined as 3.8×10^{-7} m/s according to the results of aquifer tests performed at the wells drilled in this formation in western parts of the basin, around Kışladağ locality.

3.2.1.2 Marbles (Musadağı, Kızılcasöğüt Formations)

Marbles that have a broad extension within the study area are Musadağı marbles and Middle-Upper Jurassic aged Kızılcasöğüt Formation.

Musadağı marbles dominantly outcrop in the east of Sivaslı and in the locality of Karahallı. Smaller outcrops are also observed along the base of the deep valleys below Neogene units in the south of Ulubey. They are classified as good

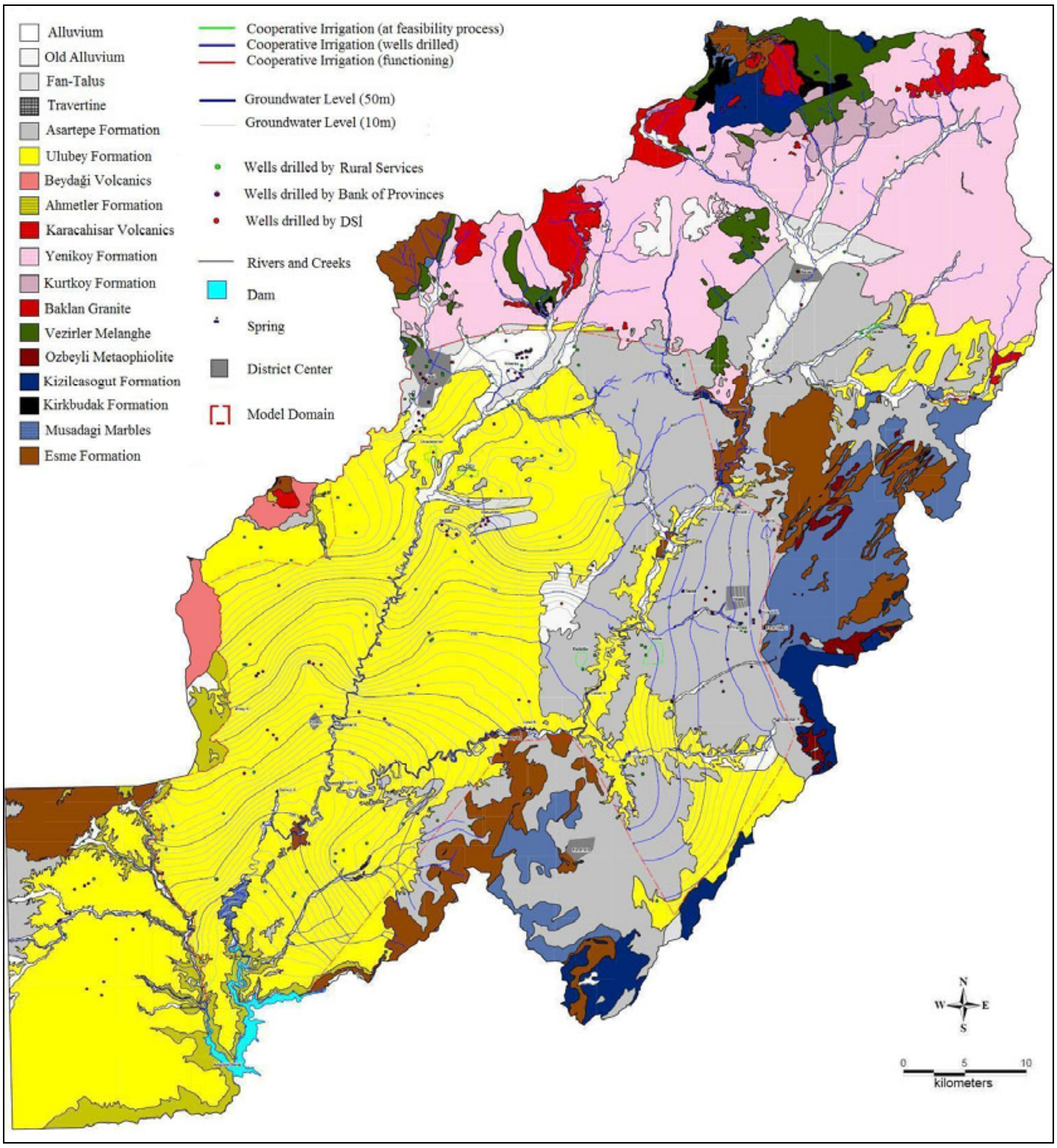


Figure 3.15 Hydrogeological map of the basin (Yazıcıgil et al., 2008)

aquifer because of their karstic properties. According to the results of pumping tests performed by DSİ at seven wells, transmissivity of the unit is determined to range between 5 m^2/day and 11361 m^2/day, while hydraulic conductivity of the unit is determined in the range between $6.0X10^{-7}$ m/s and $1.5X10^{-3}$ m/s.

Kızılcasöğüt Formation outcrops in a few localities in the northern and eastern parts of the study area. In the eastern parts it overlies Musadağı marbles unconformably. Although there is no information about the hydraulic parameters of this unit, it can be said that in hydrogeological aspects, the hydraulic properties of this unit are similar to that of Musadağı marbles.

3.2.1.3 Yeniköy Formation

Outcrops of Yeniköy Formation have a broad extension in the north of Uşak-Banaz line. This formation is dominantly made up of fluvial and lacustrine sediments. There is no well drilled in this formation within the study area that could give information about the groundwater bearing capability of this unit.

3.2.1.4 Volcanics (Beydağı, Karacahisar Volcanics)

Volcanic units that have a broad extension within the study area are Miocene aged Karacahisar volcanics and Pliocene aged Beydağı volcanics. Except an outcrop in the west of the study area, the major outcrops are in the northern parts of the study area, in the vicinity of Murat Dağı. This formation is made up of rhyodacite, lava, tuff and agglomerate. Beydağı volcanics are the younger phase of the volcanic activity in the study area. This unit has small outcrops in the western parts of the study area and outcrops extend further towards the west of watershed divide forming the western boundary of the study area. Beydağı volcanics are made up of lava flow, agglomerates and tuff. This formation has intercalations with Ahmetler and Ulubey Formations. Groundwater bearing capability of the volcanics is very limited. Hydraulic conductivity of this unit is determined between 1.4×10^{-7} and 1.6×10^{-6} m/s according to slug test results performed at the wells drilled in this unit, around Kışladağ in the western parts of the study area.

3.2.1.5 Ahmetler Formation

Outcrops of this formation are dominantly observed along the base of deep valleys in the southwestern parts of the basin. Merdivenlikuyu, Balçıklıdere and Gedikler are the members of Ahmetler Formation. This formation is made up of pebblestone, sandstone, siltstone, tuffite, mudstone, marl and limestone. Fine grained clastics are more dominant in the formation. Groundwater rate extracted from the limited number of wells drilled in this formation is very low. Yields of the wells drilled in this formation range between 0.6 and 17 L/s, and their specific capacities range between 0.07 and 0.48 L/s/m. Pumping test results performed at the wells drilled by Bank of Provinces are evaluated. According to this, transmissivity of this unit is determined in the range between 0.85 and 100 m^2/day and hydraulic conductivity is determined to range between 3.5×10^{-7} and 1.8×10^{-5} m/s. Consequently, Ahmetler Formation is classified as poor aquifer. However, it is important since it forms the impermeable base of the Ulubey aquifer.

3.2.1.6 Ulubey Formation

Ulubey Formation is the major aquifer of the study area having the broadest extension (1700 km^2). This formation has continuous outcrops especially in southern and western parts of the basin. It is made up of thick, very thick and locally massive lacustrine limestones and alternating marl units. Thickness of the unit is around 250 m. Generally bedding is horizontal or close to horizontal. It forms a broad syncline in the vicinity of Ulubey. Formation has a fractured, jointed and karstic structure. Karstic cavities and dissolution driven fractures are very common. Wells having highest yields and springs having highest discharge rates are located within the Ulubey Formation. For 66 wells drilled in this formation, yields range between dry and 50 L/s, average well yield is 13 L/s. Maximum specific capacity calculated for these wells is 71.4 L/s/m and the average specific capacity is 3.3 L/s/m. Results of pumping tests performed at 31 wells drilled by DSİ and Bank of Provinces are evaluated. According to this, transmissivity of this unit is determined to range between 5.2 and 18975 m^2/day and hydraulic conductivity is determined in the range between 4.69×10^{-7} and 2.89×10^{-3} m/s. Geometrical mean of the hydraulic conductivity is calculated as 2.79×10^{-5} m/s. In 2003, around the locality of wells licensed to Tüprag, pumping tests were performed by SRK Consulting and storativity of the aquifer is determined as 0.059 (SRK, 2003). Ulubey Formation includes all classes having poor, middle and good aquifer properties. This variability is predicted to be derived from fissure, fracture and/or fault-controlled karstification (Yazıcıgil et al., 2000).

3.2.1.7 Asartepe Formation

Asartepe Formation dominantly outcrops in the eastern parts of Banaz Stream Basin and in the south of Uşak- Banaz line. It has the broadest extension in the localities of Sivaslı and Banaz. It is made up of alternations of pebblestone, sandstone, siltstone, claystone and marl. Fine grained units are dominant. Yields of 19 wells drilled in this formation range between 0.17 and 26 L/s, average well yield is 9.46 L/s. Specific capacity of these wells ranges between 0.003 and 17.54 L/s/m, average specific capacity is 1.48 L/s/m. According to the results of pumping tests performed at ten wells drilled in this formation, transmissivity of the unit is determined in the range between 4 and 796 m^2/day and hydraulic conductivity is determined in the range between 3.1×10^{-7} and 1.0×10^{-4} m/s. Asartepe Formation is classified as good aquifer where it has a broad extension in the eastern parts of the study area around the locality of Sivaslı district.

3.2.1.8 Quaternary Deposits

Old alluvium, talus-fan deposits, travertine and alluvium are the four groups comprising the Quaternary deposits within the study area. These

Quaternary deposits commonly include fluvial cone deposits, terrace sediments and alluvium. In many locations, alluvial aquifers are efficiently utilized for irrigational purposes. In this unit, there are many shallow wells drilled by municipalities and individuals, especially in the vicinities of Uşak, Banaz and Güre. Yields of 20 wells drilled in this formation range between 1.7 and 19.1 L/s, average well yield is 10.78 L/s. Specific capacity of these wells range between 0.12 and 11.33 L/s/m, average specific capacity is 1.93 L/s/m. According to the results of pumping tests performed at four wells drilled by DSİ, transmissivity of the unit is determined in the range between 67 and 482 m^2/day and hydraulic conductivity is determined in the range between 3.93×10^{-5} and 2.32×10^{-4} m/s.

3.2.2 Hydraulic Properties of Groundwater Bearing Units

In aquifer characterization studies, aquifer geometry, aquifer parameters and their areal distribution, as well as yield and specific capacity of wells drilled in all groundwater bearing formations should be determined. Basic statistical data regarding these parameters, such as average and standard deviation, are important in hydrogeological assessment and comparison of the units within the basin. Therefore, units having broader extension within the study area with good aquifer properties are characterized (Ulubey Formation, Asartepe Formation, marbles and alluvium representing the Quaternary deposits). Then, yields, specific capacities and hydraulic conductivities of the wells drilled in each of these formations are determined by examining logs of the wells drilled by DSİ, Bank of Provinces and Rural Services.

3.2.2.1 Specific Capacity and Well Yield

Yield and specific capacity values of 117 wells drilled in the four units mentioned above (Ulubey Formation, Asartepe Formation, marbles and alluvium) are evaluated. 55 of the 117 wells are drilled by DSİ, 38 of them are drilled by Bank of Provinces, 21 of them are drilled by Rural Services and 3 of them are drilled by Tüprag Metal Mining Corp. All these wells are classified according to the unit from which they extract water and their yield and specific capacity values are presented in Table 3.7, including also averages and standard deviations of these parameters. In marbles and Ulubey Formation, which have the highest yield and specific capacity, there are also dry wells drilled. This fact can be explained by karstification in the basin.

Maximum average specific capacity value is determined as 420 L/s/m at marbles. However, very high standard deviation indicates that specific capacity of marbles is very variable. Average specific capacity for Ulubey Formation is calculated as 3.28 L/s/m. Most of the groundwater is extracted from Ulubey Formation which has the broadest extension within the study area. Average specific capacity values of the wells drilled in Asartepe Formation (1.48 L/s/m) and alluvium (1.93 L/s/m) are very close to each other. Consequently, Asartepe Formation and alluvium, which are both made up of clastic materials, can hydrogeologically be considered as a single unit.

The highest average well yield among all units is calculated as 19.20 L/s for the marbles. Average yield of the wells drilled in Ulubey Formation is calculated as 12.99 L/s. Average yield of the wells drilled in Asartepe Formation (9.46 L/s) and alluvium (10.78 L/s) are very close to each other.

Table 3.7 Yield and specific capacity values of the wells

Formation	Number of Wells	Yield (L/s)				Specific Capacity (L/s/m)			
		Min.	Max.	Avg.	Std. Dev.	Min.	Max.	Avg.	Std. Dev.
Ulubey	66	dry	50.00	12.99	9.06	dry	71.43	3.28	9.80
Asartepe	19	0.17	26.00	9.46	6.72	0.003	17.54	1.48	4.01
Marbles	12	dry	40.00	19.20	13.47	dry	420.00	58.59	131.19
Alluvium	20	1.70	19.10	10.78	4.44	0.120	11.33	1.93	2.56

3.2.2.2 Hydraulic Conductivity

Pumping test results of 67 wells drilled by DSİ and Bank of Provinces are evaluated and their transmissivity and hydraulic conductivity values are calculated. Hydraulic conductivity values calculated for the wells which are drilled in four extensive units of the study area are summarized in Table 3.8 together with their arithmetic and geometric mean and standard deviations. Highest average hydraulic conductivity values are calculated for marbles (1.51X10^{-3} m/s) and Ulubey Formation (2.89X10^{-3} m/s). Average hydraulic conductivity value is calculated as 2.39X10^{-5} m/s for Asartepe Formation and 1.41X10^{-4} m/s for alluvium. However, statistical data regarding units except the Ulubey Formation may not be very reliable due to the lack of sufficient information.

Transmissivity, hydraulic conductivity values of all 67 wells as well as the unit from which they extract water are tabulated in Table 3.9. In Table 3.9, transmissivity values calculated by DSİ are listed and they are followed by the transmissivity values calculated by two different methods: Cooper and Jacob Method and Recovery Method. The transmissivity value that will be utilized is determined as the average of all three methods if they are close to eachother. However, in case there is a transmissivity value which is not close to other two, the average value is calculated ignoring the extreme value. The chosen transmissivity values calculated in this manner, are listed in Table 3.9. Thickness and hydraulic conductivitiy value of the corresponding wells are also presented in Table 3.9.

Table 3.8 Hydraulic conductivity values of the wells (m/s)

Aquifer	Number of Wells	Min.	Max.	Arithmetic Mean		Geometric Mean	
				Avg.	Std. Dev.	Avg.	Std. Dev.
Ulubey	31	4.69 x10^{-7}	2.89 x10^{-3}	3.23 x10^{-4}	7.32 x10^{-4}	2.79 x10^{-5}	1.41 x10^{-4}
Asartepe	10	3.11 x10^{-7}	1.02 x10^{-4}	2.39 x10^{-5}	3.15 x10^{-5}	8.48 x10^{-6}	6.94 x10^{-5}
Marbles	7	6.03 x10^{-7}	1.51 x10^{-3}	4.07 x10^{-4}	6.30 x10^{-4}	6.04 x10^{-5}	1.72 x10^{-4}
Alluvium	4	3.93 x10^{-5}	2.53 x10^{-4}	1.41 x10^{-4}	1.18 x10^{-4}	9.79 x10^{-5}	3.30 x10^{-5}

Table 3.9 Evaluation of pumping test results

Well Number	Aquifer Unit	Transmissivity (m^2/day)				Thickness (m)	Hydraulic Conductivity (m/s)
		DSİ	Cooper & Jacob	Recovery	Chosen T		
64/3188	Ahmetler	-	93	106	100	62.5	1.80E-05
64/3191	Ahmetler	-	15	6.8	10.9	68.3	1.90E-06
64/3243	Ahmetler	-	62	48.6	55.3	34	1.90E-05
64/3875	Ahmetler	-	2.8	1.1	1.9	47	4.80E-07
64/3912	Ahmetler	-	-	0.9	0.9	34	2.90E-07
5287	Alluvium	-	1180	482	482	24	2.30E-04
5289-B	Alluvium	-	181	169	175	8	2.50E-04
5760	Alluvium	-	690	103	103	30	4.00E-05
5342	Alluvium	-	83.1	51.2	67.2	19.8	3.93E-05
19 (L3)	Alluvium-Ulubey	-	1090	406	406	20	2.30E-04
5288	Asartepe	-	101	87.6	94.3	168	6.50E-06
33298	Asartepe	547	381	181	369.7	118	3.60E-05
36945	Asartepe	296	254	345	298.3	114	3.00E-05
42411	Asartepe	790	802	-	796	90	1.00E-04
5289-A	Asartepe	-	3.2	8.4	5.8	48	1.39E-06
5341-A	Asartepe	-	3.9	-	3.9	145.6	3.11E-07
64/4387	Asartepe	-	27.6	14.4	21	80	3.00E-06
64/4394	Asartepe	-	86.4	86.4	86.4	67.3	1.50E-05
64/165	Asartepe	-	6.4	9.5	8	27	3.40E-06
64/166	Asartepe	-	138	86.4	112.2	32	4.10E-05
52729	Asartepe-Ulubey	3.2	14.1	9.8	12	110	1.30E-06
58156	Asartepe-Ulubey	-	323	160	241.5	113	2.47E-05
10(1)	Asartepe-Ulubey	-	196	251	223.5	33	7.80E-05
64/2121	Asartepe-Ulubey	-	17.8	14.2	16	96	1.90E-06
58280	Eşme	21.8	33	13.8	22.9	39	6.80E-06
40017-C	Musadağı	331	86.4	60.4	73.4	81	1.00E-05
40017-B	Musadağı	-	464	-	464	54.6	9.84E-05
52724-B	Musadağı	1	9	3.8	4.6	88	6.00E-07
52725	Musadağı	10954	6200	-	8577	89	1.10E-03
52726	Musadağı	9822	12900	-	11361	87	1.50E-03
58279	Musadağı	94	83.7	84.3	87.3	29	3.50E-05
58282	Musadağı	245.3	215	950	230.2	33	8.10E-05
32645	Ulubey	-	219	221	220	80	3.20E-05
35069	Ulubey	444	182	145	163.5	68	2.80E-05
35071	Ulubey	2712	2490	2570	2590.7	71	4.20E-04
35072	Ulubey	561	500	528	529.7	42	1.50E-04
35073	Ulubey	33	36.7	10.6	34.9	132	3.10E-06
40017-A	Ulubey	-	15.9	12.5	14.2	85	1.90E-06
52727	Ulubey	-	41	35	38	100	4.40E-06

Table 3.9 Evaluation of pumping test results (continued)

Well Number	Aquifer Unit	Transmissivity (m^2/day)				Thickness (m)	Hydraulic Conductivity (m/s)
		DSİ	Cooper & Jacob	Recovery	Chosen T		
52728	Ulubey	1.9	10	6.8	6.2	94	7.70E-07
52730	Ulubey	3.5	17.1	10.3	13.7	100	1.60E-06
55074	Ulubey	1432.3	1430	-	1431.2	40	4.10E-04
55075	Ulubey	4799.3	5000	-	4899.7	39	1.50E-03
55076	Ulubey	4936.9	5380	-	5158.5	58	1.00E-03
56956	Ulubey	139.8	139	954	139.4	120	1.34E-05
58452	Ulubey	2257.1	-	2480	2368.6	69	3.97E-04
58711	Ulubey	5.8	4.7	10.1	5.2	129	4.69E-07
58799	Ulubey	238.2	332	507	285.1	149	2.21E-05
58908	Ulubey	33.9	14.5	32.9	33.4	156	2.48E-06
58909	Ulubey	39500	-	-	39500	170	2.69E-03
58911	Ulubey	34.6	22.6	63.9	28.6	147	2.25E-06
58912	Ulubey	27650	-	10300	18975	76	2.89E-03
59149	Ulubey	755.7	361	286	323.5	112	3.34E-05
59231	Ulubey	316	222	469	335.7	120	3.24E-05
59263	Ulubey	-	31.4	36.1	33.8	93	4.20E-06
59264	Ulubey	15	11.7	15.3	15.2	110	1.59E-06
17 (L1)	Ulubey	-	677	527	602	51	1.40E-04
18 (L2)	Ulubey	-	292	480	480	58	9.60E-05
20 (L4)	Ulubey	-	239	259	249	52	5.50E-05
64/3130	Ulubey	-	-	6.1	6.1	50	1.40E-06
64/3165	Ulubey	-	131	13.2	131	46	3.30E-05
64/3719	Ulubey	-	292	231	261.5	72	4.20E-05
64/3729	Ulubey	-	94.6	83.5	89.1	40	2.60E-05
41027	Ulubey-Ahmetler	592	657	-	624.5	48	1.50E-04
41103	Ulubey-Ahmetler	-	-	47.2	47.2	126	4.30E-06
59311-A	Ulubey-Ahmetler	4.6	4.1	5.2	4.6	75	7.20E-07
64/3182	Ulubey-Ahmetler	-	61	31.1	46.1	49	1.10E-05

3.2.3 Areal Extent, Depth and Thickness of Groundwater Bearing Units

As far as the hydrogeological classification of the units within the Banaz Stream Basin is concerned, Musadağı and Kızılcasöğüt Formations, Ulubey Formation, Asartepe Formation and Quaternary alluvium are the most important units having good aquifer properties on regional basis. Other units either form the base due to their impermeable characteristics or do not have regional significance due to their limited and/or disconnected outcrops.

Hydrogeological system should conceptually be defined before a numerical model that will be used to test groundwater management scenarios is set up. As a result of a detailed investigation on aquifer characterization and evaluation of gathered data; Ulubey Formation, Asartepe Formation and alluvium are considered in conceptual aquifer model. Although marbles have good aquifer properties, there is not enough data to define their regional geometry, groundwater levels, boundary conditions and hydraulic properties. Having similar hydraulic properties and overlapping extensions, Asartepe Formation and alluvium are considered as a single unit. As a result, Ulubey Formation that is the most important aquifer of the study area and Asartepe Formation that is considered as a single unit with alluvium are defined separately in the mathematical model. As it is mentioned above, marbles having broader extension along southern and eastern parts of the basin are not included in mathematical model due to lack of data. Instead, lateral flows between marbles and simulated units are considered in modeling stage. Figure 3.16 represents the boundaries of model and areal distribution of the simulated units within the model boundaries. As it can be implied from the figure, extension of Ulubey aquifer within the drainage area of Banaz Stream Basin is taken as basis for the model domain. Asartepe Formation and alluvium, overlying Ulubey Formation in northern and eastern parts of the model domain are only simulated in these localities.

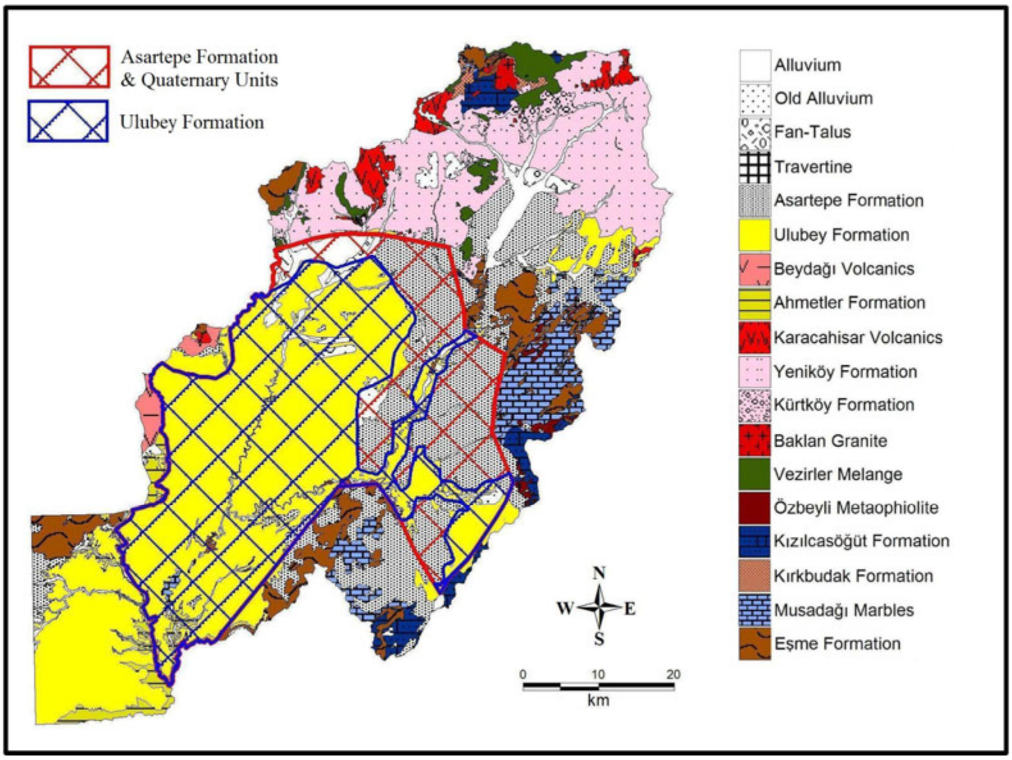


Figure 3.16 Location of Ulubey aquifer and overlying units within the study area

3.2.3.1 Aquifer Geometry

Ground surface elevation of the study area is obtained by digitizing a total of 40 1/25000 scaled topographic maps. A Digital Elevation Model (DEM) with 10 m grid size has been developed by Yazıcıgil et al. (2008) as given in Figure 3.17.

In order to create bottom elevation map of Ulubey Formation, logs of wells drilled by DSİ, Bank of Provinces and Rural Services are evaluated and basement rock (Ahmetler Formation, Eşme Formation and Musadağı marbles) elevation are determined. At localities where there is no information about the bottom of Ulubey Formation, data and cross-sections in geophysical investigation reports of DSİ and MTA are utilized. Locations of geophysical resistivity points and wells which are utilized to create bottom elevation map of Ulubey Formation are shown on Figure 3.18. Figure 3.19 shows the bottom elevation map of Ulubey Formation, which is

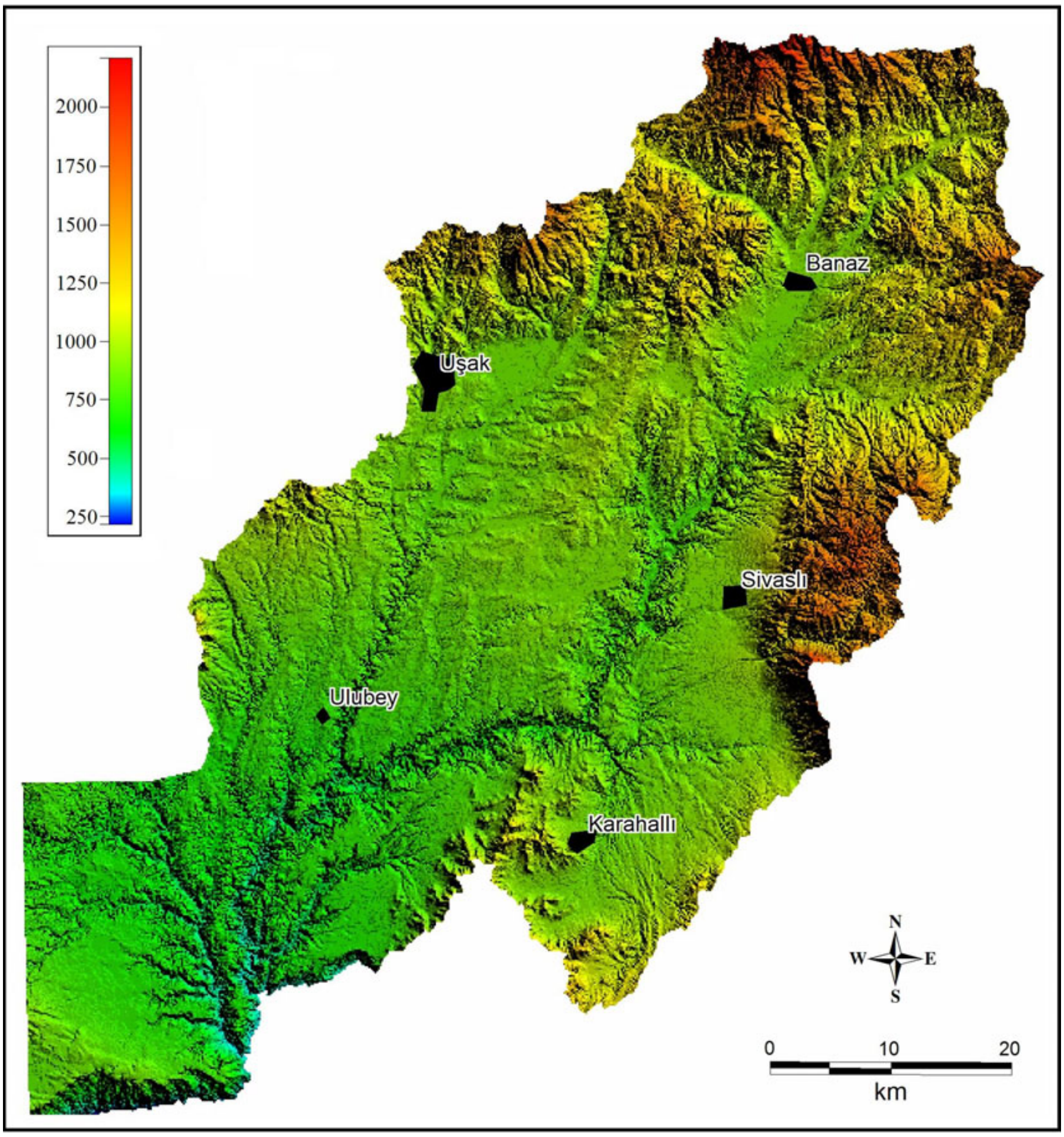


Figure 3.17 Digital elevation model (DEM) with a grid size of 10 m (Yazıcıgil et al., 2008)

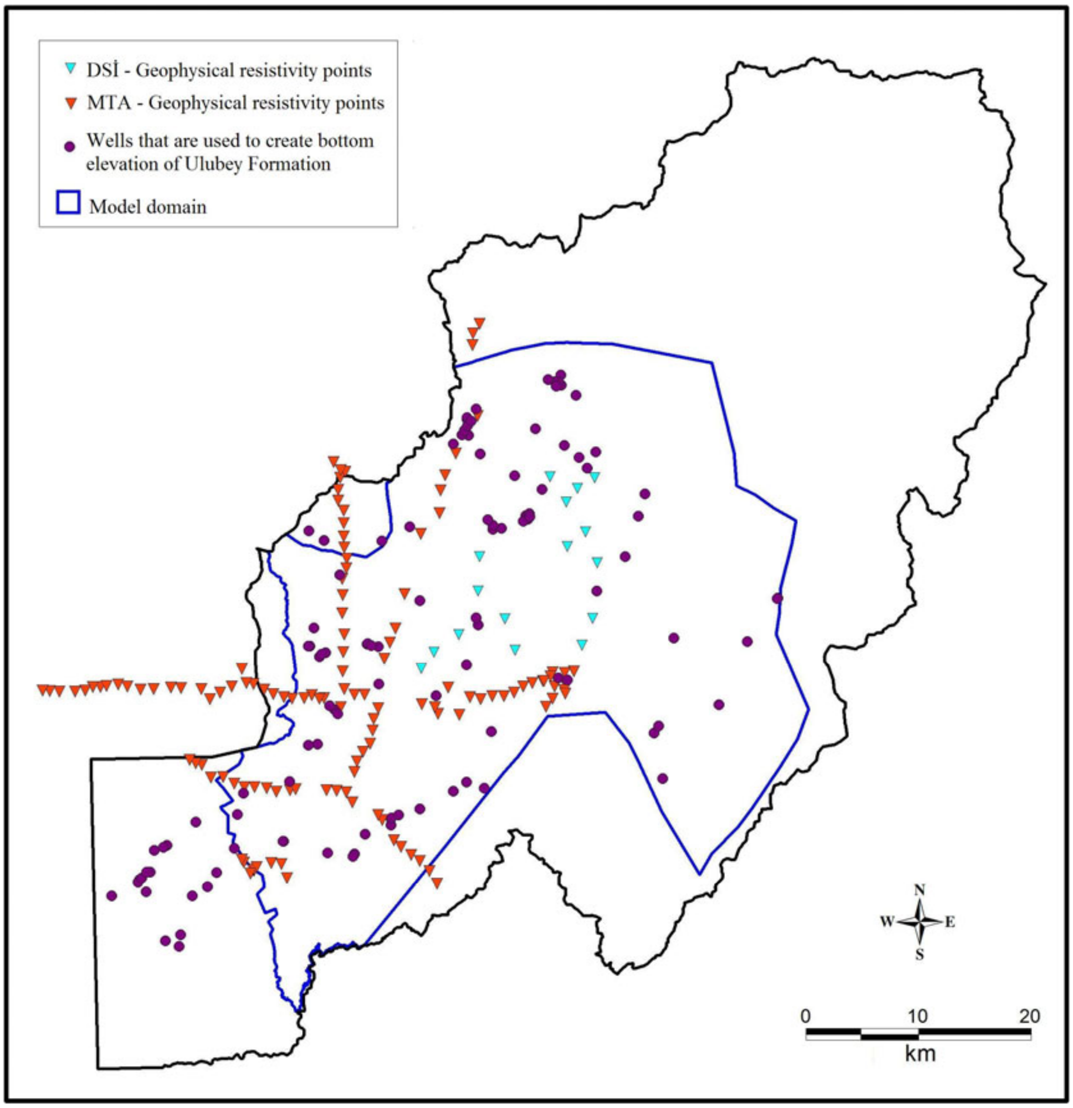


Figure 3.18 Locations of geophysical resistivity points and wells which are utilized to create bottom elevation map of Ulubey Formation

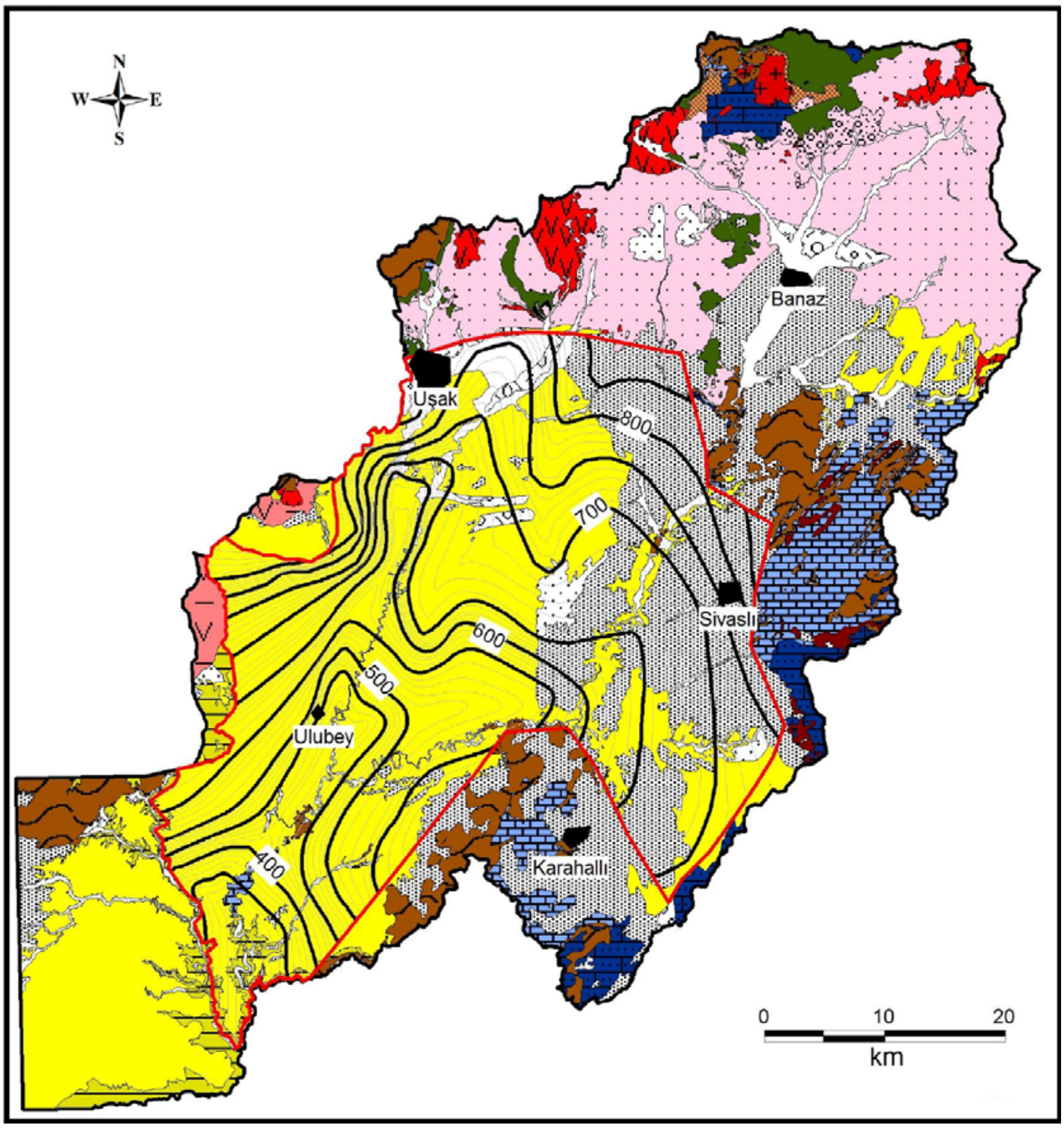


Figure 3.19 Bottom elevation map of Ulubey Formation

developed by utilizing well logs and geophysical investigation reports. According to this map, bottom elevation of Ulubey Formation is below 350 m in the locality of outlet of the basin in southwest and it is over 1000 m in the vicinity of Sivaslı in northeast. Furthermore, valleys along which Banaz and Yavu Streams flow can be observed in the bottom elevation map of the aquifer.

Thickness of units overlying the Ulubey Formation is again predicted from the well logs and fieldwork and it is subtracted from the topographical elevation to get the bottom elevation of these units, in other words the top elevation of the Ulubey Formation.

3.2.3.2 Areal Distribution of Groundwater Levels

In determination of aquifer geometry, areal distribution of groundwater levels should also be determined in addition to the bottom elevation of aquifer. Static groundwater levels measured at wells drilled in different times within Banaz Stream Basin are utilized in order to develop groundwater elevation map. Moreover, groundwater elevation measurements performed by DSİ at predetermined wells and water level measurements along Banaz and Yavu Streams, which are conducted within the scope of the project "Hydrogeological Investigation and Groundwater Management Plan for Ulubey Aquifer – Uşak" (Yazıcıgil et al., 2008) are utilized. Groundwater elevation map of Ulubey aquifer showing areal distribution of groundwater levels is presented in Figure 3.20.

As it can be seen in Figure 3.20, groundwater elevation is around 900 m in the north along Uşak-Banaz line and it decreases southwards. Groundwater elevation is around 600 m in the locality of Ulubey and decreases to 410 m at Adıgüzel Dam, in the southern boundary of the basin. Groundwater elevation map shows that between Uşak-Ulubey line Yavu Stream has influent characteristics whereas in all other localities Yavu and Banaz Streams have effluent characteristics. Moreover, recharge of groundwater to Asartepe and Ulubey Formations along the eastern boundary of model domain formed by marbles and

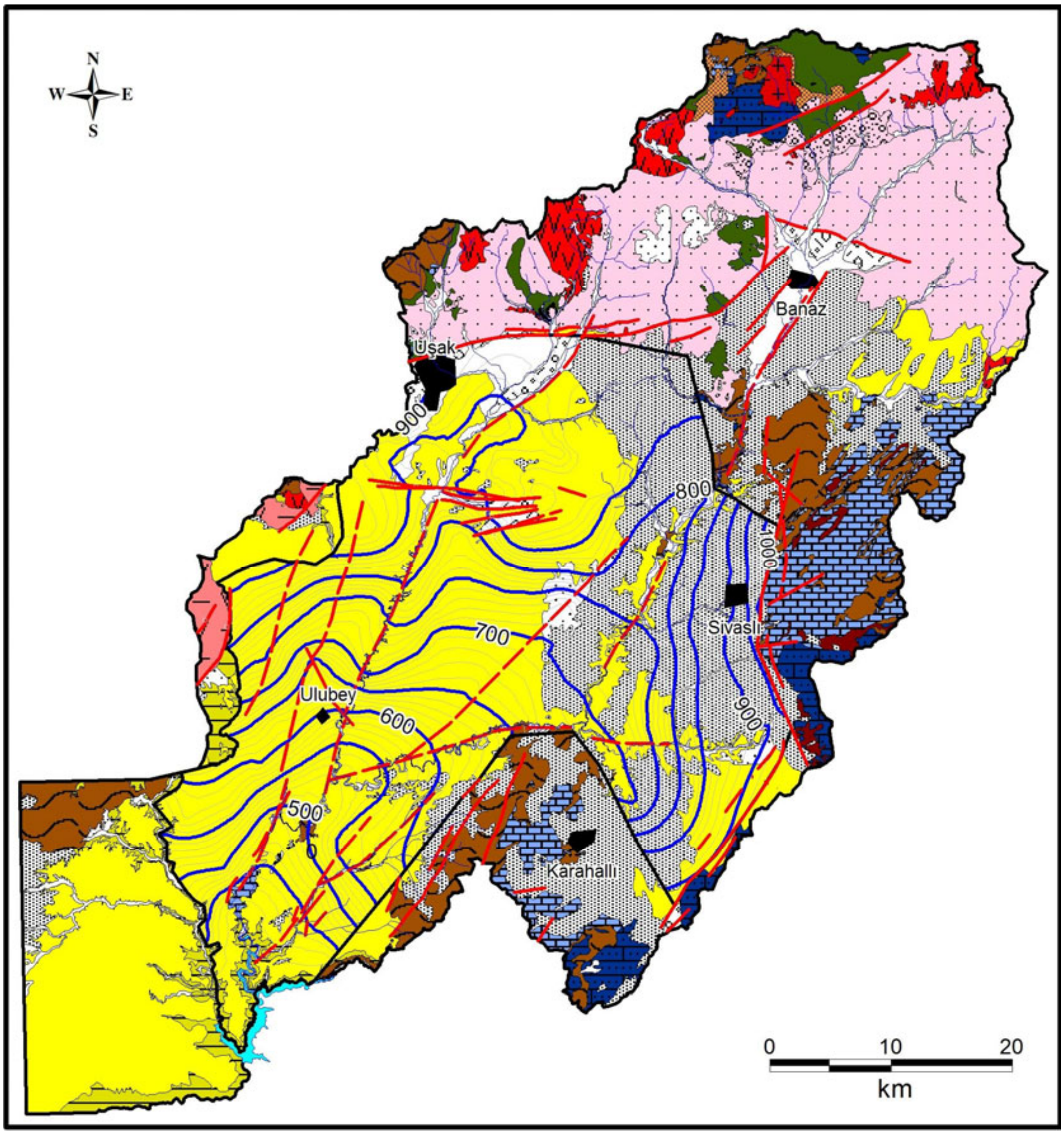


Figure 3.20 Groundwater elevation map of Ulubey aquifer

along the northern boundary can also be seen in groundwater elevation map. Local anomalies in groundwater elevation map can be explained by existence of faults around these localities. According to this groundwater elevation map, hydraulic gradient is around 0.023 around Sivaslı, 0.022 around Ulubey and 0.009 in the inner parts of the basin between Yavu and Banaz Streams.

3.2.3.3 Temporal Changes in Groundwater Levels

Water level measurements have been performed by DSİ at 11 wells, since 1965 in order to monitor temporal changes in groundwater levels. Among these 11 wells, 5 of them penetrate the Ulubey Formation, 3 wells tap the alluvium, 2 wells penetrate marbles, and one is located in Asartepe Formation. Table 3.10 lists the information about these monitoring wells, such as monitoring period, location and formation. Figure 3.21 shows the distribution of these monitoring wells throughout the study area. Moreover, within the scope of project "Hydrogeological Investigation and Groundwater Management Plan for Ulubey Aquifer – Uşak" groundwater levels were measured at 23 predetermined wells between May-October 2007 (Yazıcıgil et al., 2008).

Table 3.10 Information about monitoring wells

Well Number	Formation	Monitoring Period	Coordinates	
			Easting	Northing
5286	Ulubey	1965-2006	730900	4254300
5287	Alluvium	1994-1995	731700	4264800
5289-C	Alluvium	1965-2006	739265	4291499
5341-A	Asartepe	1965-2005	711043	4284136
5760	Alluvium	1994-1995	739500	4288800
35071	Ulubey	1990-2005	710667	4270044
35072	Ulubey	1990-2005	709206	4262096
35073	Ulubey	1994-1996	717350	4256522
35074	Ulubey	1994-1996	720000	4264475
40017-B	Marbles	1995-2005	751275	4282750
40017-C	Marbles	1995-1996	753625	4281200

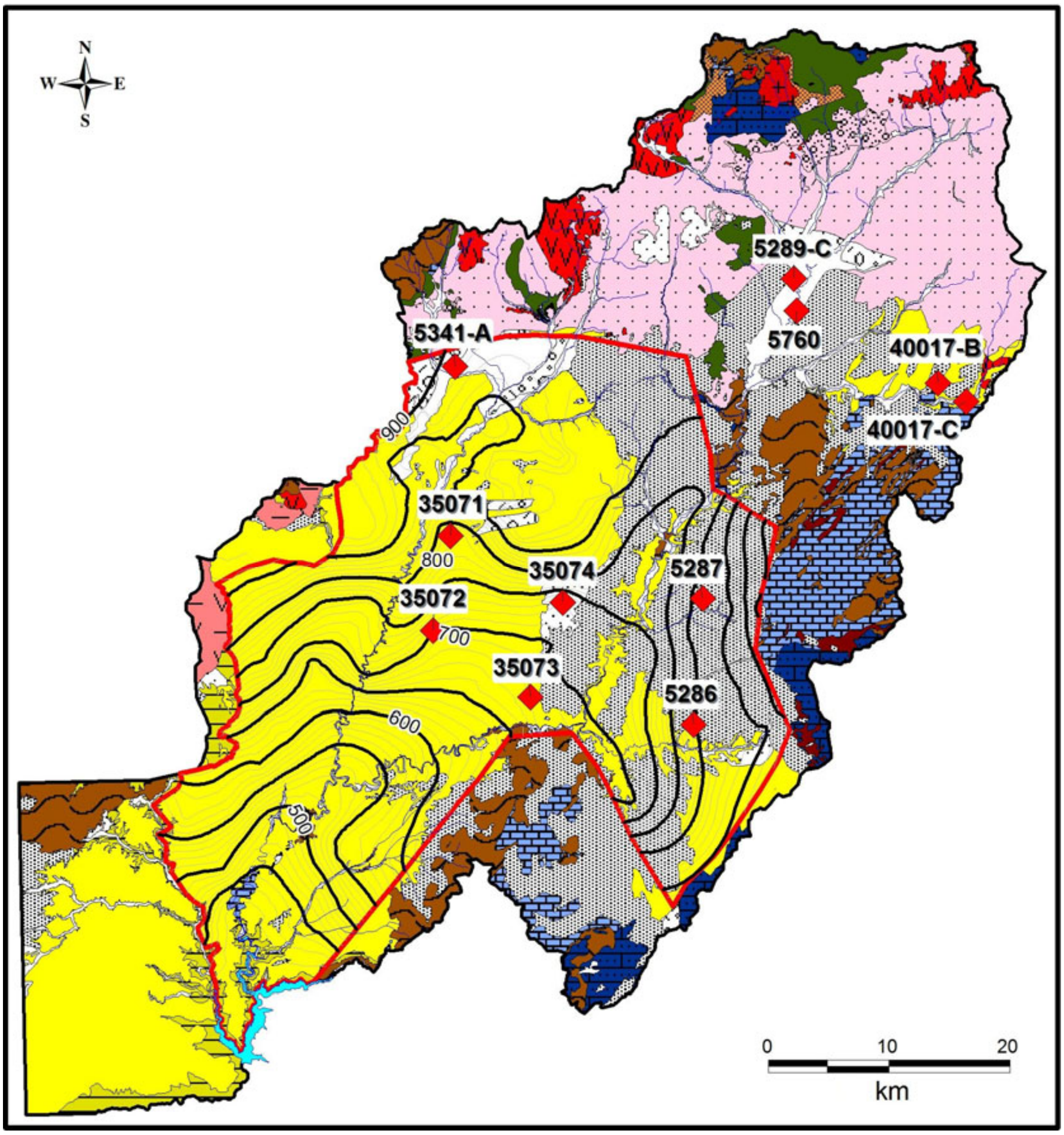


Figure 3.21 Locations of monitoring wells

Four wells, each of which penetrate Ulubey Formation, Asartepe Formation, alluvium and marble units, are selected among these 11 monitoring wells in order to detect changes in groundwater levels in each of the units separately. According to this, Ulubey Formation, Asartepe Formation, alluvium and marble units are represented by the wells 5286, 5341-A, 5289-C and 40017-B, respectively. Graphs showing the temporal changes in groundwater levels at the selected wells are presented in Figures through 3.22 and 3.25.

At the two wells representing marbles monthly groundwater level measurements were only performed in 1995 and 1996, since then groundwater levels have only been measured twice. There are continuous monthly groundwater level measurements in the period 1965-2006, at the three wells representing the units that will be simulated in the numerical model, Ulubey (5286), Asartepe (5341-A) and alluvium (5289-C). Temporal changes in groundwater levels at these three wells are shown on Figure 3.26. In order to relate change in groundwater levels and precipitation, cumulative deviation from mean annual precipitation graph for the same time period is prepared (Figure 3.27).

Examination of Figures 3.26 and 3.27 together shows that during the dry period between 1981 and 1996, Asartepe Formation and alluvium are the units that have been affected most, while Ulubey Formation and marbles are almost not influenced. Figure 3.28 demonstrates groundwater levels recorded at five monitoring wells in Ulubey Formation (5286, 35071, 35072, 35073, 35074) in period 1990-2007. As it can be seen from this figure, groundwater levels of Ulubey aquifer are slightly affected by the wet period of 1990-1996, dry period of 1997-2003 and wet period 2004-2007. However, during the past 17 years there has been no decline in groundwater levels due to pumping from wells. Furthermore, this situation implies that due to non increasing pumping rates, equilibrium conditions of Ulubey aquifer still persist.

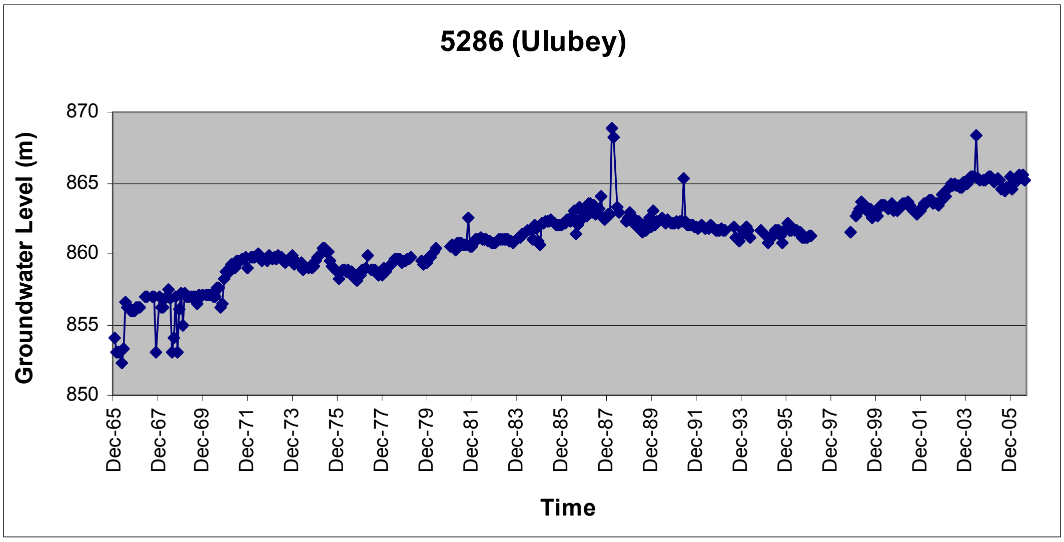


Figure 3.22 Temporal variation of groundwater in monitoring well 5286 representing Ulubey Formation

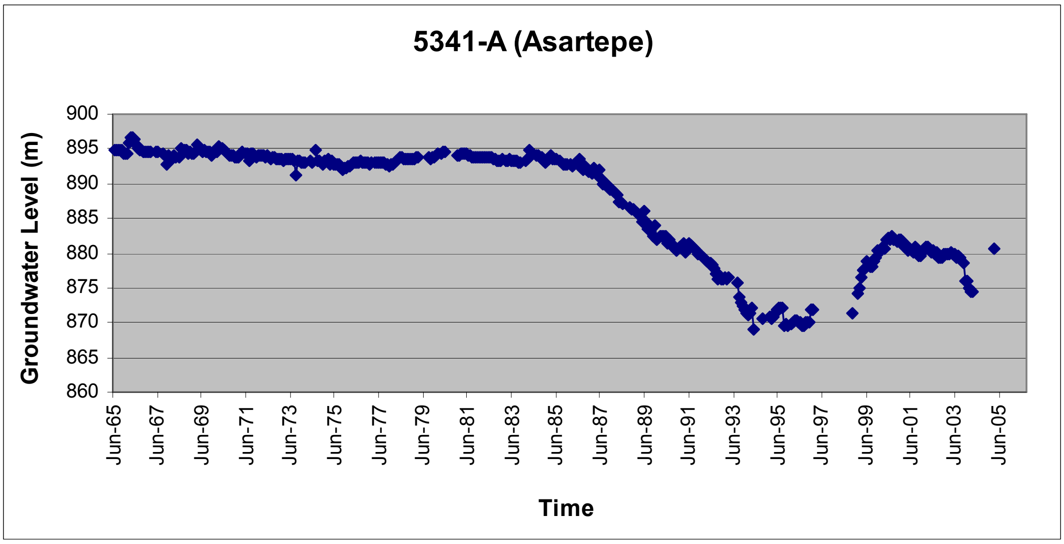


Figure 3.23 Temporal variation of groundwater in monitoring well 5341-A representing Asartepe Formation

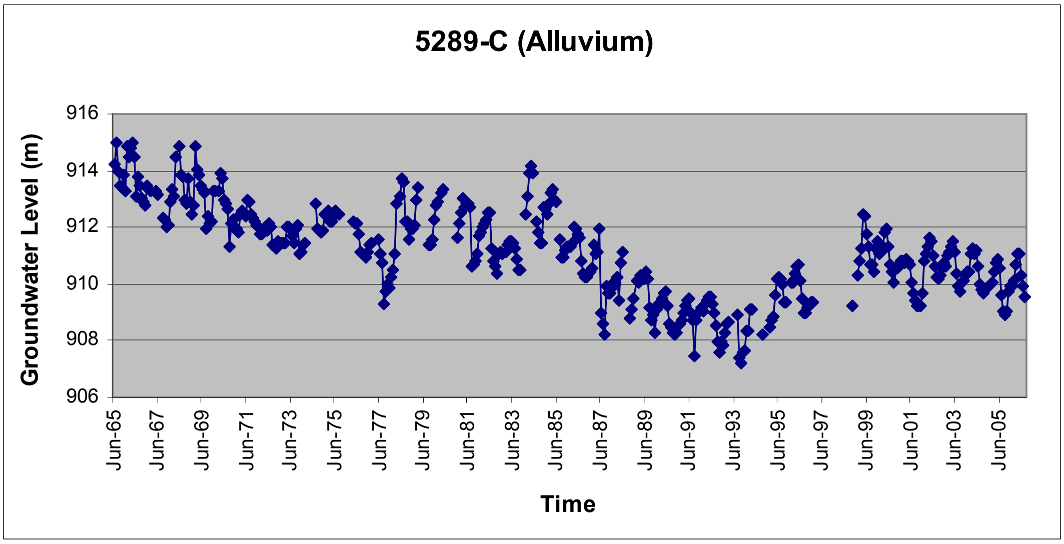


Figure 3.24 Temporal variation of groundwater in monitoring well 5289-C representing alluvium

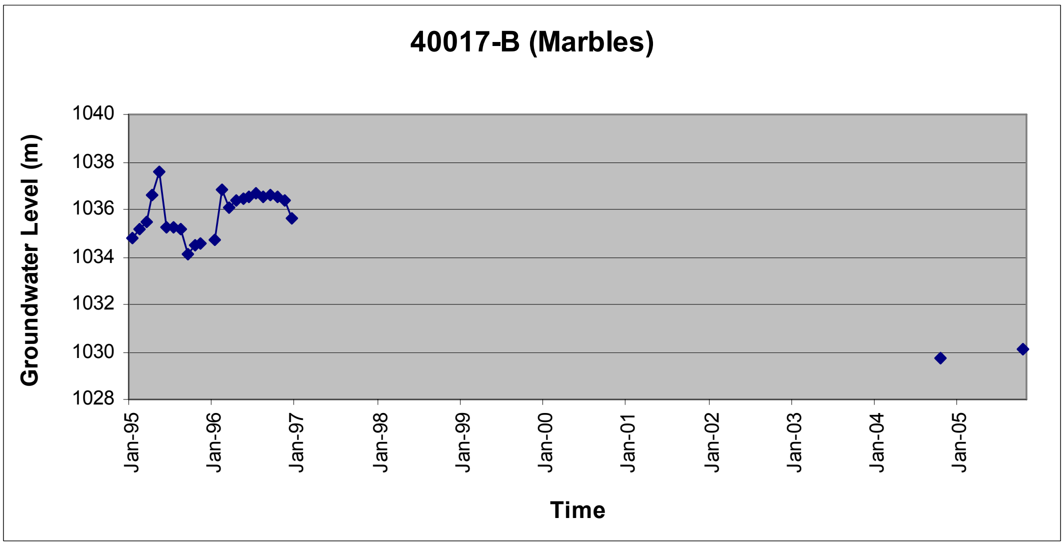


Figure 3.25 Temporal variation of groundwater in monitoring well 40017-B representing marbles

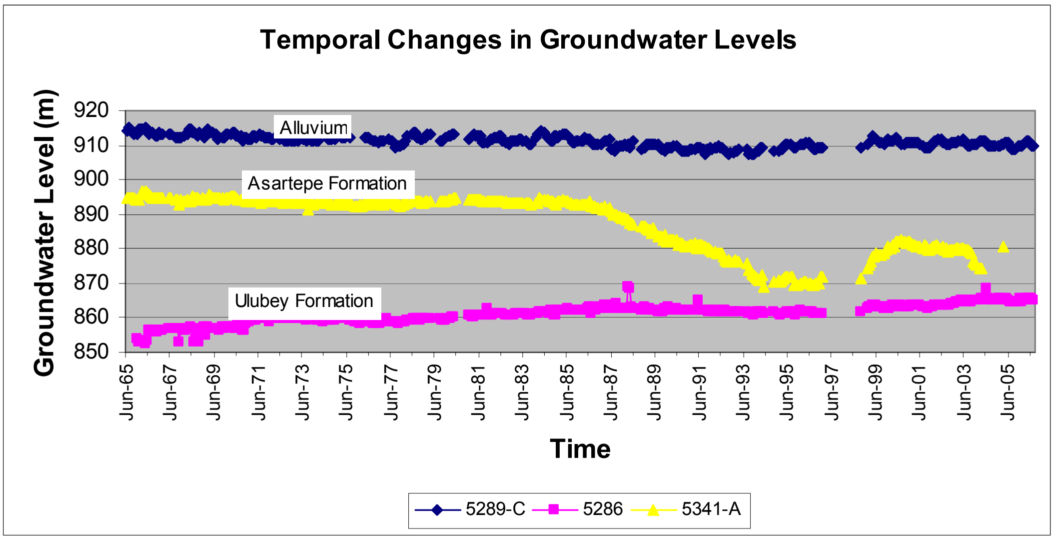


Figure 3.26 Temporal changes in groundwater levels measured at the wells representing Ulubey Formation, Asartepe Formation and alluvium

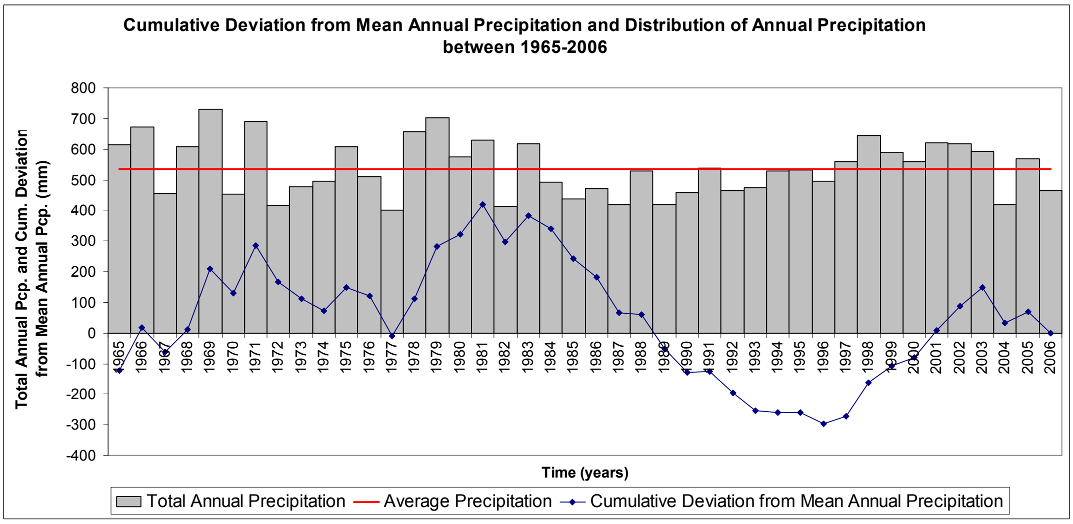


Figure 3.27 Cumulative deviation from mean annual precipitation graph for period 1965-2006

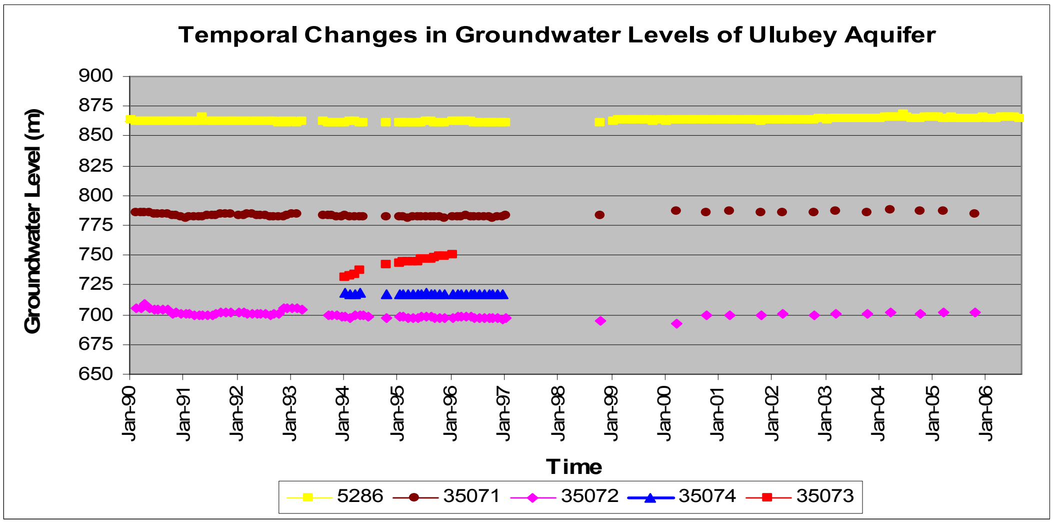


Figure 3.28 Temporal changes in groundwater levels of Ulubey aquifer between 1990 and 2007

3.2.3.4 Saturated Thickness

Saturated thickness map of Ulubey aquifer is obtained by subtracting bottom elevation map from groundwater level map of Ulubey Formation in digital environment (Figure 3.29). According to the map given in Figure 3.29, maximum saturated thickness is observed as 250-300 m along Yavu Stream especially between Uşak and Ulubey. In the inner parts of the basin saturated thickness ranges between 100 and 150 m.

3.2.3.5 Depth to Groundwater

Map of depth to static groundwater level for Ulubey aquifer is obtained by subtracting groundwater level map from digitized topographical map in digital environment (Figure 3.30). Depth to groundwater is less than 50 m in the south and east of Uşak, around Sivaslı and its south, along Banaz and Yavu Stream Valleys. In the inner parts of the basin and in the east and south of Ulubey, groundwater levels drop rapidly and depth to groundwater exceeds 150 m (Figure 3.30).

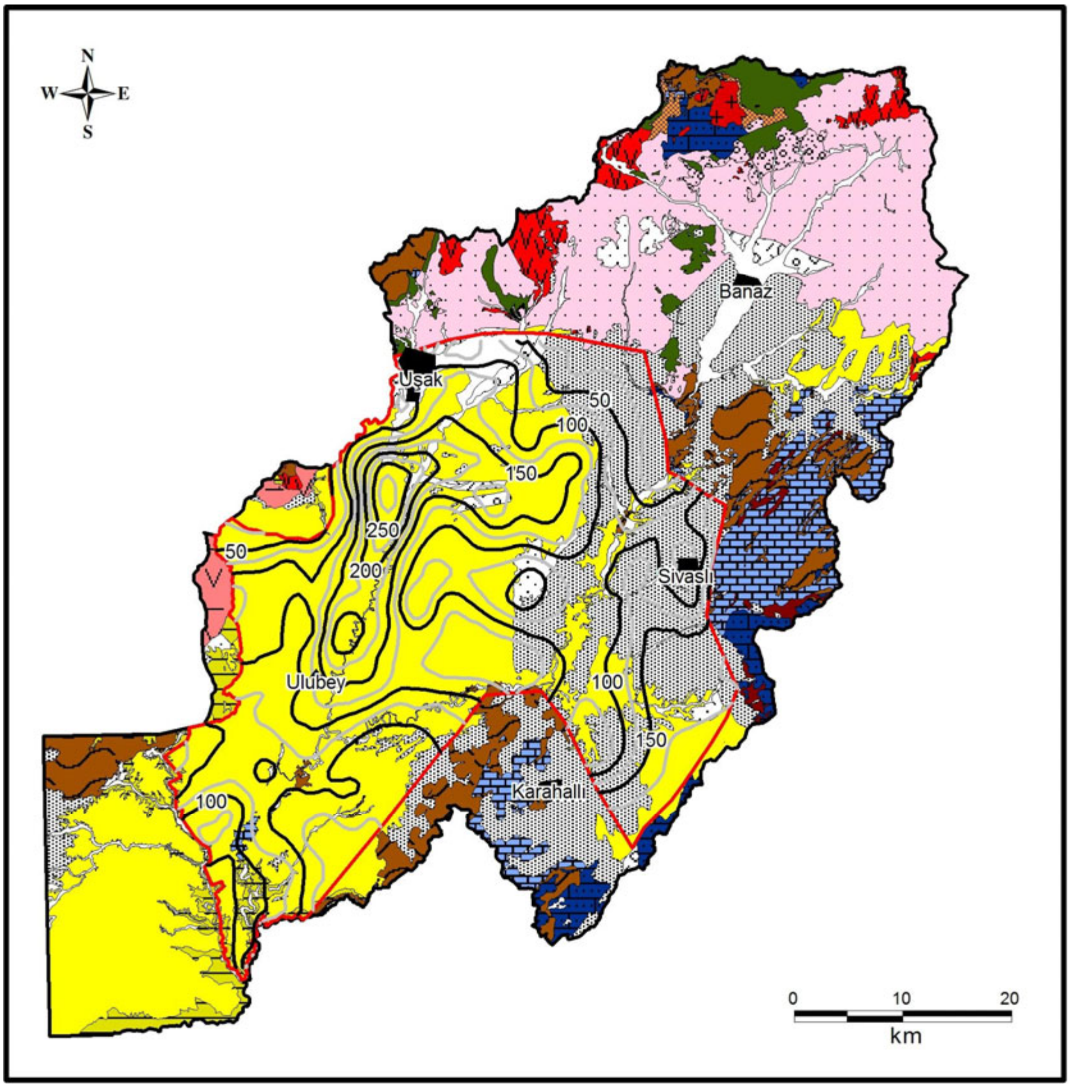


Figure 3.29 Saturated thickness map of Ulubey aquifer

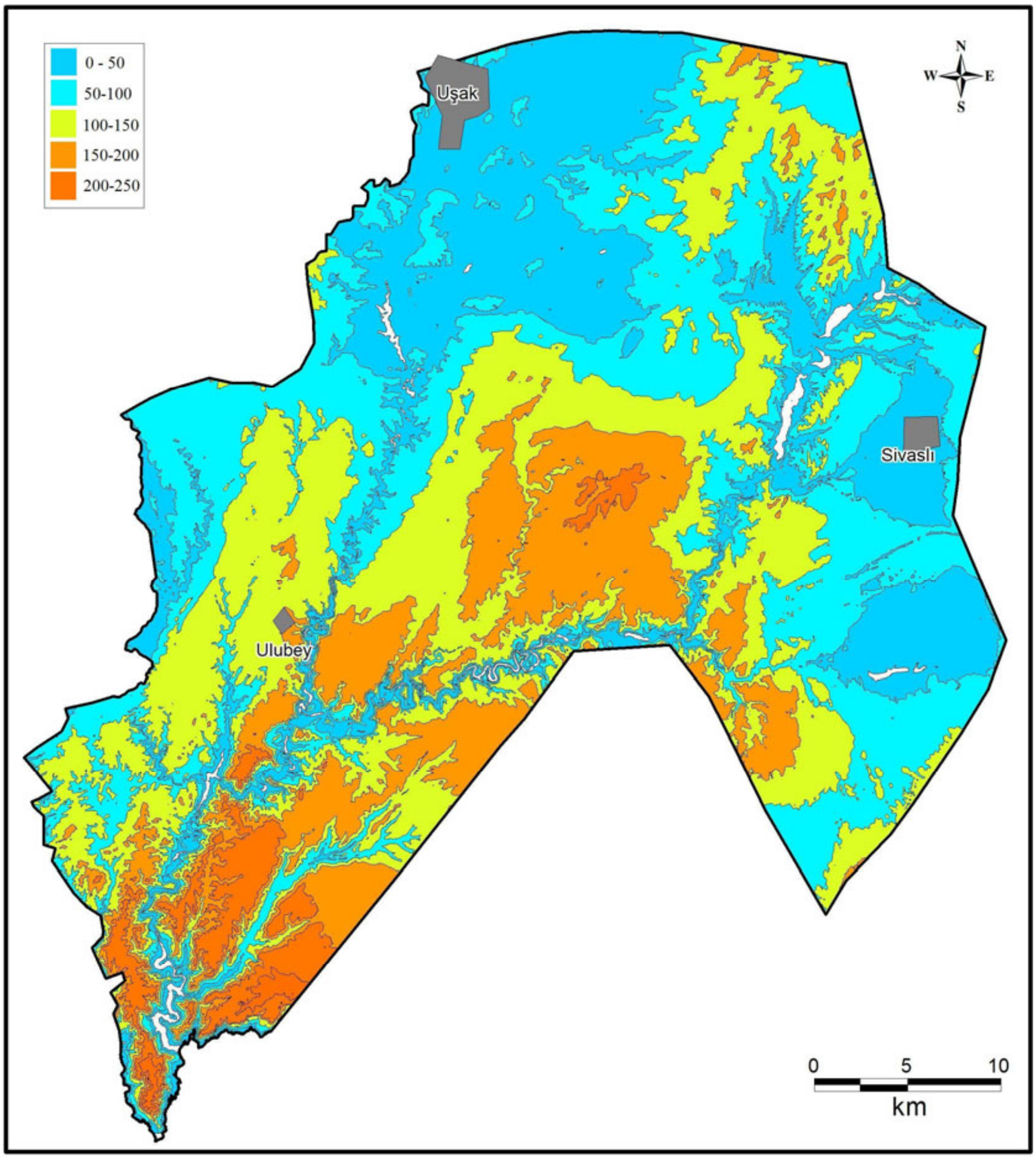


Figure 3.30 Depth to static groundwater level map of Ulubey aquifer

3.3 Groundwater Consumption

Amount of groundwater extracted from alluvium and Asartepe Formation, which are assumed to be a single layer in mathematical flow model, and from Ulubey Formation is separately calculated. In order to calculate the amount of groundwater extracted from each of these two units, groundwater consumption is classified into two groups. First group includes amount of groundwater extracted for drinking, domestic and industrial uses, whereas second group includes amount of groundwater extracted for irrigational uses.

3.3.1 Groundwater Consumption for Domestic and Industrial Uses

Groundwater for drinking, domestic and industrial purposes is basically supplied from wells drilled by Bank of Provinces, Rural Services and DSİ. In order to determine the amount of groundwater extracted from these wells, information attained from municipalities within the study area during field studies and population data from census of year 2000 are utilized.

During the field study which was carried out within the scope of "Hydrogeological Investigation and Groundwater Management Plan for Ulubey Aquifer – Uşak" project in April 2007, interviews were held with the municipalities. During these interviews, information such as coordinates of springs and wells that supply water to the municipality and amount of water that is consumed by the municipality, collected. Data from census of year 2000 are obtained from DİE and these are utilized to relate amount of groundwater consumed and population. Groundwater consumption is assumed to be 250 L/day/capita for municipalities and 200 L/day/capita for villages. Amount of groundwater consumption is calculated for Ulubey Formation, Asartepe formation including alluvium and the whole basin (Table 3.11, Table 3.12, and Table 3.13). Figure 3.31 represents location of wells that supply water to municipalities and villages.

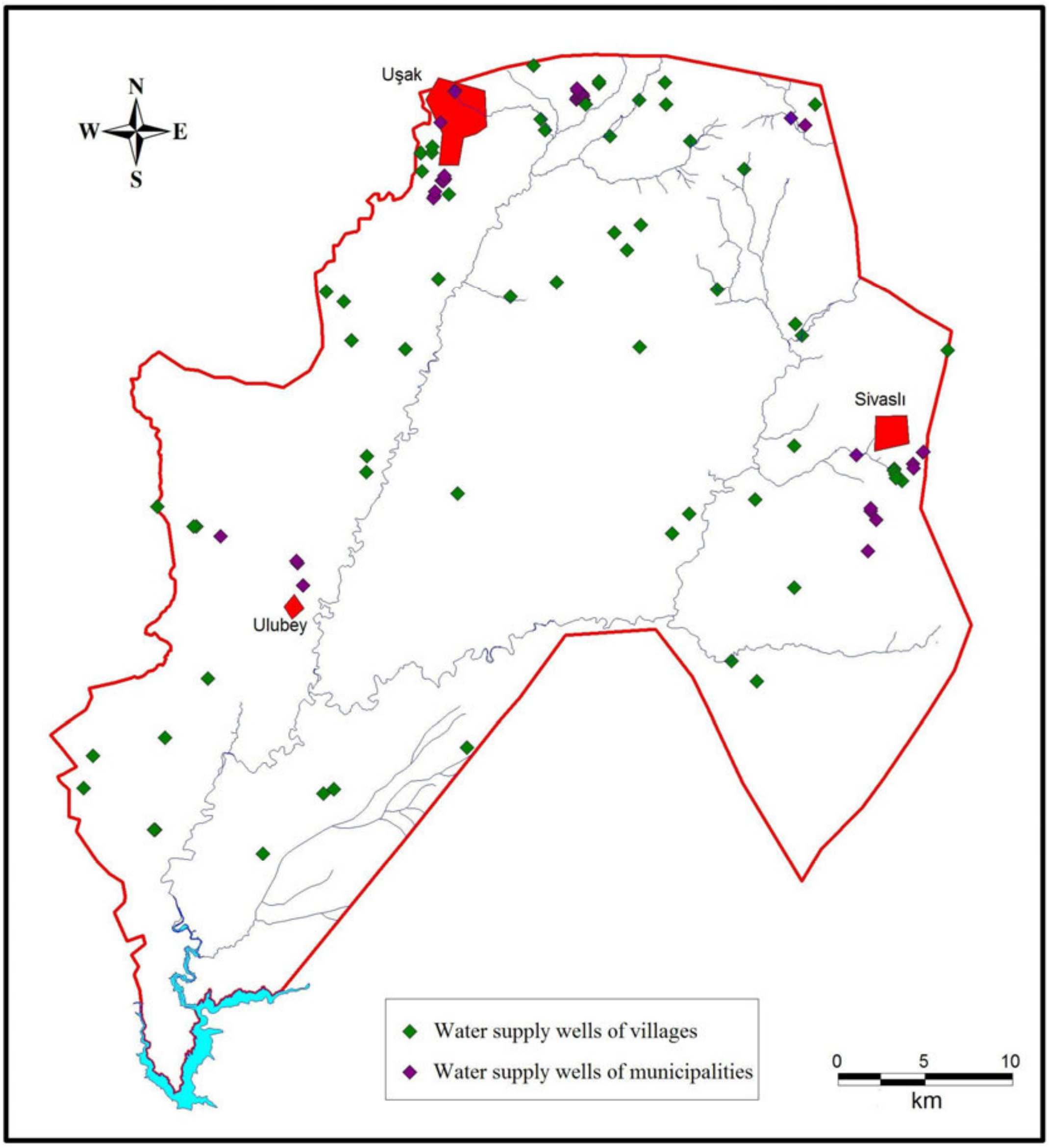


Figure 3.31 Locations of water supply wells of municipalities and villages

Table 3.11 Number of wells supplying groundwater to municipalities and villages and amount of groundwater consumption (Ulubey Formation)

ULUBEY	Number of Wells	Consumption (m^3/day)	Consumption (hm^3/year)
Villages	53	3934.32	1.44
Municipalities	12	8496.63	3.10
Total	65	12430.94	4.54

Table 3.12 Number of wells supplying groundwater to municipalities and villages and amount of groundwater consumption (Asartepe Formation and alluvium)

ASARTEPE-ALLUVIUM	Number of Wells	Consumption (m^3/day)	Consumption (hm^3/year)
Villages	8	836.30	0.31
Municipalities	23	20093.40	7.33
Total	31	20929.70	7.64

Table 3.13 Number of wells supplying groundwater to municipalities and villages and amount of groundwater consumption (total)

TOTAL	Number of Wells	Consumption (m^3/day)	Consumption (hm^3/year)
Villages	61	4770.62	1.74
Municipalities	35	28590.03	10.44
Total	96	33360.65	12.18

According to these three tables, annual amount of groundwater supplied from Ulubey aquifer for drinking and domestic uses is 3.10 hm^3 for municipalities and it is 1.44 hm^3 for villages. So, total amount of groundwater supplied from Ulubey aquifer for drinking and domestic uses of municipalities and villages within the study area is 4.54 hm^3 annually. This amount also includes groundwater consumption of institutions which use water directly from the network. Hence, groundwater consumption of institutions which are not connected to the network and using their own wells to pump groundwater should also be determined. In order to determine the amount of groundwater consumed in this manner, registered information in DSİ records of these wells are utilized. Finally, 28 institutions were detected within the study area that supply groundwater from their own wells drilled in Ulubey aquifer and amount of groundwater consumed by these institutions is calculated as 1.05 hm^3, annually. When this number is added to the amount of groundwater consumed by municipalities and villages for drinking and domestic purposes, it makes a total of 5.59 hm^3/year. It means that within the modeled area total amount of groundwater extracted from Ulubey aquifer for drinking, domestic and industrial purposes is 5.59 hm^3 annually.

Annual amount of groundwater supplied from Asartepe Formation and alluvium for drinking and domestic uses is 7.33 hm^3 for municipalities and it is 0.31 hm^3 for villages. Amount of groundwater consumed by two institutions which are not connected to the network and using their own wells is 0.04 hm^3 annually for Asartepe Formation and alluvium. So, within the modeled area total amount of groundwater extracted from Asartepe Formation and alluvium for drinking, domestic and industrial purposes is 7.68 hm^3 annually.

To sum up, within the modeled area total amount of groundwater consumption for drinking, domestic and industrial purposes is 13.27 hm^3 annually.

3.3.2 Groundwater Consumption for Irrigational Uses

Within the study area, groundwater used for irrigational purposes is pumped from the wells drilled by individuals. By April 2007, 334 registered wells were detected in DSİ records, which were drilled by individuals for irrigational purposes in Ulubey Formation, Asartepe Formation and alluvium. Locations of these wells are shown on Figure 3.32. Number of wells drilled by individuals and amount of groundwater consumed from these wells for industrial and irrigational purposes are presented in Tables 3.14, 3.15 and 3.16.

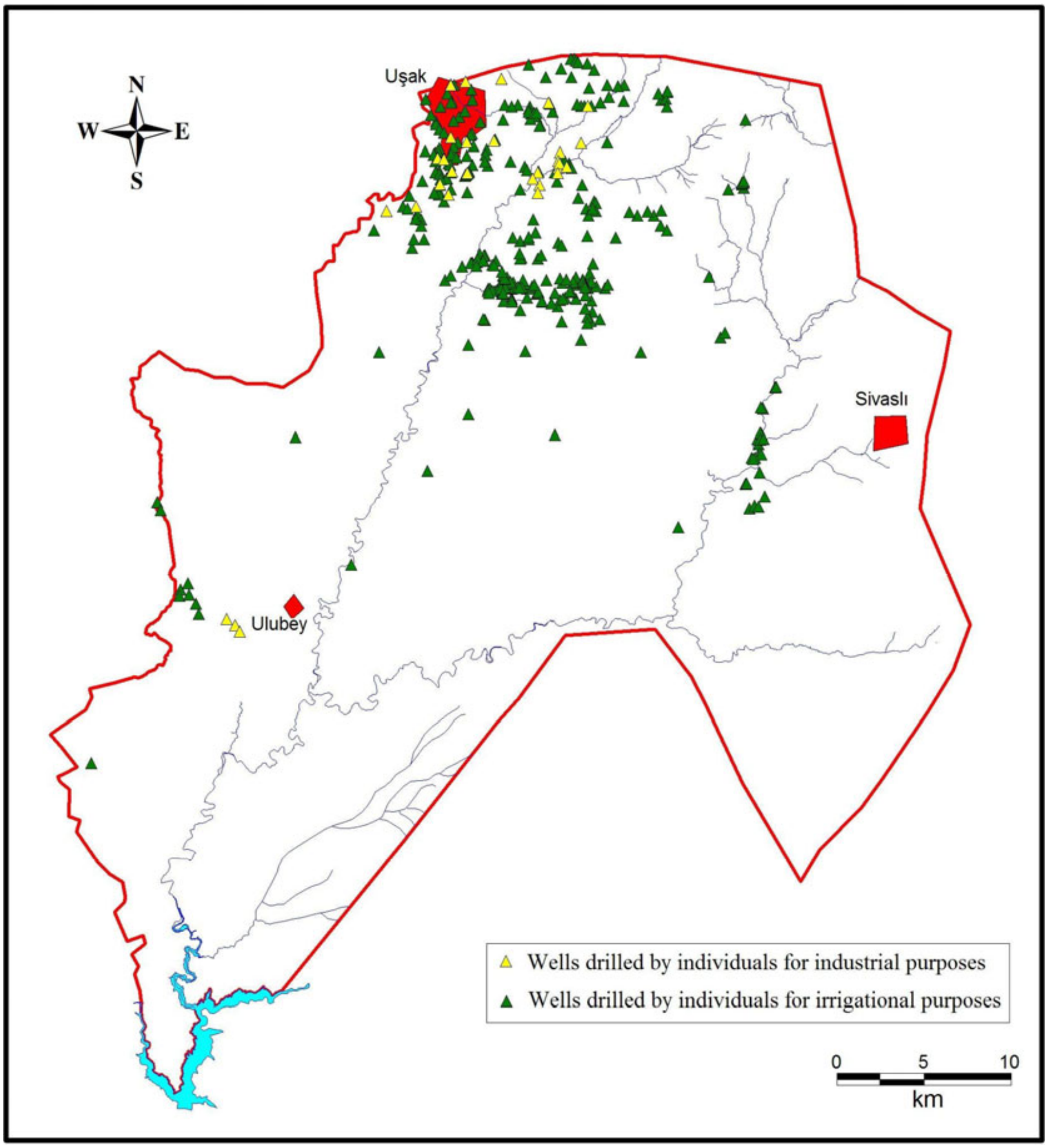


Figure 3.32 Locations of wells drilled by individuals for industrial and irrigational purposes

Table 3.14 Number of wells supplying groundwater for industrial and irrigational purposes and amount of groundwater consumed (Ulubey Formation)

ULUBEY	Number of Wells	Consumption (m^3/day)	Consumption (hm^3/year)
Industrial purposes	28	2886.66	1.05
Irrigational purposes	311	1439.34	0.53
Total	339	4326.00	1.58

Table 3.15 Number of wells supplying groundwater for industrial and irrigational purposes and amount of groundwater consumed (Asartepe Form. and alluvium)

ASARTEPE -ALLUVIUM	Number of Wells	Consumption (m^3/day)	Consumption (hm^3/year)
Industrial purposes	2	101.37	0.04
Irrigational purposes	23	54.63	0.02
Total	25	156.00	0.06

Table 3.16 Number of wells supplying groundwater for industrial and irrigational purposes and amount of groundwater consumed (total)

TOTAL	Number of Wells	Consumption (m^3/day)	Consumption (hm^3/year)
Industrial purposes	30	2988.03	1.09
Irrigational purposes	334	1493.97	0.55
Total	364	4482.00	1.64

Annual amount of groundwater allocated by DSİ for irrigational purposes is 0.53 hm^3 for Ulubey aquifer and 0.02 hm^3 for Asartepe Formation and alluvium. So, total amount of groundwater extracted for irrigational purposes within the modeled area is 0.55 hm^3 annually. Only one (Yazıtepe) of the 11 irrigational cooperatives planned by DSİ within the basin is currently active. In Yazıtepe cooperative, there are 4 wells (52724-B, 52725, 52726, 40017-C) used for irrigation. Logs of these wells indicate that they extract groundwater from

Musadağı marbles. That is why these wells are not taken into consideration in the calculation of amount of groundwater extracted for irrigational purposes.

As a result of the calculations to determine the amount of groundwater extraction, it is determined that from Ulubey aquifer 5.59 hm^3 of groundwater is extracted annually for drinking, domestic and industrial purposes and 0.53 hm^3 of groundwater is extracted annually for irrigational purpose. Total amount of groundwater extracted annually from Ulubey aquifer is 6.12 hm^3. From Asartepe Formation and alluvium 7.68 hm^3 of groundwater is extracted annually for drinking, domestic and industrial purposes and 0.02 hm^3 of groundwater is extracted annually for irrigational purpose. Total amount of groundwater extracted annually from Asartepe Formation and alluvium is 7.70 hm^3. From all these units 13.27 hm^3 of groundwater is extracted annually for drinking, domestic and industrial purposes and 0.55 hm^3 of groundwater is extracted annually for irrigational purpose. Total amount of groundwater extracted annually from all the units within the modeled domain is 13.82 hm^3 (Table 3.17, 3.18, 3.19).

Table 3.17 Number of wells within the model domain and amount of groundwater consumed (Ulubey Formation)

ULUBEY	Number of Wells	Consumption (m^3/day)	Consumption (hm^3/year)
Drinking, domestic and industrial purposes	93	15317.61	5.59
Irrigational purposes	311	1439.34	0.53
Total	404	16756.95	6.12

Table 3.18 Number of wells within the model domain and amount of groundwater consumed (Asartepe Formation and alluvium)

ASARTEPE - ALLUVIUM	Number of Wells	Consumption (m^3/day)	Consumption (hm^3/year)
Drinking, domestic and industrial purposes	33	21031.07	7.68
Irrigational purposes	23	54.63	0.02
Total	56	21085.70	7.70

Table 3.19 Number of wells within the model domain and amount of groundwater consumed (total)

TOTAL	Number of Wells	Consumption (m^3/day)	Consumption (hm^3/year)
Drinking, domestic and industrial purposes	126	36348.68	13.27
Irrigational purposes	334	1493.97	0.55
Total	460	37842.65	13.81

3.4 Conceptual Hydrologic Budget

Hydrological budget, which can be defined by calculating annual recharge and discharge, can also be determined by different methods as far as case-specific conditions and data base suffice. First of all, conceptual hydrological budget of modeled Ulubey aquifer is set up by using basic hydrological data. However, due to lack of data, it is not possible to determine each component of the budget. Nevertheless, this step is compulsory because the budget that will be calculated by mathematical model should be checked with the conceptual budget at least for the components that could be determined conceptually. Following paragraphs discuss the components of hydrologic budget of Ulubey aquifer that could be calculated.

As continuous and long term flow measurements are only available for the period 1986-1992, this period is taken as basis throughout the calculations. Data such as, precipitation and temperature recorded at the stations within or around the basin, flow rates measured at the station DSİ-24 located at the outlet of the basin and flow rates measured at the stations DSİ-1, DSİ-14 and DSİ-15 representing inflow rates of the modeled Ulubey aquifer, are calculated for this time period. Locations of these flow measurement stations are shown on Figure 3.2. Missing flow rates at these stations, especially between the months December and April, are interpreted either by linear approach or by comparing with the stations having records for the data of missing period (Table 3.20). Interpreted values are shown in red color in Table 3.20.

Table 3.20 Average monthly flow rates recorded at DSİ stations 1, 14, 15 and 24 (m^3/s)

No	Months											
	X	XI	XII	I	II	III	IV	V	VI	VII	VIII	IX
1	0.234	0.317	0.393	0.470	0.546	0.623	0.700	0.523	0.413	0.367	0.197	0.138
14	0.467	0.693	1.071	1.449	1.827	2.204	2.582	1.756	1.043	0.107	0.032	0.050
15	0.460	1.110	1.499	1.887	2.276	2.664	3.053	1.889	1.024	0.063	0.000	0.000
24	3.298	4.606	5.589	5.410	5.346	7.915	10.00	7.700	4.728	3.042	3.228	3.387

Precipitation and temperature values between the years 1986-1992, representing a dry period are calculated using records of the stations which were operating in this time period. According to the results of these calculations, for the whole basin isothermal and isohyetal maps (Figures 3.33 and 3.34) are developed representing the period 1986-1992 and average temperature (12.04˚C) and average precipitation (455.67 mm/year) of this time period are determined. For the area comprising the Ulubey aquifer average temperature is determined as 12.73˚C and average precipitation is determined as 424.69 mm/year within this time period. The results indicate that the area comprising the Ulubey aquifer is exposed to higher temperature and lower precipitation than the whole basin due to its position. According to these results, during the dry period between the years 1986 and 1992, amount of precipitation over the area of 1700 km^2 comprising the Ulubey aquifer is 722 hm^3/year.

Total annual stream discharge from the area comprising the Ulubey aquifer can be calculated by subtracting the sum of the flow rate recorded at the station number 1 (12.9 hm^3/year), which is located at the entrance to the Ulubey Formation, and average of flow rates recorded at the stations number 14 and 15 (38.3 hm^3/year), which are also located close to the entrance to Ulubey Formation, from average flow rate recorded at the station number 24 (169 hm^3/year), which is located at the outlet of the basin. Total annual stream discharge from the area comprising the Ulubey aquifer calculated in this manner equals to 117.8 hm^3.

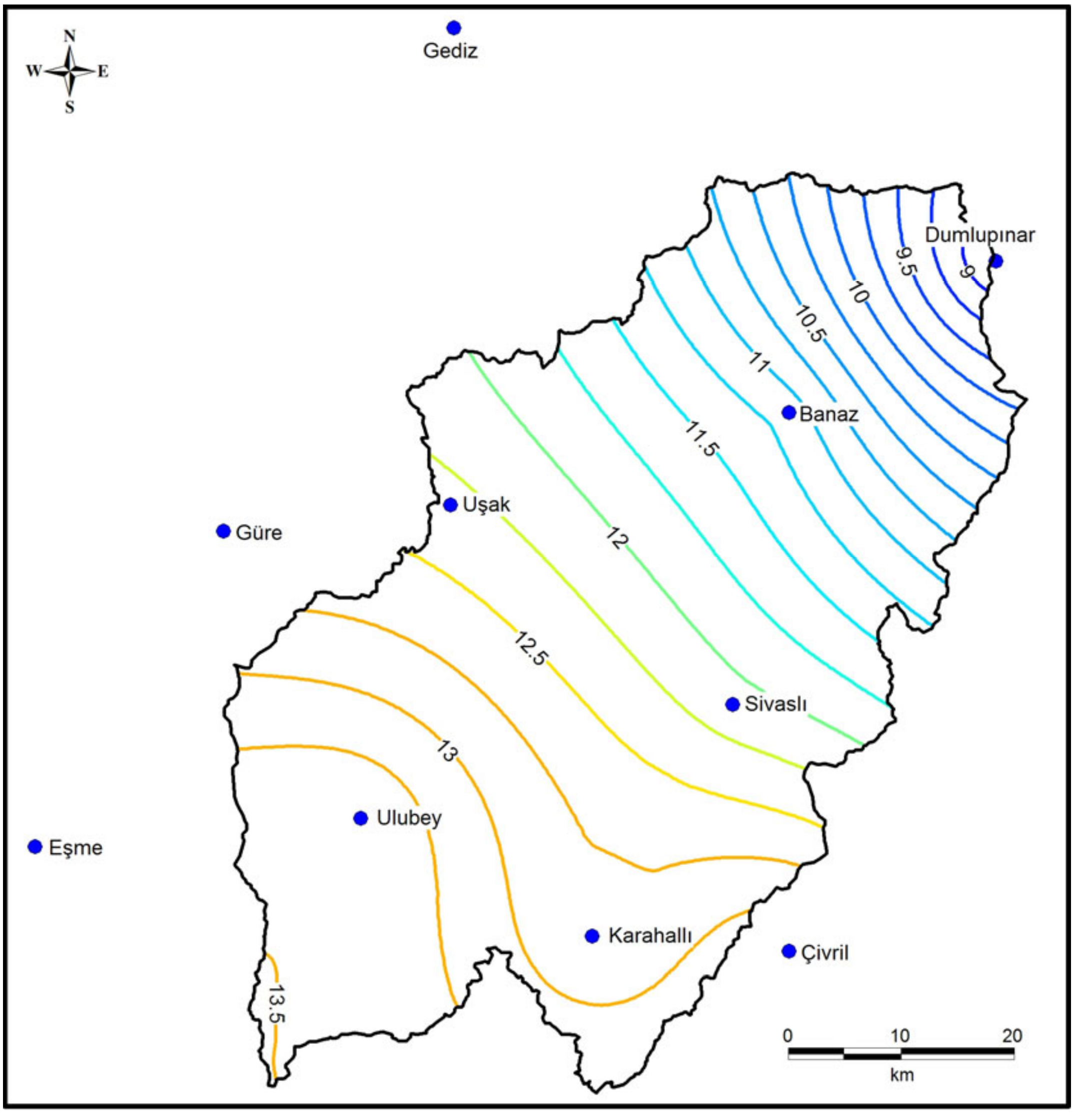


Figure 3.33 Isothermal map representing the years 1986-1992 (˚C)

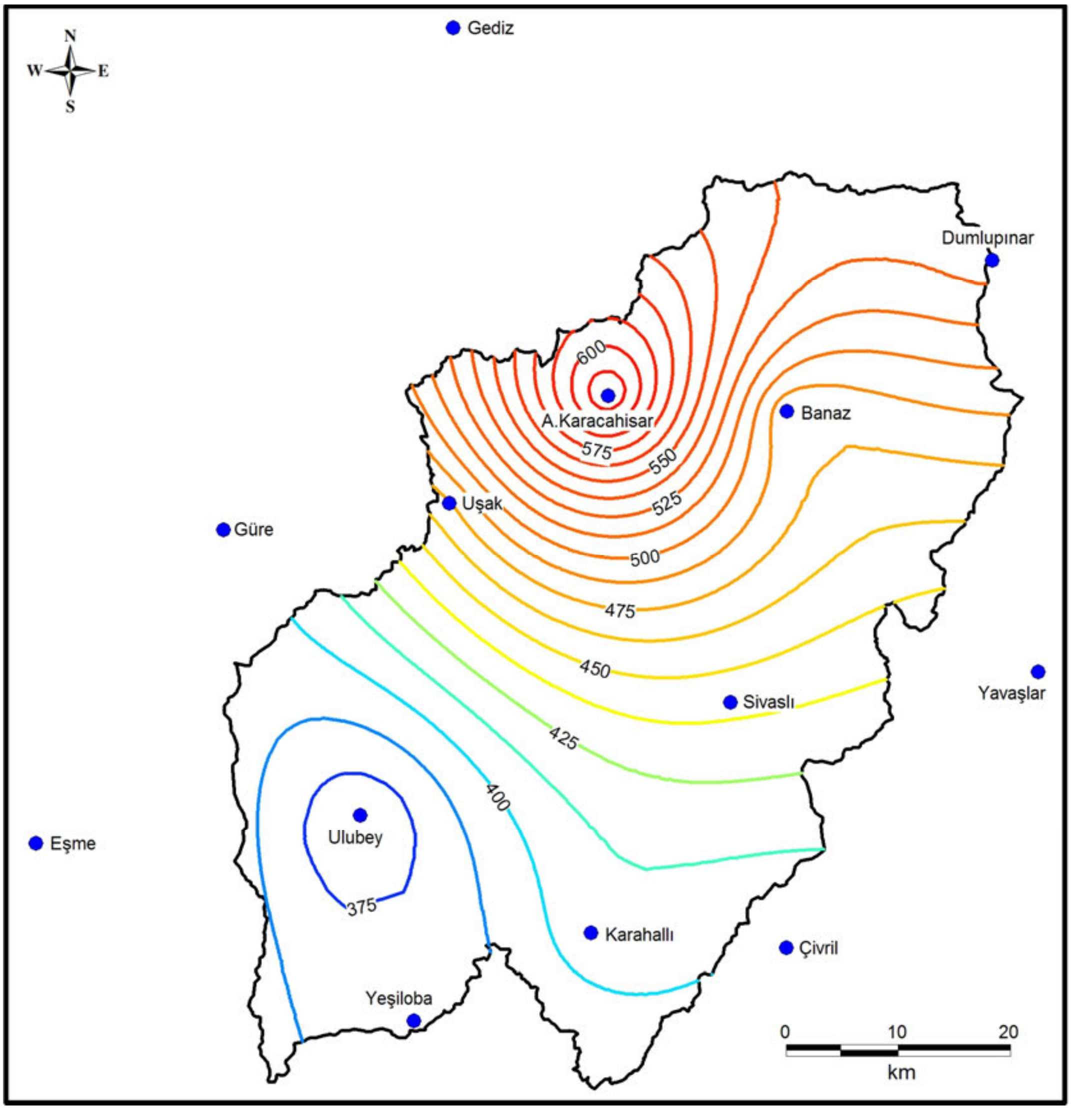


Figure 3.34 Isohyetal map representing the years 1986-1992 (mm/year)

In dry period between 1986 and 1992 amount of precipitation recorded in July, August and September is so little that it can not produce surface run off. Therefore, it is concluded that in these months stream flow is completely made up of baseflow. Amount of groundwater discharged from Ulubey aquifer, i.e. baseflow can be calculated by subtracting the sum of the flow rate recorded at the station number 1 (0.234 m^3/s), which is located at the entrance to Ulubey Formation, and average of flow rates recorded at the stations number 14 and 15 (0.042 m^3/s), which are also located close to the entrance to Ulubey Formation, from average flow rate recorded at the station number 24 (3.219 m^3/s), which is located at the outlet of the basin. In other words, amount of groundwater discharged from Ulubey aquifer to the surface waters is 92.8 hm^3 annually (2.943 m^3/s). This amount of baseflow is consistent with the one that is calculated by DSİ (1993) as 89.6 hm^3 annually (2.840 m^3/s).

By subtracting annual baseflow (92.8 hm^3) from annual discharge (117.8 hm^3), the amount of water that is transmitted from precipitation to surface flow is calculated as 25 hm^3 annually for the area of Ulubey aquifer. Isohyetal elevation of the area comprising modeled Ulubey aquifer is 424.69 mm/year that corresponds to a precipitation of 722 hm^3/year for the dry period (1986-1992). Finally, effective precipitation can be calculated by subtracting the amount of water that is transmitted from precipitation to surface flow (25 hm^3/year) from total amount of precipitation (722 hm^3/year). Thus, effective precipitation equals to 697 hm^3/year for the area comprising the Ulubey aquifer, in other words effective precipitation for the modeled domain is 410 mm/year.

Some of the effective precipitation is lost by evapotranspiration, while the rest percolates into the ground and recharges groundwater. In order to calculate evapotranspiration component of effective precipitation, which is 410 mm or 697 hm^3 annually, Turc prediction method is utilized (Equation 3.1) (Turc, 1961).

$$E_t = \frac{P}{\left[0.9 + \left(\frac{P}{L}\right)^2\right]^{\frac{1}{2}}} \quad (3.1)$$

E_t : Evapotranspiration (mm/year)

P : Average annual effective precipitation (mm)

L $= 300+25*T+0.05*T^3$

T : Average annual temperature (˚C)

Using Formula 3.1, annual evapotranspiration is calculated as 370.7 mm. By subtracting the amount of water lost by evapotranspiration (370.7 mm/year) from effective precipitation (410 mm/year), amount of groundwater recharge from precipitation is calculated as 39.3 mm annually (66.8 hm^3/year).

Apart from the method explained in detail so far, Thornthwaite method is also utilized to determine the amount and distribution of recharge to groundwater (Thornthwaite, 1948). In this way, it is possible to compare the amount of groundwater recharge calculated by different methods. In order to calculate the amount of groundwater recharge from precipitation by Thornthwaite method, average monthly temperature and precipitation values recorded at meteorological stations within and around the basin (Banaz, Güre, Sivaslı, Eşme, Ulubey, Karahallı, Uşak, Dumlupınar, Çivril, Gediz) representing the dry period between 1984 and 1995 are utilized. Initial soil moisture is assumed to be 100 mm in the calculations with Thornthwaite method, by which groundwater recharge is calculated for each of the meteorological stations and then areal distribution of recharge is determined (Figure 3.35). By this method annual groundwater recharge is calculated as 39.4 mm, or 67 hm^3 for the area comprising the Ulubey aquifer.

To sum up, groundwater recharge calculated by two different methods (66.8 and 67.0 hm^3/year) are very close to each other indicating that methods used and assumptions made were compatible with the characteristics of the basin.

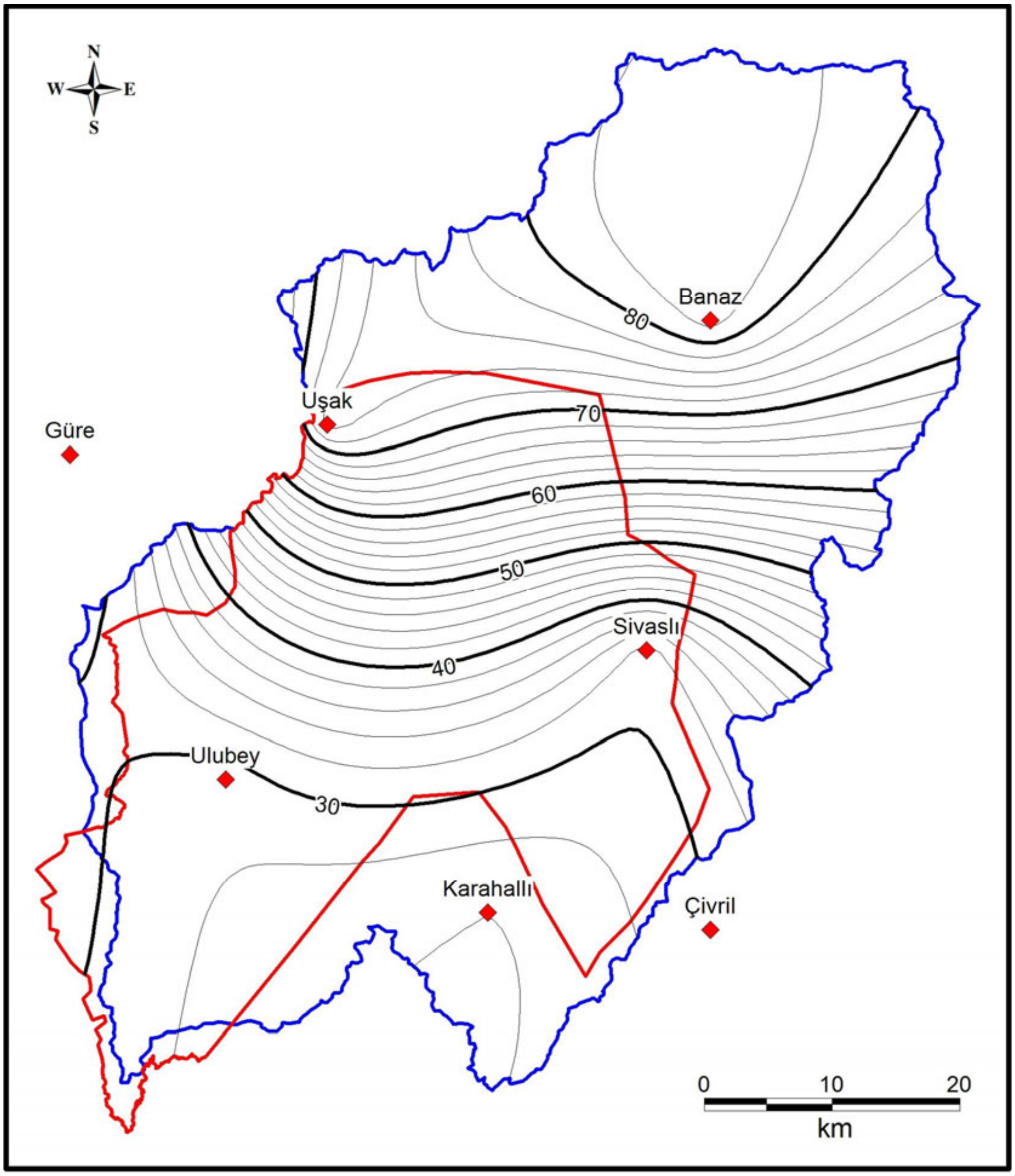


Figure 3.35 Areal distribution of groundwater recharge (mm/year)

As a result, the extent of Ulubey aquifer is 1700 km^2, 482.3 km^2 of which is overlain by Asartepe Formation and alluvium. By a simple ratio, it is calculated that direct recharge to Ulubey aquifer is only 48 hm^3/year. The only recharge component of the groundwater budget, is the recharge from precipitation (48 hm^3/year). On the other hand, if discharge components of the groundwater budget, which are baseflow (92.8 hm^3/year), groundwater extracted from wells (6.12 hm^3/year), spring discharge (6.0 hm^3/year) are summed up, it makes a total discharge of 104.9 hm^3/year. Discharge of springs along Yavu and Banaz Streams are not included in discharge through springs as their discharge is considered as baseflow. Finally the gap between recharge and discharge of Ulubey aquifer (56.9 hm^3/year) implies that approximately 57 hm^3 of groundwater has to be reduced from the reserve and groundwater levels have to decline continuously. However, as it is shown on Figure 3.28, groundwater levels of Ulubey aquifer has been stabilized since 1990. This fact proves that aquifer is recharged from other units and it may also discharge to other units. That is why a mathematical groundwater flow model has to be utilized in order to determine the groundwater flow budget of Ulubey, Asartepe and alluvium aquifers. Groundwater budget calculated by this method will be discussed in detail in Chapter 5.

CHAPTER 4

GROUNDWATER FLOW MODEL

4.1 Model Description

A “model” is a representation of a real world system with proper simplifications and assumptions. Models are widely utilized in understanding mechanisms and testing possible responses of real world systems in every branch of science, as well as hydrogeology.

Hydrogeologic models, simulating the groundwater flow and transport mechanisms, can serve for a wide range of applications, which are listed by Mandle (2002) as follows:

- Prediction of the possible fate and migration of contaminants for risk evaluation.
- Tracking the possible migration pathway of groundwater contamination.
- Evaluation of design of hydraulic containment and pump-and-treat systems.
- Design of groundwater monitoring networks.
- Wellhead protection area delineation.
- Evaluation of regional groundwater resources.
- Prediction of the effect of future groundwater withdrawals on groundwater levels.

Moreover, groundwater models could be used as tool to understand the systems behaviours and they are informative and predictive.

The aim of setting up a hydrogeological model for this study is to evaluate the groundwater budget of the Ulubey aquifer system and to predict the effects of future management scenarios on groundwater levels, spring discharges and baseflows.

There are basically three types of groundwater models: physical, analog and mathematical models. A physical model, in general, is rescaled representation of the original systems, for instance sand tank models are miniature aquifer systems demonstrating flow and transport mechanisms. An analog model is based on the similar characteristics and processes of different systems, even if they are physically irrelevant; for example flow of water can be associated with electrical current, where flow rate, hydraulic gradient, hydraulic conductivity are represented by electrical current, potential difference and resistance respectively. A mathematical model differs from other models in its attempt to simulate the actual behavior of a system through the solution of mathematical equations (Schwartz et al., 1990).

A further step is the solution of mathematical models, in other words the solution of differential equations representing groundwater flow and transport processes. These equations can either be solved by analytical methods, which provide exact solutions to equations that describe very simple conditions, or by numerical methods, which utilize approximations of equations that describe very complex conditions (Mandle, 2002). The advantages of an analytical solution, when it is possible to apply one, are that it usually provides an exact solution to the governing equation and is often relatively simple and efficient to obtain. However, analytical solutions can only be applied for certain boundary conditions under simplifying assumptions. For most field problems, the mathematical benefits of obtaining an exact analytical solution are probably outweighed by the errors introduced by the simplifying assumptions of the complex field environment that are required to apply the analytical model. Alternatively, for problems where the simplified analytical models are inadequate, the partial differential equations can be approximated numerically. In doing so, the continuous variables are replaced with discrete variables that are defined at grid blocks (or nodes). Thus, the continuous differential equation, which defines hydraulic head or solute concentration everywhere in the system, is replaced by a finite number of algebraic equations that defines the hydraulic head or concentration at specific points. This system of algebraic equations generally is solved using matrix techniques (Konikow, 2000).

Numerical models use approximations (e.g. finite differences, or finite elements) to solve the differential equations describing groundwater flow or solute transport. The approximations require that the model domain and time be discretized. In this discretization process, the model domain is represented by a network of grid cells or elements, and the time of the simulation is represented by time steps. The accuracy of numerical models depends upon the accuracy of the model input data, the size of the space and time discretization (the greater the size of the discretization steps, the greater the possible error), and the numerical method used to solve the model equations (Mandle, 2002).

In this study, modular finite-difference groundwater flow model (MODFLOW-2000) developed by the U.S. Geological Survey (USGS) is utilized (Harbaugh et al., 2000). The mathematical model used as a basis of the developed model and the method of numerical solution are discussed below in detail.

4.1.1 Computer Code Selection

In this study, Argus ONE (Open Numeric Environment) software is utilized which enables data groups to be stored in different layers and enables the logical and mathematical relations between these layers. Argus ONE is a GIS software in which several models, such as MODFLOW, MT3DMS, ZONEBUDGET, SEAWAT and SUTRA, can be integrated. In order to properly determine groundwater potential of the Ulubey aquifer, located in the Banaz Stream Basin, a groundwater flow model characterizing the system is created by MODFLOW GUI (Graphical User Interface for Argus ONE) (Shapiro et al., 1997; Hornberger and Konikow, 1998; Winston, 1999; and Winston, 2000) integrated in Argus ONE. MODFLOW GUI is a software developed by U.S. Geological Survey, which supports several versions of MODFLOW known as modular three-dimensional finite difference groundwater flow model, such as MODFLOW-2000 (Harbaugh et al., 2000; Hill et al., 2000) and MODFLOW-1996 (Harbaugh and McDonald, 1996).

The applications of MODFLOW started to grow up by 1980's and since then MODFLOW has continuously evolved with additional packages and programs. The reasons why MODFLOW is chosen within the scope of this study can be listed as follows:

- MODFLOW can simulate a wide variety of hydrologic processes in the field conditions in three dimensions.
- MODFLOW is capable of simulating various geological features such as different hydrogeological units, heterogeneity and anisotropy. The model also includes structural elements like faults and tilted layers.
- Confined aquifers, unconfined aquifers and aquitards can be simulated under both steady state and transient state conditions.
- A variety of hydrological features including rivers, streams, drains, springs, reservoirs and wells; as well as hydrological processes including evapotranspiration and recharge can be simulated.
- Hydrological simulations used in MODFLOW has been verified worldwide by modeling studies.
- In many legal cases, MODFLOW has been accepted as a legitimate approach in the analysis of groundwater systems, in foreign countries.

4.1.2 Mathematical Model

Groundwater modeling begins with a conceptual understanding of the physical problem. The next step in modeling is translating the physical system into mathematical terms. The governing flow equation for three-dimensional saturated flow in saturated porous media is given in Equation 4.1 (Kumar, 2006).

$$\frac{\partial}{\partial x}\left(K_{xx}\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_{yy}\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_{zz}\frac{\partial h}{\partial z}\right)-Q=S_s\frac{\partial h}{\partial t} \qquad 4.1$$

where,

K_{xx}, K_{yy}, K_{zz}	: hydraulic conductivity along x, y, z axes (L/T)
h	: piezometric head (L)
Q	: volumetric flux per unit volume representing source/sink terms (T^{-1})
S_s	: specific storage coefficient of porous material (L^{-1})
t	: time (T)

Equation 4.1 when combined with boundary and initial conditions, describes transient three-dimensional groundwater flow in a heterogeneous and anisotropic medium, provided that the principal axes of hydraulic conductivity are aligned with the coordinate directions (Harbaugh et al., 2000).

4.1.3 Numerical Solution

The Groundwater Flow Process of MODFLOW solves the Equation 4.1 using the finite difference method in which groundwater flow system is divided into a grid of cells. For each cell, there is a single point called a node, at which head is calculated (Figure 4.1).

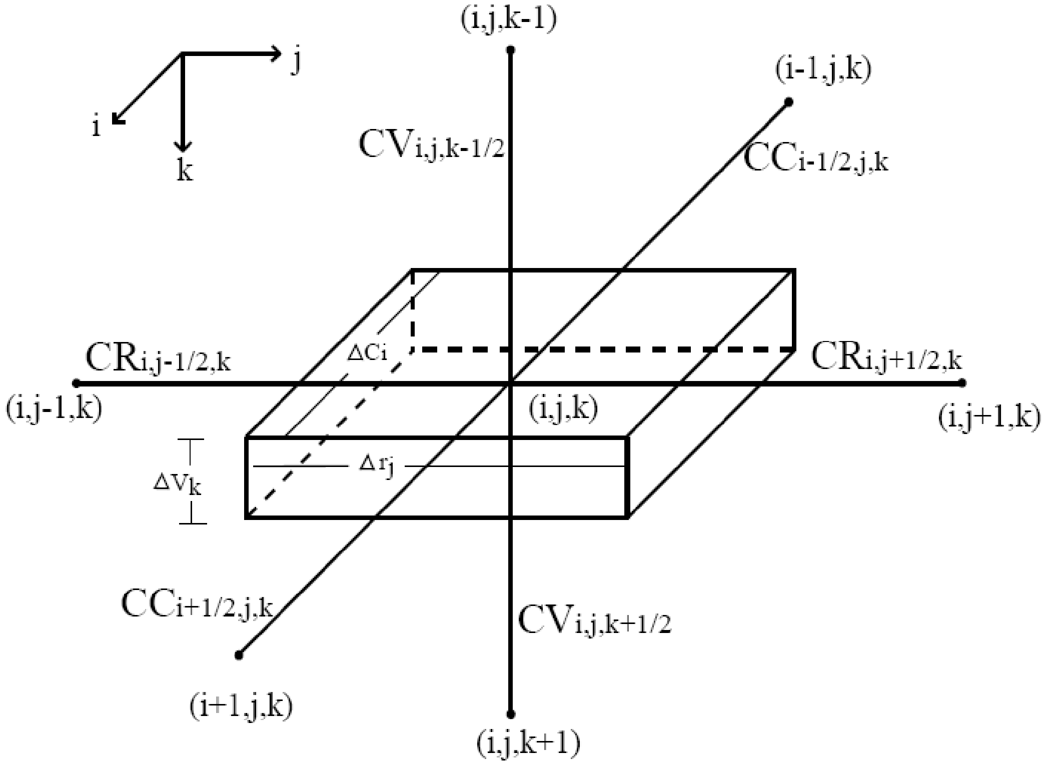


Figure 4.1 Definition of conductance terms between model cells

The finite difference equation for a cell is (McDonald and Harbaugh, 1988):

$$
\begin{aligned}
& CR_{i,j-1/2,k}\left(h^m_{i,j-1,k}-h^m_{i,j,k}\right)+CR_{i,j+1/2,k}\left(h^m_{i,j+1,k}-h^m_{i,j,k}\right) \\
& +CC_{i-1/2,j,k}\left(h^m_{i-1,j,k}-h^m_{i,j,k}\right)+CC_{i+1/2,j,k}\left(h^m_{i+1,j,k}-h^m_{i,j,k}\right) \\
& +CV_{i,j,k-1/2}\left(h^m_{i,j,k-1}-h^m_{i,j,k}\right)+CV_{i,j,k+1/2}\left(h^m_{i,j,k+1}-h^m_{i,j,k}\right) \\
& +P_{i,j,k}h^m_{i,j,k}+Q_{i,j,k}=SS_{i,j,k}(DELR_j\times DELC_i\times THICK_{i,j,k})\frac{\left(h^m_{i,j,k}-h^{m-1}_{i,j,k}\right)}{t_m-t_{m-1}}
\end{aligned}
\qquad 4.2
$$

where,

$h^{m}_{i,j,k}$	: head at cell i, j, k at time step m (L)
CV, CR, CC	: hydraulic conductances, or branch conductances, between node i, j, k and a neighboring node (L^2/T)
$P_{i,j,k}$	: sum of coefficients of head from source and sink terms (L^2/T)
$Q_{i,j,k}$	: sum of constants from source and sink terms (L^2/T), with $Q_{i,j,k}$<0 for flow out of the groundwater system, $Q_{i,j,k}$>0 for flow in (L^3/T)
$SS_{i,j,k}$	: specific storage (L^{-1})
$DELR_j$	: cell width of column j in all rows (L)
$DELC_i$	: cell width of row i in all columns (L)
$THICK_{i,j,k}$	: vertical thickness of cell i, j, k (L)
t^m	: time at step m (T)

To designate hydraulic conductance between nodes, as opposed to hydraulic conductance within a cell, the subscript notation "1/2" is used. For example, $CR_{i,j+1/2,k}$ represents the conductance between nodes i, j, k and i, j+1, k. The application of the Equation 4.2 to all cells defines a set of simultaneous equations, and these equations are solved for each node (Harbaugh et al., 2000).

The finite difference equation is solved by what are known as iterative methods. On the basis of the fixed head values, plus the initial guesses, Equation 4.2 is solved for each node on the basis of the values at the surrounding four nodes. During solution, for each node, other than the first one and the last one, the head values at some of the adjacent nodes will be based on the initial guess, while at the remainder of the adjacent nodes the head value will already have been recomputed. Once the head at each node has been recomputed, the difference between the initial guess and the recomputed head is determined. The process is repeated until the maximum difference in head values from one iteration to the next is less than some present value known as the convergence criterion. The smaller that value is, the more iterations, and hence the longer period of time, it takes to reach the solution. There is some practical trade-off between accuracy of the solution and the amount of computer time expended to reach it (Fetter, 2001).

In this study, Preconditioned Conjugate-Gradient (PCG2) (Hill, 1990) is used to solve the finite difference equations for hydraulic head, with a convergence criterion 0.05 m.

4.2 Conceptual Model of the Aquifer System

According to the hydrogeological classification of the units within the Banaz Stream Basin described in detail in Chapter 3, Musadağı and Kızılcasöğüt Formations, Ulubey Formation, Asartepe Formation and Quaternary alluvium are determined as the most important units having good aquifer properties on regional basis. Other units either form the base due to their impermeable characteristics or do not have regional significance due to limited or disconnected outcrops.

Before setting up the numerical model that will be used to develop a groundwater management program, hydrogeological system should conceptually be defined. As a result of a detailed investigation on aquifer characterization and evaluation of gathered data; Ulubey Formation, Asartepe Formation and alluvium are considered in conceptual aquifer model. Having similar hydraulic properties and overlapping extensions, Asartepe Formation and alluvium are considered as a single unit. As a result, Ulubey Formation that is the most important aquifer of the study area and Asartepe Formation that is considered as a single unit with alluvium are defined separately on mathematical model. Asartepe Formation and alluvium, overlie Ulubey Formation in northern and eastern parts of the model domain.

As it is mentioned before in Chapter 3 in detail, marbles having broad extension along southern and eastern parts of the basin have good aquifer properties. However, there is not enough data to define their regional geometry, groundwater levels, boundary conditions and hydraulic properties. That is why marbles are not included in mathematical model, instead, lateral flows between marbles and other simulated units are considered in modeling stage.

Finally, a model of two layers, upper one simulating Asartepe Formation and alluvium, and lower one simulating Ulubey Formation, is designed and lateral flow from marbles to the system is taken into account during simulation.

4.3 Finite Difference Grid

The first stage of groundwater flow model design is setting up the finite difference grid. For this purpose, aquifer system is splitted into blocks in which hydrogeological parameters are assumed to be uniform. Although hydrogeological parameters do not change within a single block, they may change from block to block. Consequently, the smaller the block size, the better simulated the aquifer parameters. On the contrary, the smaller the block size, the more time and computer memory required to solve the model. Moreover, hydrogeological parameters may not be available for each single block. Therefore, minimum number of blocks that are capable of representing the heterogeneity of the aquifer, distribution of available data and aquifer boundaries should be utilized.

Among the factors considered in determination of model domain are the faults separating different geological units, zones where saturated thickness is at least 10 m and boundaries where impervious units outcrop. The resulting model area is shown on Figure 4.2. Model grid is oriented in the direction of anisotropy axis (NE-SW), which also coincides with the alignment of Banaz and Yavu Streams. This aquifer area is splitted into blocks with uniform size of 500 m by 500 m. In the progressive stages of modeling, grid size is refined up to 100 m by 100 m, along Banaz and Yavu Streams and around the localities of significant faults.

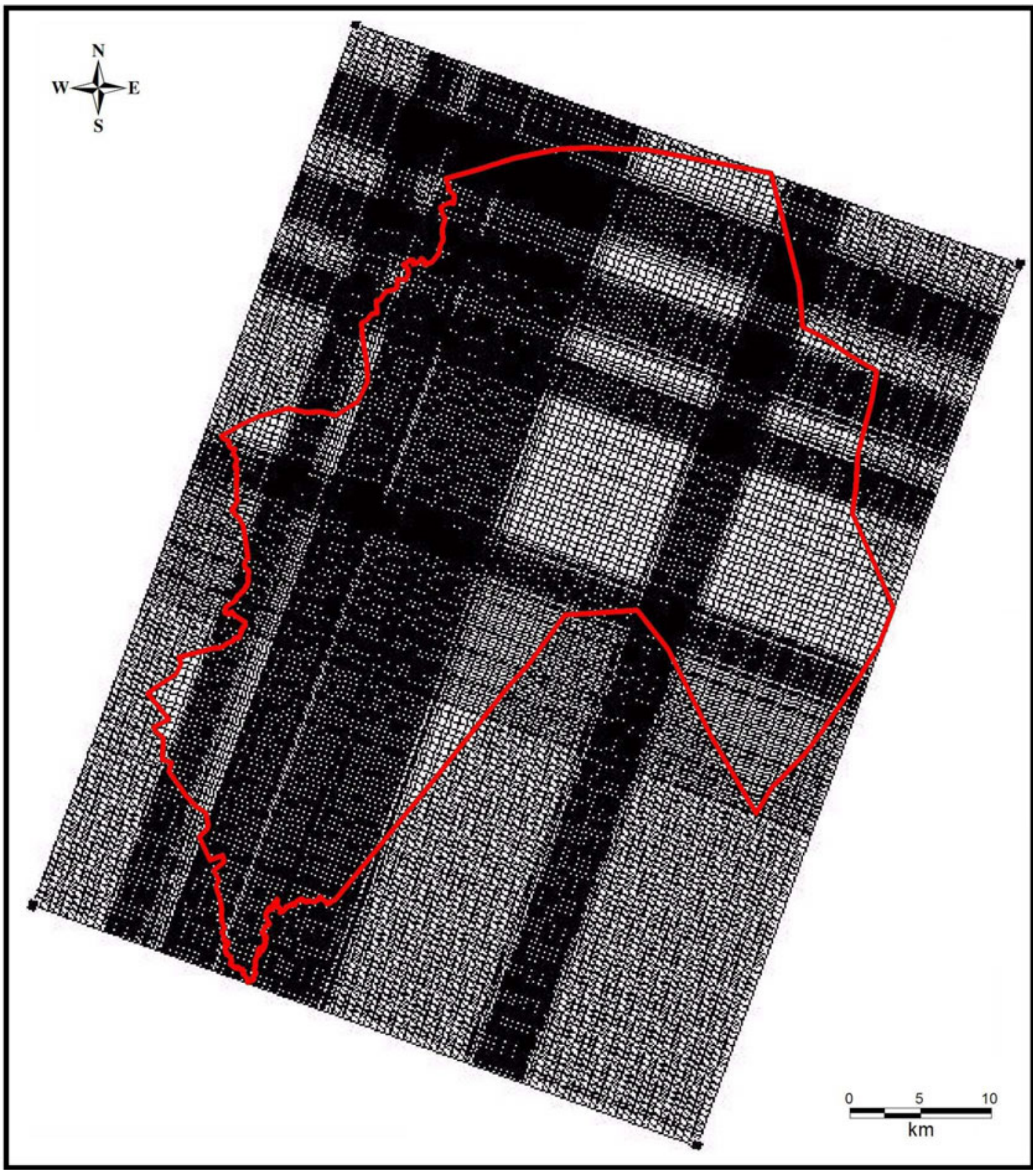


Figure 4.2 Groundwater flow model finite difference grid

4.4 Boundary Conditions

Model boundaries are determined considering geological and hydrogeological characteristics of the basin. During calibration stage, boundary conditions and geological structure of the aquifer are superposed and embedded into the model grid. Boundary conditions of the model have to be discussed separately for the two layers constituting the model. First layer representing Asartepe Formation and alluvium does not spread continuously throughout the model domain. This layer overlies the second layer representing Ulubey Formation, which has a continuous extent throughout the model domain, in the north and east of the model domain (Figure 4.3). Due to the fact that first layer representing Asartepe Formation and alluvium does not spread continuously throughout the model domain, this layer is defined as inactive except the area shown with red color in Figure 4.3. In other words, this layer is simulated only in the area shown with red color in Figure 4.3.

The northern boundary of the model is determined as the fault separating the outcrops of Yeniköy Formation from Ulubey Formation and Asartepe Formation and alluvium overlying Ulubey Formation in this locality. In order to simulate the continuous recharge to the model domain through this fault zone, general head boundary condition is utilized.

Adıgüzel Dam forming the southern boundary of the model is simulated by constant head boundary condition with 410 m head elevation, which represents water level elevation at the dam.

Lithological boundary between Ulubey Formation and both Ahmetler Formation and Beydağı volcanics forms the western boundary of the model except Çamdere locality. As the conductances of these two units (Ahmetler Formation and Beydağı volcanics) are lower than that of Ulubey Formation, it is assumed that groundwater flow through this boundary is negligible and therefore, no flow boundary condition is utilized. In a small locality along the western boundary of the model, to simulate the groundwater flow into the study area from the portion of

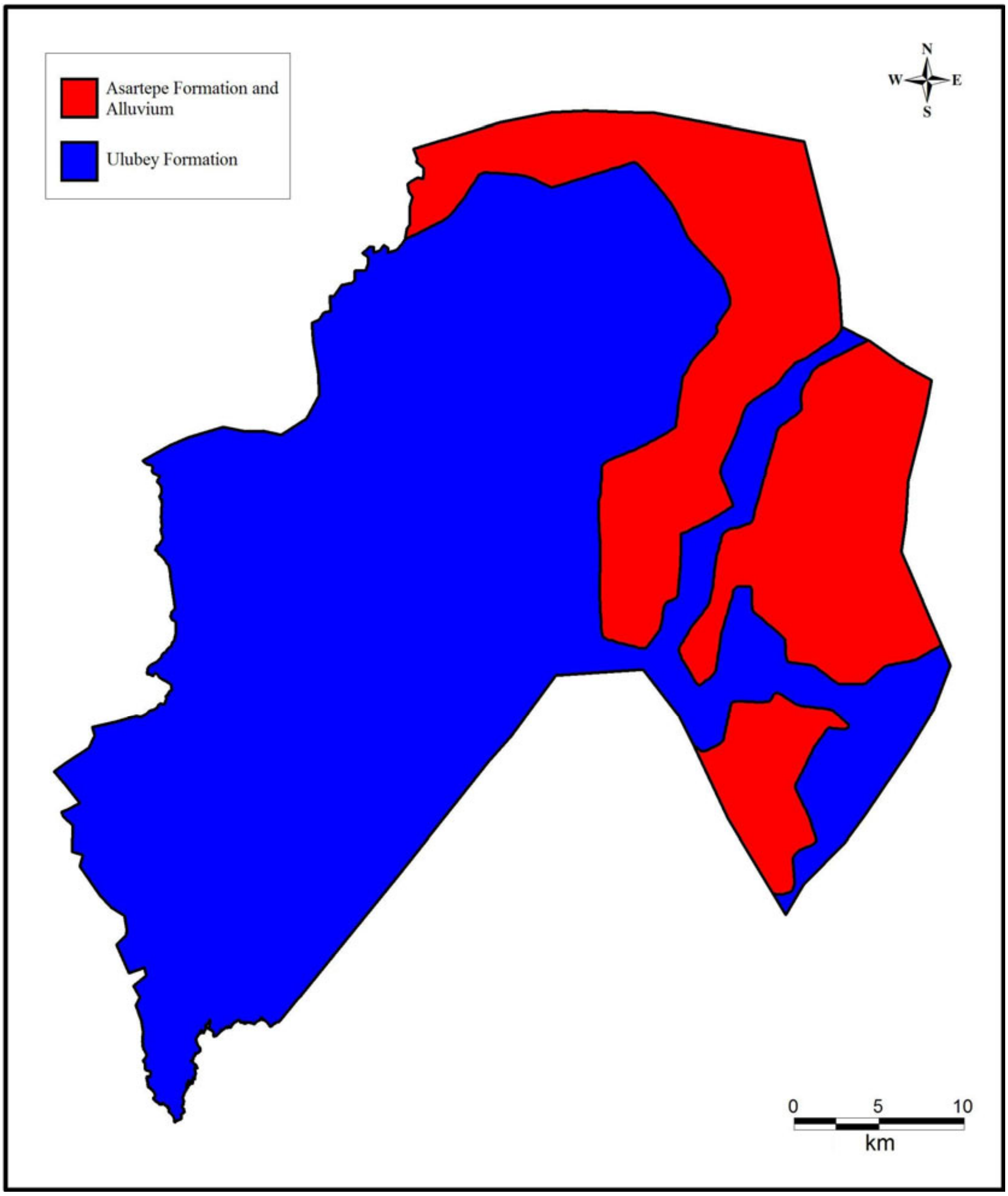


Figure 4.3 Units simulated in the groundwater flow model

Ulubey Formation in northwest around Güre, general head boundary condition is used along the groundwater equipotential contour of 860 m. Amount of groundwater recharge along this boundary into the model domain is determined during calibration studies.

The southeastern boundary of the model around Karahallı and the eastern boundary of the model in the east of Sivaslı are formed by the faults aligned in these directions. These faults separate the marbles, which extends eastwards from the study area, from Ulubey Formation, Asartepe Formation and alluvium. General head boundary condition is used to simulate the recharge from marbles into the model domain along the eastern boundary and discharge from the model domain into the marbles around Karahallı.

The northeastern boundary of the model is formed by the impervious units cropping out around the valley through which Banaz Stream flows. Around this locality Ulubey Formation is overlain by Asartepe Formation and alluvium, which extend out of the model domain towards northeast. Hence, for the first model layer representing Asartepe Formation and alluvium, general head boundary condition is used to simulate the lateral groundwater flow from the portion of these two units extending towards northeast. Groundwater flow into Ulubey Formation through this boundary is assumed to be negligible. Therefore, for the second model layer representing Ulubey Formation, no flow boundary condition is utilized along this boundary.

Banaz and Yavu Streams are simulated with River Package in the model. Water level measurements performed in April and May 2007 along Banaz and Yavu Streams are taken as basis in determination of stage of river and conductance of river is determined during calibration. Springs located on Sivaslı and Ulubey Plains (İnay, Sarıkız, Sivaslı1, Sivaslı2 and Pınarbaşı1) are simulated with Drain Package and conductances of these drains are determined during calibration. Springs having high discharge rates and located along Banaz and Yavu Streams (Cabar, Avgan, Kocapınar and Uyuz) are considered within River Package as they discharge directly at the flow elevation of these streams.

NE-SW aligned faults located in the west of Ulubey are defined as pervious zones because of the associated spring discharges and they are simulated with high hydraulic conductivity zones. E-W faults located in the north of model domain are defined as impervious zones because of the anomalies in groundwater levels and they are simulated with Horizontal Flow Barrier.

Groundwater table forms the upper hydrogeological boundary of the model except the locations of Banaz and Yavu Streams and Adıgüzel Dam. Impervious units overlain by Ulubey Formation constitute the lower boundary of the model.

Boundary conditions of the two layers, upper one simulating Asartepe Formation and alluvium, and lower one simulating Ulubey Formation, are given in Figures 4.4 and 4.5, respectively. Groundwater extraction from these units is simulated by Well Package and locations of these wells are also presented in Figures 4.4 and 4.5.

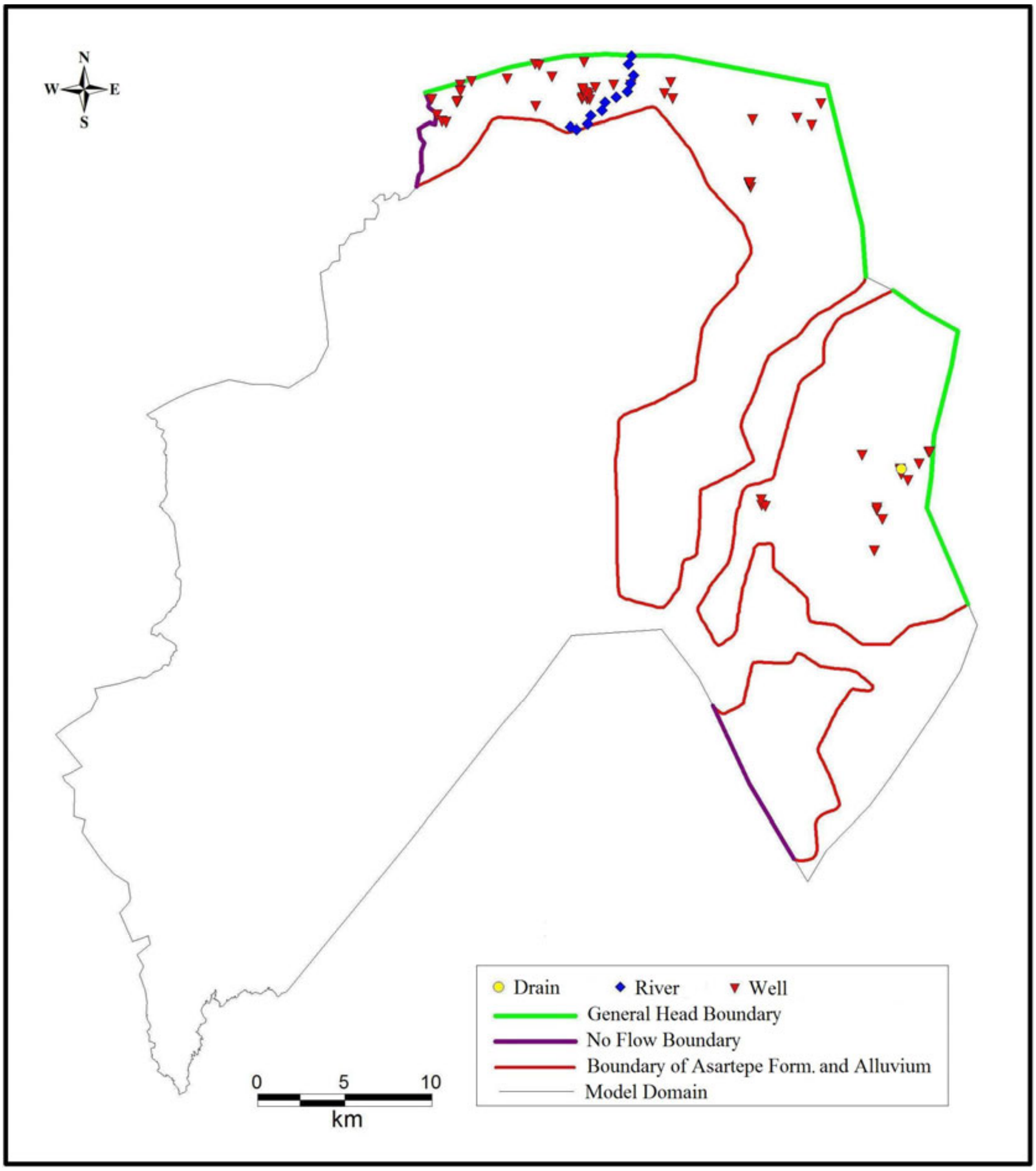


Figure 4.4 Boundary conditions of Asartepe and alluvium aquifers

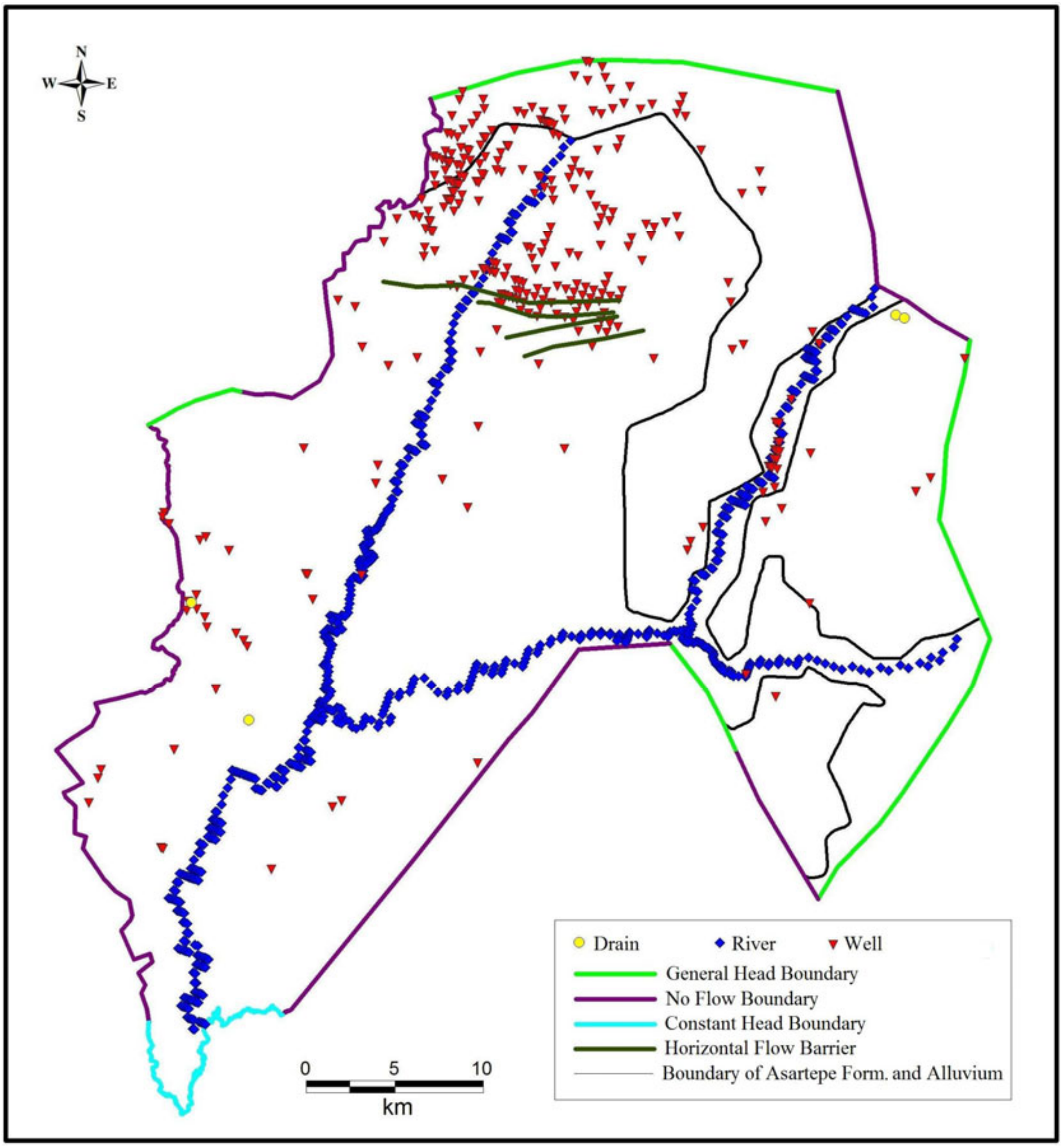


Figure 4.5 Boundary conditions of Ulubey aquifer

CHAPTER 5

CALIBRATION OF THE GROUNDWATER FLOW MODEL

5.1 Model Parameters

After the determination of model grid and boundary conditions, recharge and discharge parameters and hydraulic parameters of the units are input into the model. Calibration process is finalized when a good match between the groundwater levels observed in the field and calculated by the model is achieved.

5.1.1 Groundwater Recharge

Recharge from precipitation into the model domain is calculated with different methods, which are discussed in Chapter III in detail. Recharge calculated by Thornthwaite method is used in the model because by this method, it is possible to calculate the recharge at each station (Thornthwaite, 1948). The recharges calculated for different stations are further used to create equi-recharge map of aquifer enabling the simulation of areal distribution of recharge (Figure 5.1). By this manner, for each block within the model domain recharge value is determined by interpolation between equi-recharge curves and assigned to the highest active block. For example, if a block of the upper model layer representing Asartepe Formation and alluvium goes dry, recharge is directly assigned to the block of the lower model layer representing Ulubey Formation, which is active.

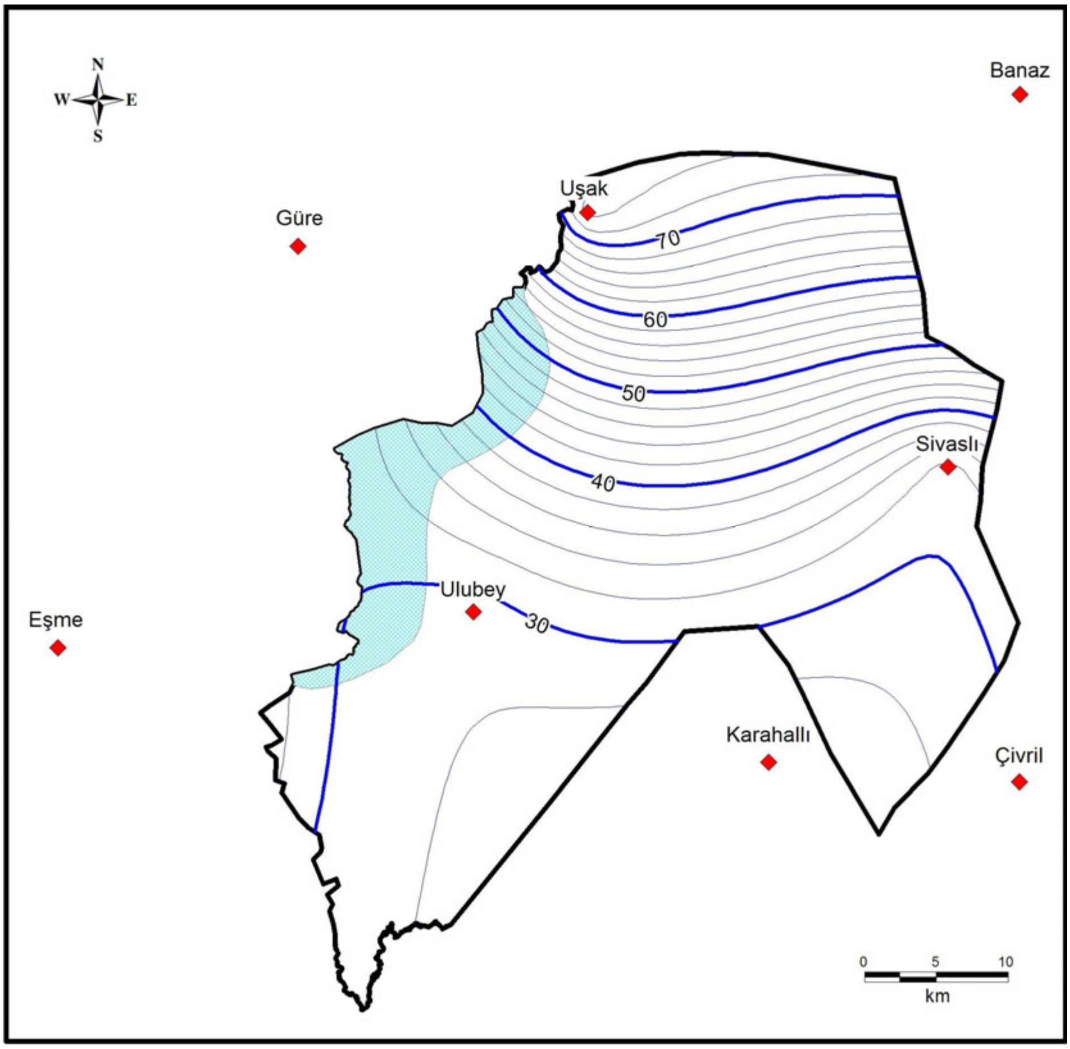


Figure 5.1 Areal distribution of recharge within the model domain (mm/year) and meteorological stations for which recharge is calculated by Thornthwaite method

In addition to the recharge from precipitation, a portion of the surface flow coming from the mountainous region located in the west of the model domain, percolate into the groundwater through Ulubey limestones in the plain area within the model domain. Amount of water that forms the surface flow in the mountainous area of 88.5 km^2 is calculated as 10.09 hm^3/year, by using the annual surface flow value for Uşak meteorological station (114 mm/year). It is supposed that this water percolates into groundwater within an area of 148.8 km^2 which is shown on Figure 5.1 with blue color. To sum up, 67.8 mm of extra recharge from surface flow is calculated for this area.

5.1.2 Hydraulic Conductivity

In the first attempt, hydraulic conductivities calculated for 31 wells drilled in Ulubey formation and 14 wells drilled in Asartepe Formation and alluvium and the distribution of hydraulic conductivity created in this manner is considered. During calibration, these values are changed so that new values assigned are compatible with the characteristics of these units except İnay and Karin Faults. Calibrated hydraulic conductivity values of Ulubey aquifer are shown in Figure 5.2. Vertical hydraulic conductivity values, which are affective on the vertical interactions between the two layers of the model, are assigned in the model based on the assumption that vertical hydraulic conductivity values are equal to the one tenth of the horizontal hydraulic conductivity values of the same model block.

Geology and structural geology of the basin indicate NE-SW aligned faults and fractures within the model domain. Hence, an anisotropy factor of 1.5 is applied in the model in this direction. Moreover, İnay and Karin Faults aligned in the same direction with the fracture system, recharge İnay and Sarıkız Springs, respectively. According to this property of these two faults, they are simulated as high hydraulic conductivity zones in the model and their hydraulic conductivity values are determined during calibration studies.

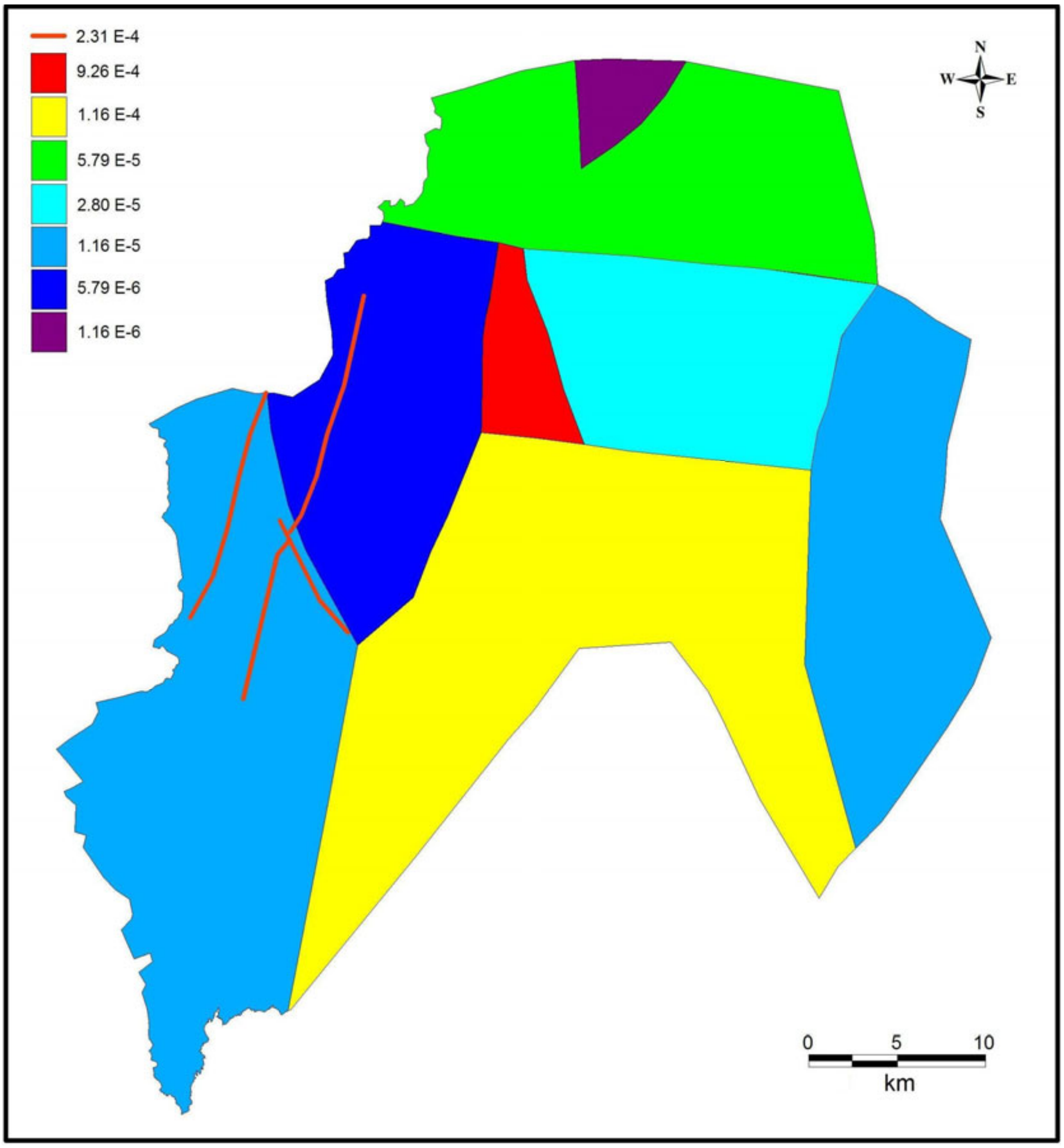


Figure 5.2 Distribution of hydraulic conductivity of Ulubey aquifer within the model domain (m/s)

5.2 Calibration

During calibration studies, input parameters of the model, such as hydraulic conductivity, recharge and conductances of drains and rivers are modified by trial and error. Input parameters of the model are modified within the geological and hydrogeological limits of the simulated units until a good correlation of groundwater levels, spring discharges and baseflows observed in the field and calculated by the model is achieved.

Model is calibrated under steady state conditions according to the observed groundwater levels of the Ulubey aquifer. Although groundwater levels recorded in Asartepe Formation and alluvium do not maintain steady state conditions, the primary concern of this study is Ulubey aquifer. Moreover, there is not enough data which can be used to develop a groundwater level map for Asartepe Formation and alluvium which could show the areal distribution of groundwater levels in these units. Hence, these units are included in the groundwater flow model just to determine their interactions with the Ulubey aquifer. The amount of discharge through springs and streams are also considered in the calibration process. Hydraulic conductivity, anisotropy, conductances of drain, river and general head boundary conditions are modified during calibration. Storage coefficient is not used under steady state flow conditions.

Two criteria are considered in order to test how well the model represents the field conditions. One of these criteria is the consistency of measured and calculated groundwater levels, spring discharges and baseflows; the other criterion is the consistency of the conceptual and calculated budget of the system.

5.2.1 RMS (Root Mean Square Error)

During calibration studies one of the objectives is the minimization of RMS (Root Mean Square Error) or RMS percentage. These two concepts can be defined by the Equations 5.1 and 5.2, respectively.

$$RMS = \left[\frac{1}{n} \sum_{i=1}^{n} \left(h_0 - h_h \right)_i^2 \right]^{0.5} \tag{5.1}$$

$$RMS(\%) = \frac{RMS}{(h_0)_{\max} - (h_0)_{\min}} \tag{5.2}$$

In these equations,

n : total number of observation points,

h_0 : observed groundwater level,

h_h : calculated groundwater level.

The points for which observed and calculated groundwater levels are compared and whose distribution is presented in Figure 5.3 can be classified as: points at which river stages along Banaz and Yavu streams are measured in April 2007; springs and wells drilled by DSİ, Bank of Provinces and Rural Services which are utilized to create groundwater level map

However, these points are not distributed uniformly throughout the model domain to represent the whole aquifer area. That is why artificial head observation points are introduced to the model area with 2500 m intervals. At these artificial head observation points, observed groundwater levels are imported from the groundwater level map of the Ulubey aquifer.

Observed groundwater levels and calculated groundwater levels at the end of calibration with 5.06% tolerance (RMS %) are presented in Figures 5.4 and 5.5, respectively. As it can be seen from these figures, at the end of calibration a good match between observed and calculated groundwater levels is achieved. Figure 5.6 represents the graphical relation between observed and calculated groundwater levels at all observation points discussed above.

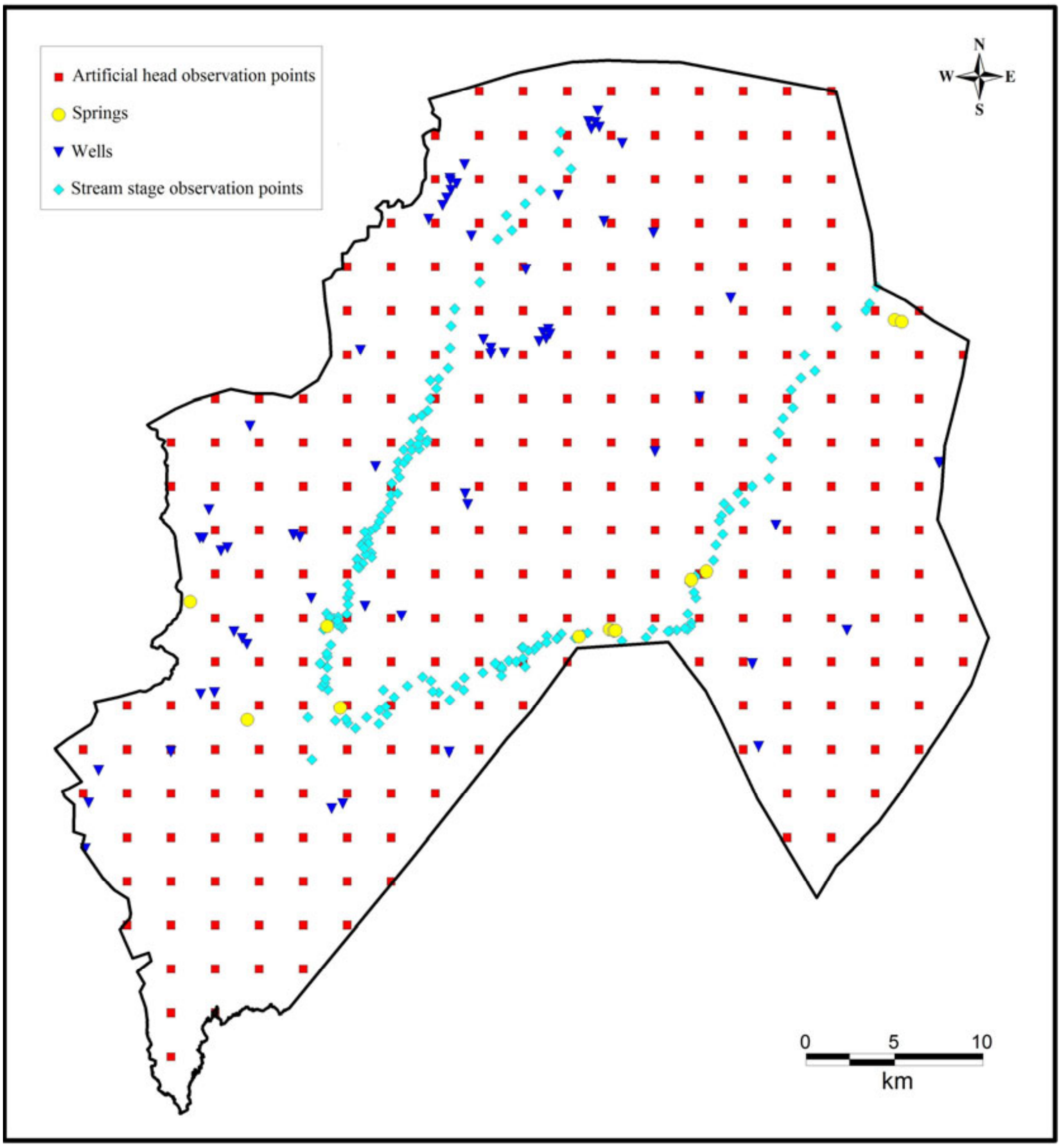


Figure 5.3 The points for which observed and calculated groundwater levels are compared during calibration

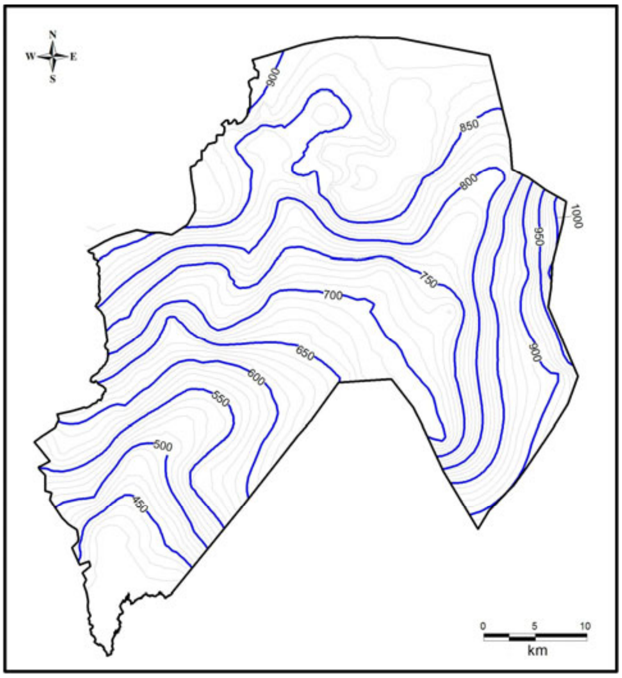


Figure 5.4 Observed groundwater levels

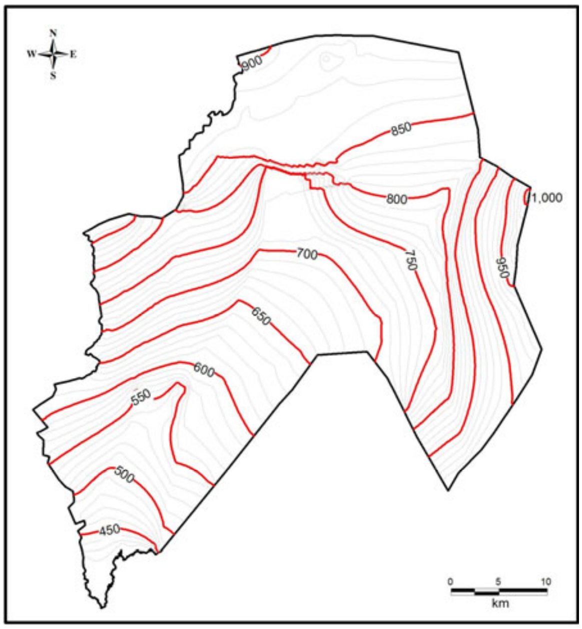


Figure 5.5 Calculated groundwater levels

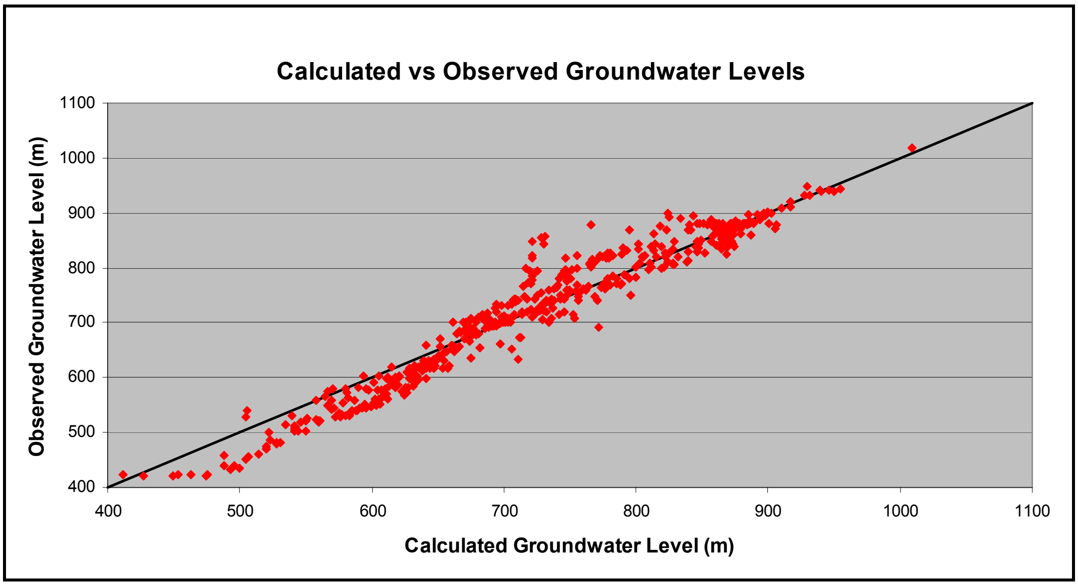


Figure 5.6 The graphical relation between calculated and observed groundwater levels

5.2.2 Baseflow and Spring Discharges

In addition to the match of calculated and observed groundwater levels, it is also very important to achieve a good correlation between the measured data in the field, such as spring discharges and baseflows along Banaz and Yavu Streams, and those calculated by the model. Graphical relations of calculated and observed spring discharges and baseflows are shown on Figures 5.7 and 5.8, respectively. As it can be implied from these graphs, a very good match between the calculated and observed values of spring discharges and baseflows is achieved, which confirms the reliability of model results.

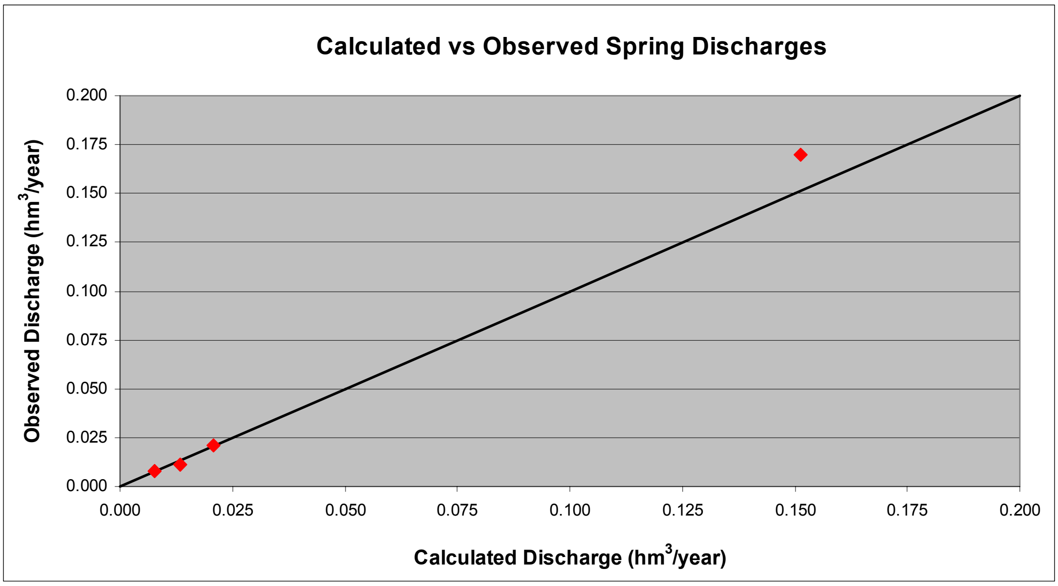


Figure 5.7 The graphical relation between calculated and observed spring discharges

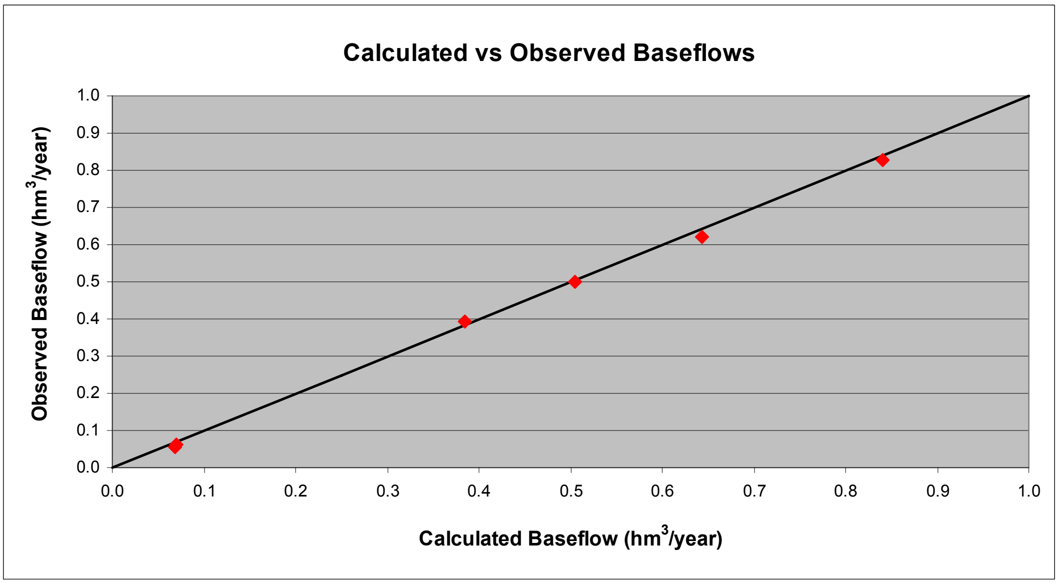


Figure 5.8 The graphical relation between calculated and observed baseflows

5.2.3 Calculated Groundwater Budget

During calibration, at the end of each run of the model, calculated groundwater budget is compared with the conceptual budget. Groundwater budget calculated by the model under steady state conditions is separated into two such that each sub-budget belongs to different model layers. By this way, it is possible to determine recharge and discharge mechanisms of each layer one by one and it is also possible to observe the interactions between these layers, one of which represents Ulubey Formation and the other represents Asartepe Formation and alluvium. Groundwater budgets calculated at the end of calibration for Asartepe Formation and alluvium, for Ulubey Formation and for the whole model domain are given in Tables 5.1, 5.2 and 5.3, respectively. According to the results of the model, recharge and discharge components of the groundwater budget calculated under equilibrium conditions are examined. Asartepe Formation and alluvium, forming the upper layer of the model, are recharged from precipitation (5.83 hm^3/year), from lateral flow along northern, northeastern and eastern boundaries (48.59 hm^3/year) and from Ulubey Formation (10.14 hm^3/year), which make a total recharge of 64.56 hm^3/year. 83 % (53.49 hm^3/year) of the total recharge is discharged into Ulubey Formation, 6 % (3.75 hm^3/year) is discharged as baseflow, 10 % (6.66 hm^3/year) is discharged through wells and remaining 1% (0.66 hm^3/year) is discharged through springs. Ulubey aquifer, forming the bottom layer of the model, is recharged from precipitation (64.12 hm^3/year), from lateral flow (62.10 hm^3/year), from surface flow (10.09 hm^3/year), from Banaz and Yavu Streams (0.42 hm^3/year), and from Asartepe-Alluvium aquifer (53.49 hm^3/year), which make a total recharge of 190.22 hm^3/year. 55 % (103.71 hm^3/year) of the total recharge is discharged as baseflow into Banaz Stream, 28 % (53.94 hm^3/year) is discharged by subsurface flow. The other components of discharge are to Asartepe and alluvium with 5 % (10.14 hm^3/year), to Adıgüzel Dam with 6 % (10.87 hm^3/year), through wells with 3 % (6.12 hm^3/year), through springs with 3 % (5.44 hm^3/year). Discharge of springs along Yavu and Banaz Streams are included in discharge as baseflow as they discharge at stream stage elevation.

Table 5.1 Groundwater budget of Asartepe Formation and alluvium

Recharge (hm^3/year)		Discharge (hm^3/year)	
Precipitation	5.83	Wells	6.66
Subsurface Inflow	48.59	Subsurface Outflow	0.00
Streams	0.00	Springs	0.66
Ulubey Formation	10.14	Streams	3.75
		Ulubey Formation	53.49
Total Recharge	64.56	Total Discharge	64.56

Table 5.2 Groundwater budget of Ulubey Formation

Recharge (hm^3/year)		Discharge (hm^3/year)	
Precipitation	64.12	Wells	6.12
Subsurface Inflow	62.10	Subsurface Outflow	53.94
Surface Inflow	10.09	Springs	5.44
Streams	0.42	Streams	103.71
Asartepe Formation and alluvium	53.49	Adıgüzel Dam	10.87
		Asartepe Formation and alluvium	10.14
Total Recharge	190.22	Total Discharge	190.23

Table 5.3 Groundwater budget of whole model domain

Recharge (hm^3/year)		Discharge (hm^3/year)	
Precipitation	69.95	Wells	12.78
Subsurface Inflow	110.69	Subsurface Outflow	53.94
Surface Inflow	10.09	Springs	6.10
Streams	0.42	Streams	107.47
		Adıgüzel Dam	10.87
Total Recharge	191.15	Total Discharge	191.15

5.3 Sensitivity Analysis

Sensitivity analysis is very beneficial in determination of the parameter or parameters which are effective on the model results. The results of sensitivity analysis are not only useful in planning of possible data collection in the future but also in the minimization of the model errors. During sensitivity analysis, at each attempt one parameter of the model is modified while keeping others constant. The criteria used to determine the sensitivity of the model to input parameters are groundwater levels and tolerance (RMS %), which are compared to that of the calibrated model at the end of each run in sensitivity analysis.

A series of simulations are performed in order to test the sensitivity of the model to changes in several parameters, such as recharge from precipitation, hydraulic conductivity and anisotropy and also to test the effects of changes in these parameters to model results. Tolerance (RMS %) calculated at the end of each simulation of sensitivity analysis for recharge from precipitation, hydraulic conductivity and anisotropy are shown in Figures 5.9, 5.10 and 5.11, respectively. According to these graphs, model is very sensitive to increase and decrease in hydraulic conductivity and increase in the recharge from precipitation, whereas it is not as sensitive to the changes in anisotropy as the other two parameters.

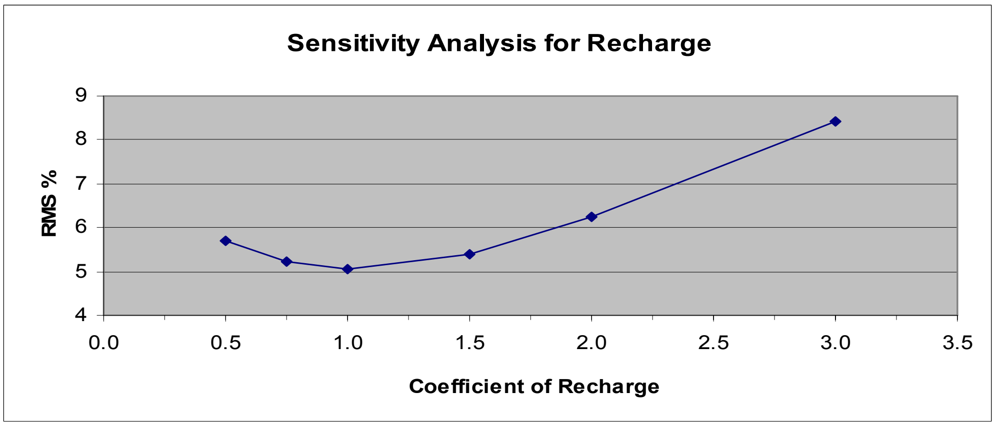


Figure 5.9 Results of sensitivity analysis for recharge

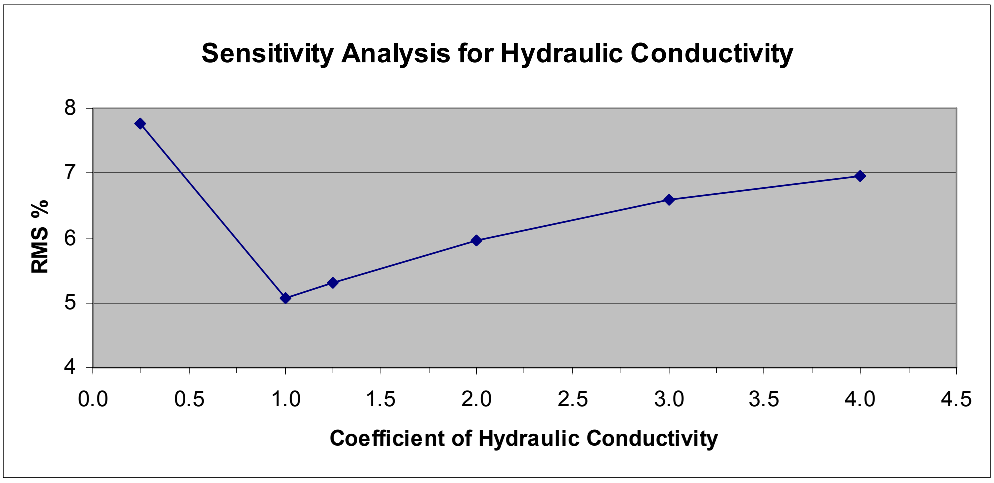


Figure 5.10 Results of sensitivity analysis for hydraulic conductivity

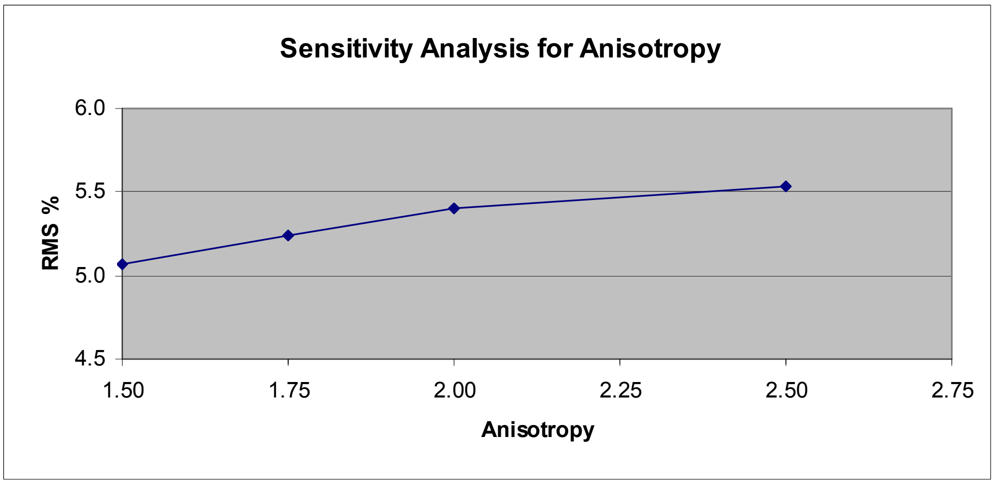


Figure 5.11 Results of sensitivity analysis for anisotropy

CHAPTER 6

GROUNDWATER MANAGEMENT SCENARIOS

6.1 Introduction

At the end of calibration under steady state conditions, a good correlation between the observed and calculated values of groundwater levels, spring discharges and baseflows is achieved. This fact proves that calibration stage is successfully finalized and groundwater flow model is capable of representing the field conditions. Hence, it is concluded that this model could be used to test the effects of several future pumping schedules on Ulubey aquifer system. For this purpose, several management scenarios are set up under transient conditions and their effects are tested. A planning period of 20 years, from May 2007 to April 2027, is simulated in the model. The model is run under transient conditions for this planning period, which is divided into 240 time steps on monthly basis.

Based on the results of Thornthwaite Method used in the calculation of recharge, recharge from precipitation is assumed to take place in the months of February, March and April and recharge from surface runoff is assumed to take place in the months March and April. It is assumed that there is no recharge to groundwater from precipitation or surface runoff in the other months. Areal distributions of recharge in these months, which are calculated by Thornthwaite method, are introduced into the model (Thornthwaite, 1948). A storage coefficient of 0.059 is used, which is determined at the wells drilled by Tüprag Metals Mining Corp. (SRK, 2003 & 2005).

Data produced by running the groundwater flow model with monthly time steps within the planning period between May 2007 and April 2027, under different pumping schedules that change according to the related scenario, are presented in the form of maps, graphs and tables. For each scenario, model outputs are presented in the following three sets:

- Drawdown maps showing the changes in groundwater levels at the end of planning period of 20 years; two sets of drawdown maps are provided in order to better demonstrate the areal drawdown at the end of dry (August 2026) and wet (April 2027) seasons.
- Monthly groundwater level hydrographs for 20 years planning period at monitoring wells within the basin (35071, 35072, 35073, 35074, 5286), at each irrigational cooperative area (İkisaray, Çoğuplu, Ovademirler, Yavu, Yayalar, Budaklar and Susuzören) represented by one well and at two predetermined critical points (Observation wells 1 & 2).
- Annual water budget tables of Ulubey aquifer for 20 years planning period.

Figure 6.1 demonstrates the location of the wells for which groundwater level hydrographs are prepared. Observation Well 1 is an artificial monitoring point located between the wells drilled by Tüprag Metal Mining Corp. and Ulubey town. Observation Well 2 is an artificial monitoring point which represents one of the proposed pumping well locations to meet the future demand of Uşak city. Groundwater levels indicated in hydrographs only represent the average drawdown in the aquifer depending on the size of the block, and do not take well losses into account. Hence, the actual drawdowns will be more than the drawdowns calculated by the model. Information about each scenario and results obtained are discussed below in detail.

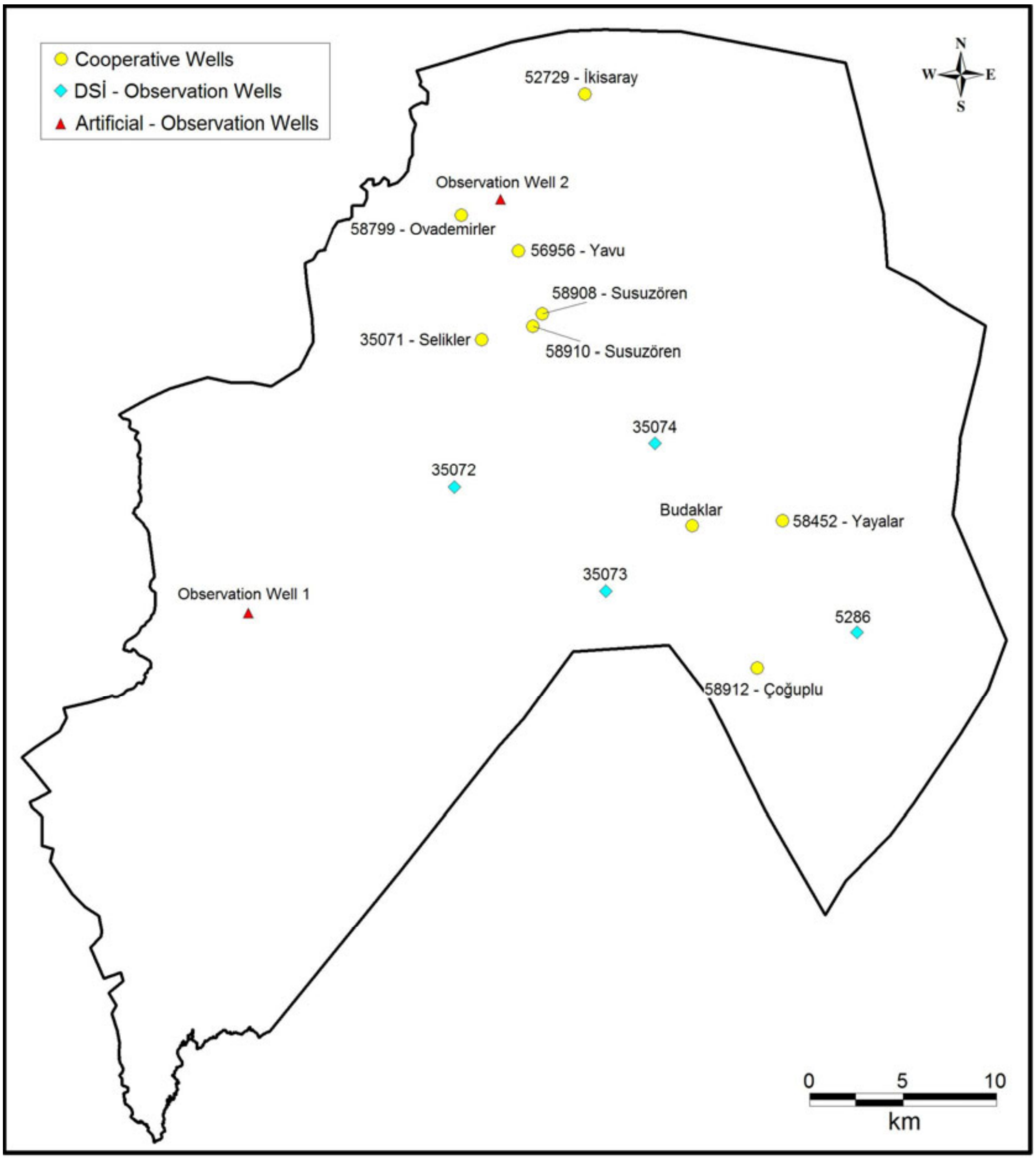


Figure 6.1 Location of the wells for which groundwater level hydrographs are prepared

6.2 Scenario A

Scenario A is based on the assumption that current pumping rates will continue throughout the planning period of the next 20 years except the changes in the pumping rates of four wells licensed to Tüprag Metals Mining Corp.. Pumping schedules of these four wells are assigned for a period of 16 years based on the predictions on Environmental Impact Assessment Report (EIA) (Encon et al., 2003). Pumping schedule of these wells is presented in Table 6.1. According to this schedule these wells are operated for the first 16 years of the planning period.

Table 6.1 Pumping schedule of wells of Tüprag Metal Mining Corp.

Well Name	1.PHASE (m^3/day)		2.PHASE (m^3/day)	
	Jan., Feb., March, Oct., Nov., Dec.	Apr., May, June, July, Aug., Sep.	Jan., Feb., March, Oct., Nov., Dec.	Apr., May, June, July, Aug., Sep.
PW-1	362.88	602.64	1151.28	1296
PW-2	483.84	803.52	1535.04	1728
PW-3	120.96	200.88	383.76	449.28
PW-4	483.84	803.52	1535.04	1728
Total	1451.52	2410.56	4605.12	5201.28

Continuation of the current pumping rates throughout the planning period of 20 years, do not create a significant change in groundwater levels. Drawdown maps of August 2026 and April 2027 (Figures 6.2 and 6.3) demonstrates that maximum residual drawdown is about 1.5 m in August 2026 and about 1 m in April 2027. Moreover, hydrographs given in Figure 6.4 indicate that groundwater levels at each of these observation points at the end of 20 years planning period are 0.15-0.20 m higher than the initial conditions of April 2007, except observation point 1 at the locality of Tüprag wells. The reasons of the rise in groundwater levels are probably that 2007 was a relatively dry year causing lower initial heads

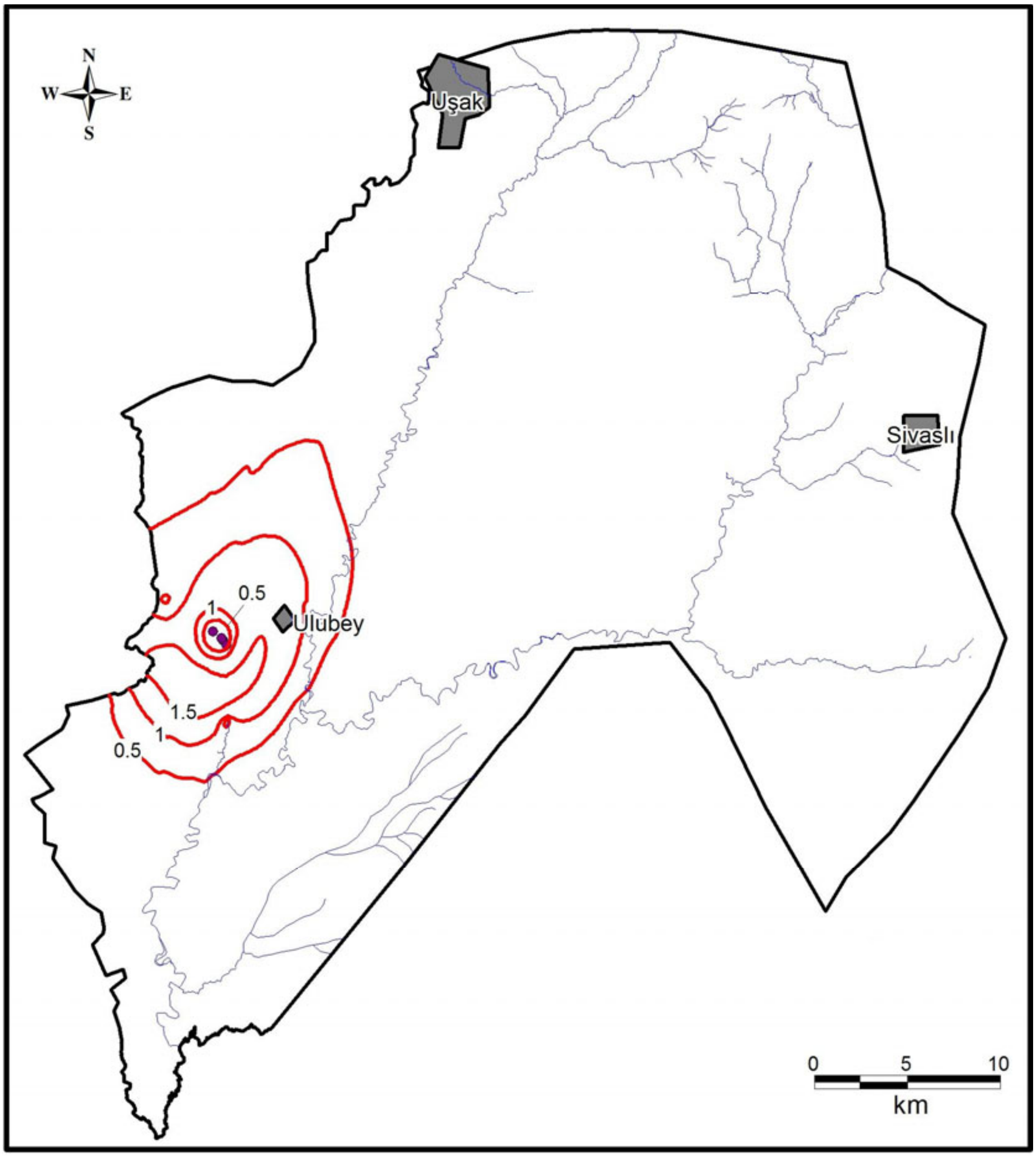


Figure 6.2 Drawdown map resulted from the pumping schedule predicted for Scenario A, in August 2026

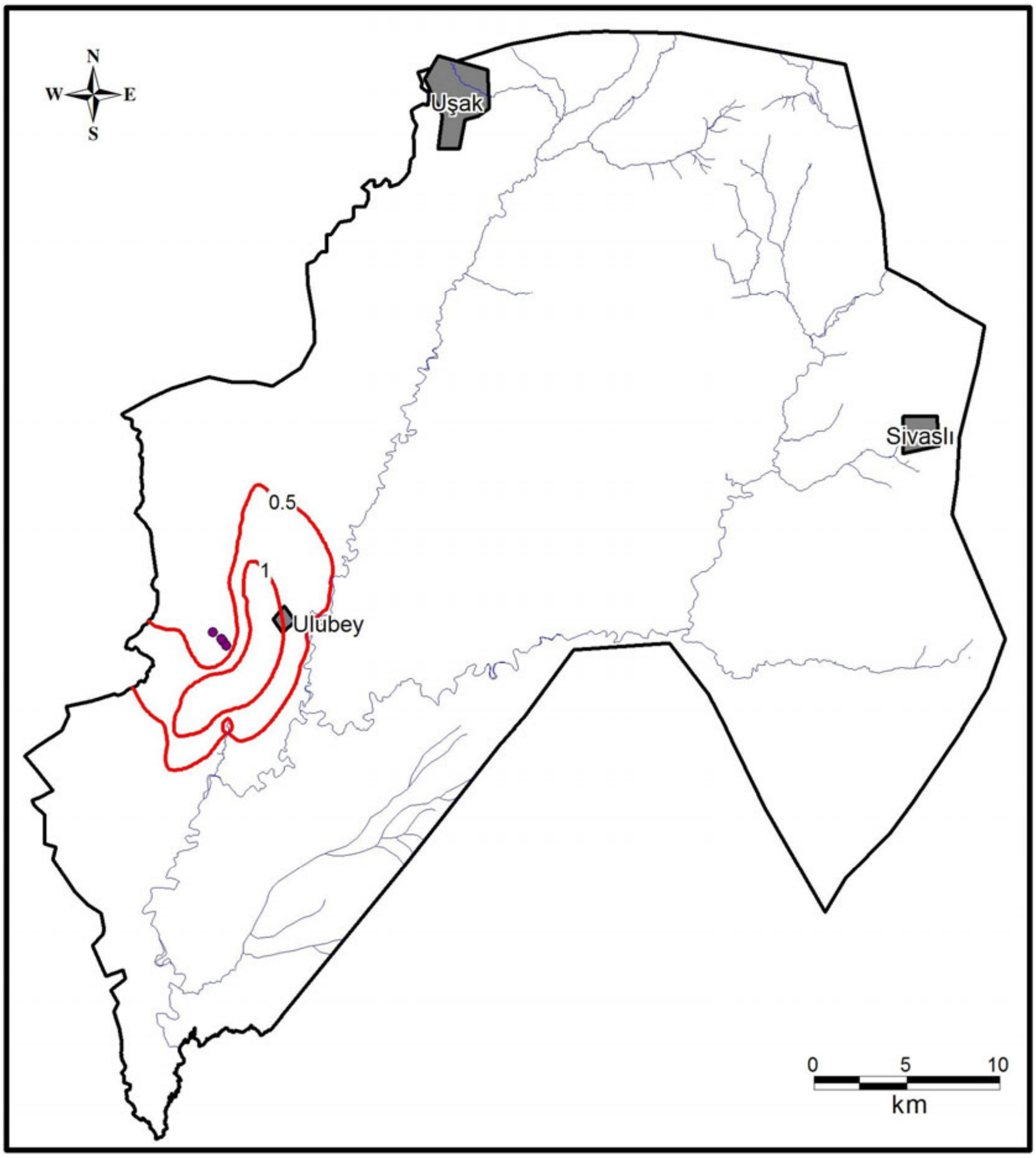


Figure 6.3 Drawdown map resulted from the pumping schedule predicted for Scenario A, in April 2027

and recharge of an average period is input in the model. As a result, starting from April 2007 groundwater levels rise and by the end of the planning period a new equilibrium is reached except annual fluctuations. The rise in groundwater levels during the whole planning period of 20 years is about 0.2-0.3 m, which is insignificant. However, in the locality of İkisaray, Ovademirler and Yavu cooperatives located in the north of the model domain, the rise in groundwater levels reaches 1.0-1.5 m. The reason why the rise in groundwater levels are higher in this locality is the existence of E-W aligned faults in the downstream direction, which are predicted to be impermeable. Because of these faults acting as barriers against groundwater flow direction, groundwater can not be transmitted southwards effectively in this locality that is recharged from north.

Hydrograph of artificial Observation Well 1 located between Tüprag wells and Ulubey town, indicate that groundwater level is 620.4 m in April 2007 and then as a result of pumping from Tüprag wells groundwater level declines to 617 m at the end of 16th year. However, after these wells are shut down, groundwater level rises back to 619.4 m in April 2027 (Figure 6.4). Finally, a residual drawdown of about 1 m is produced.

Annual water budget table of Ulubey aquifer for 20 years planning period for Scenario A points out that there is no significant change in recharge and discharge values (Table 6.2). Moreover, change in groundwater reserve indicates an average increase of 0.60 hm^3/year.

As a result, continuation of current pumping schedule will not create a significant change in groundwater levels and reserve of Ulubey aquifer compared to the present situation under average recharge conditions.

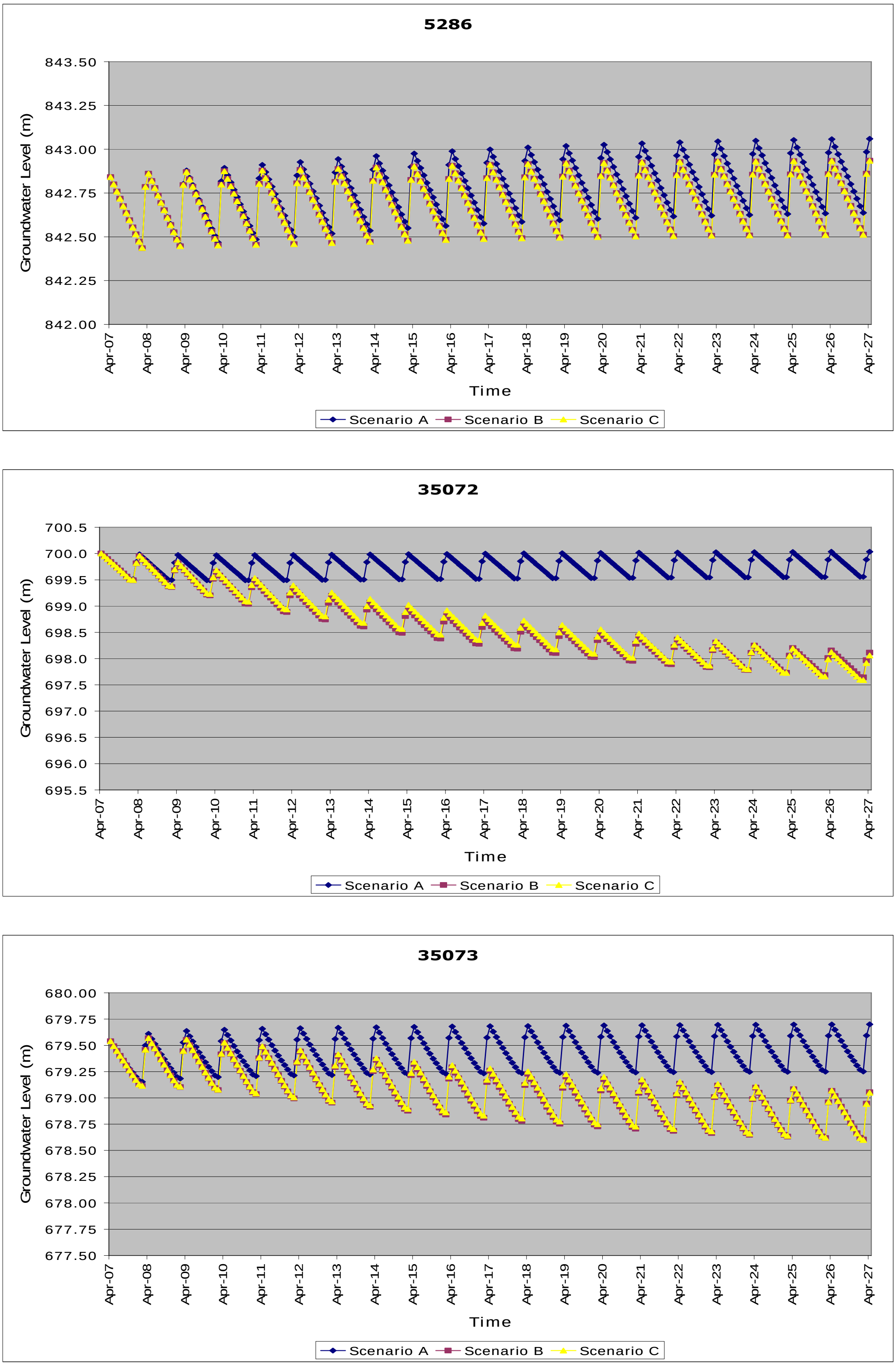
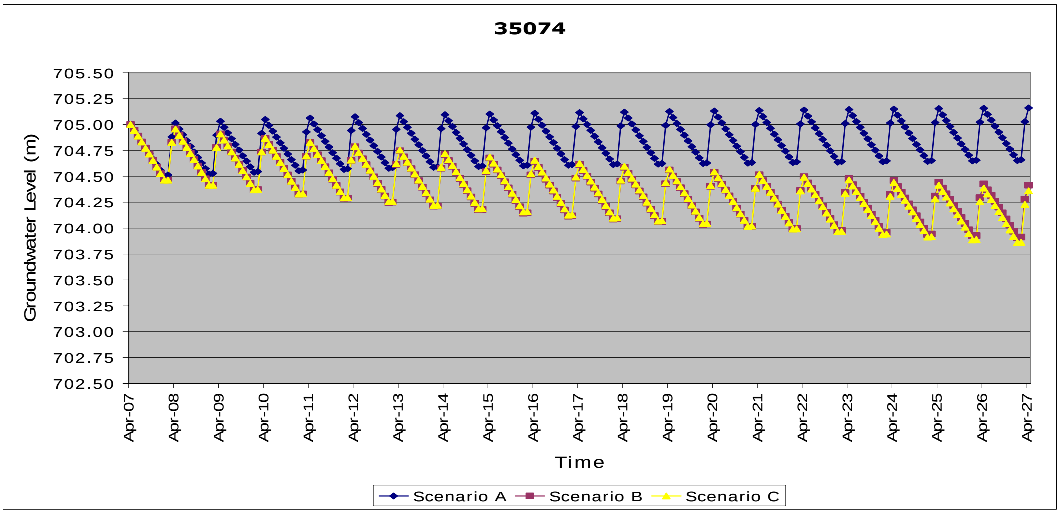
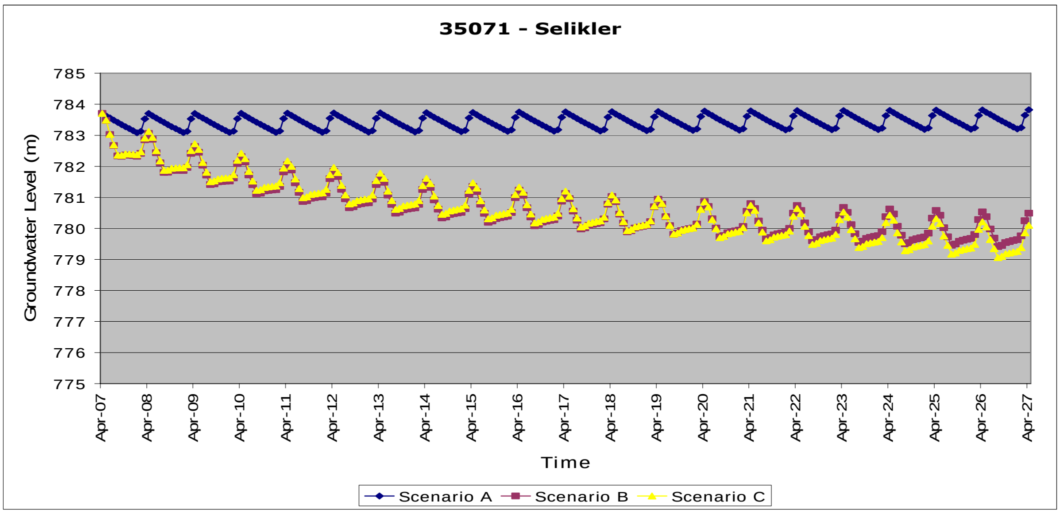


Figure 6.4 Hydrographs for Scenarios A, B and C





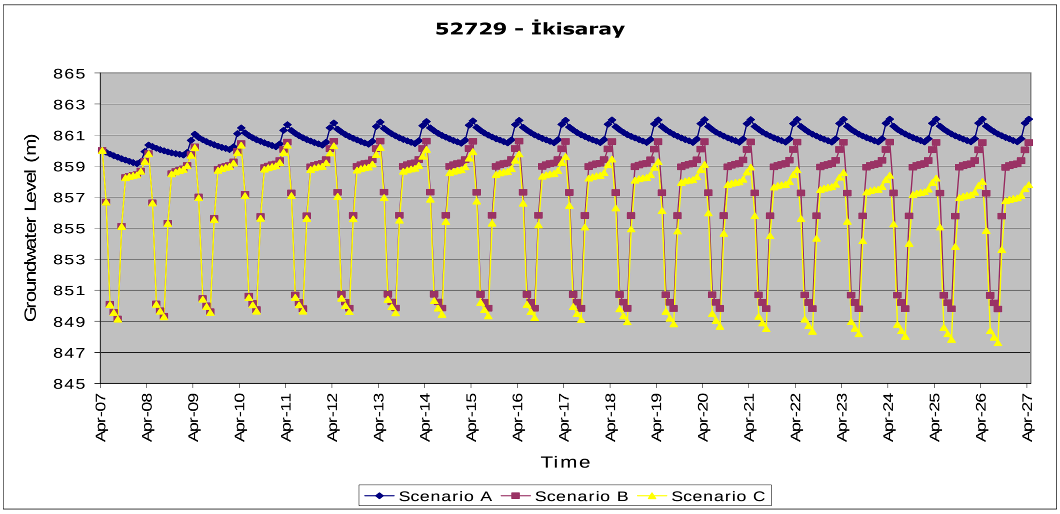
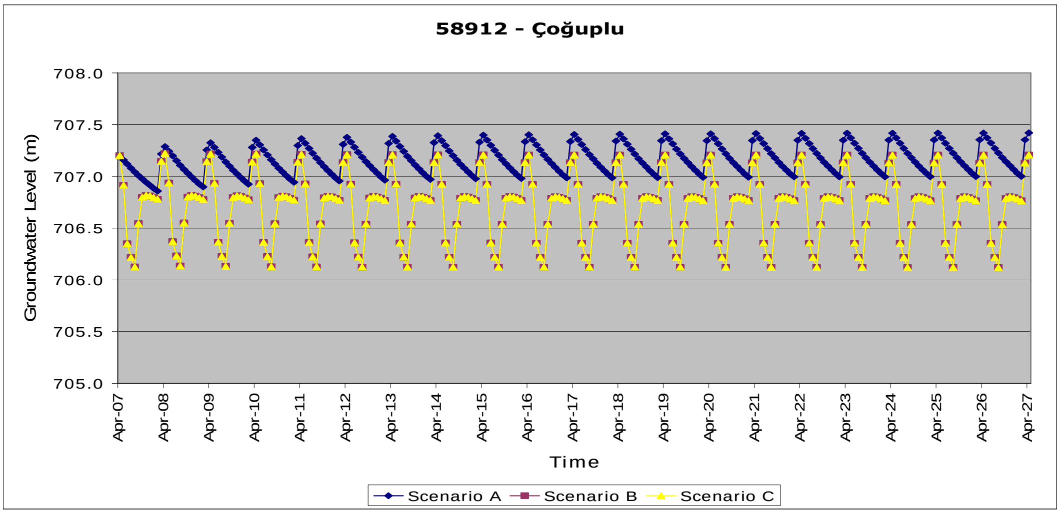
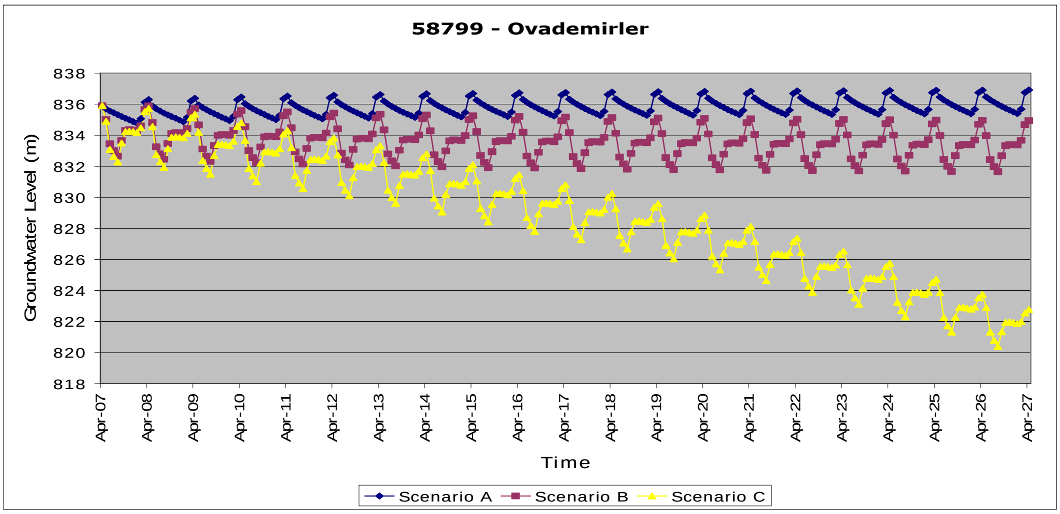


Figure 6.4 Hydrographs for Scenarios A, B and C (continued)





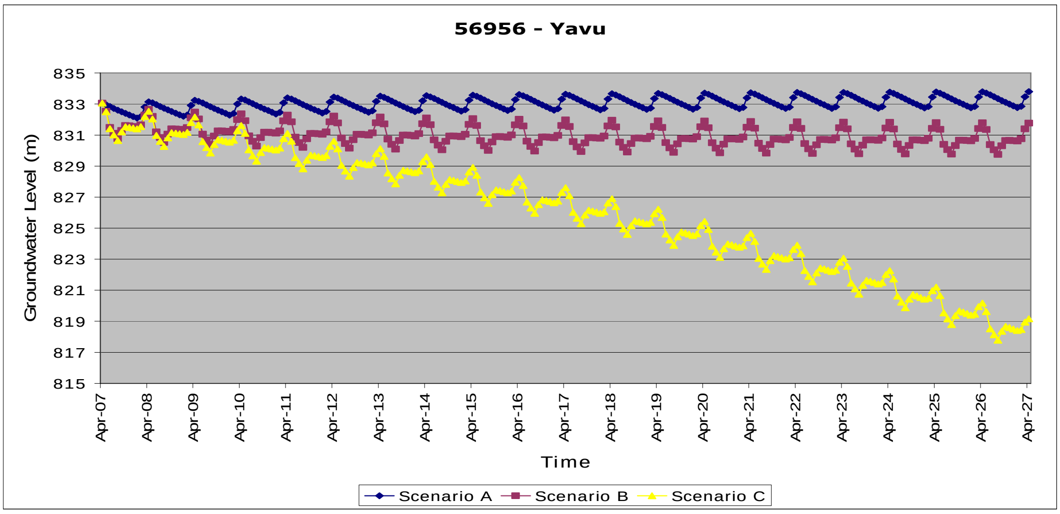
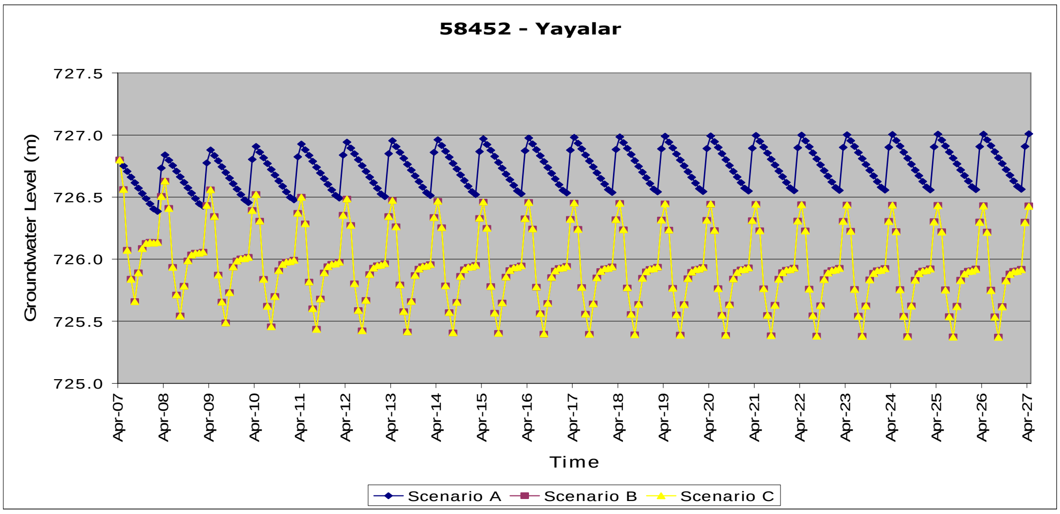
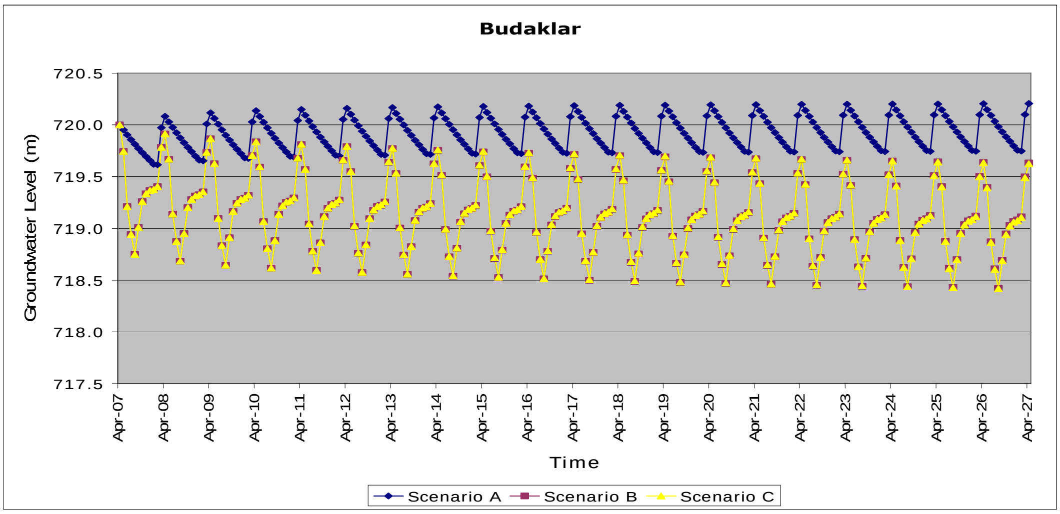


Figure 6.4 Hydrographs for Scenarios A, B and C (continued)





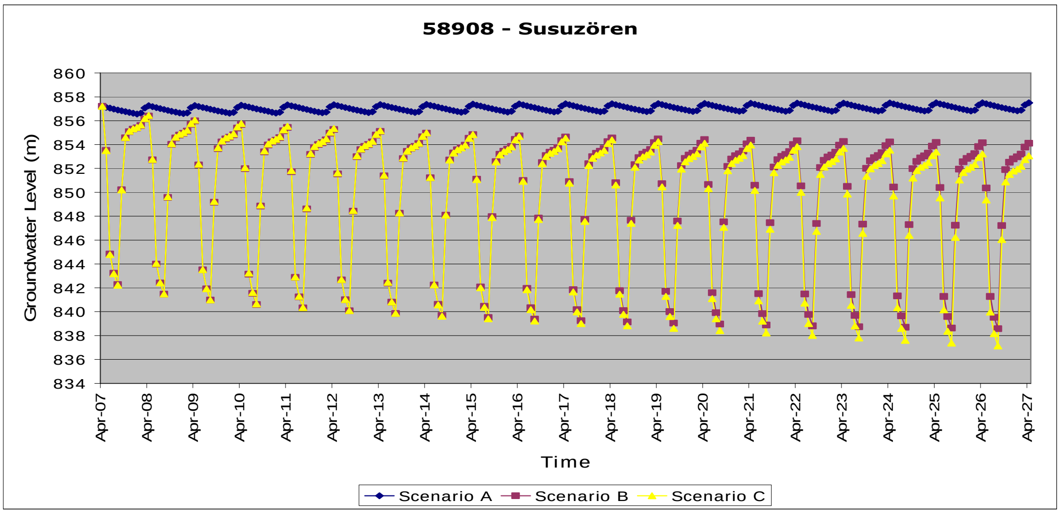
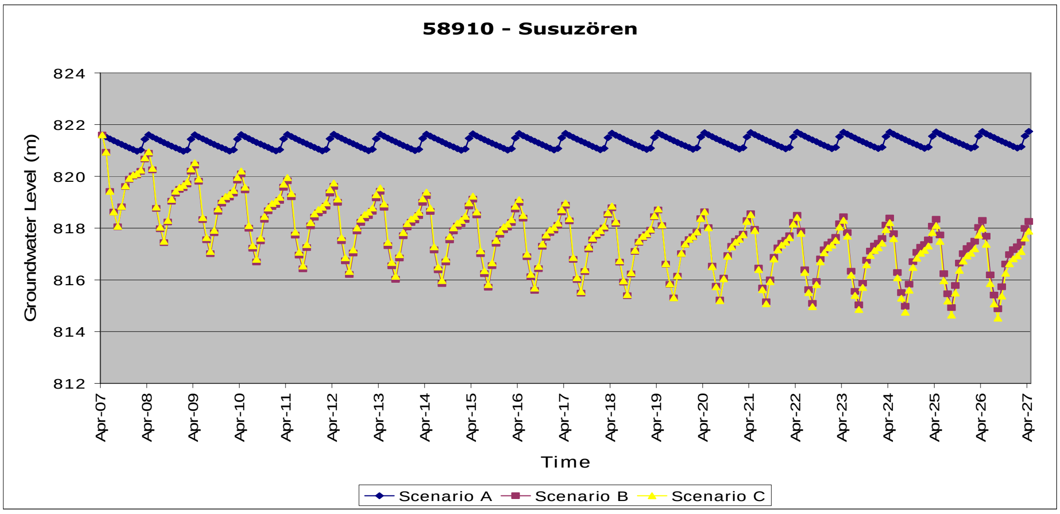
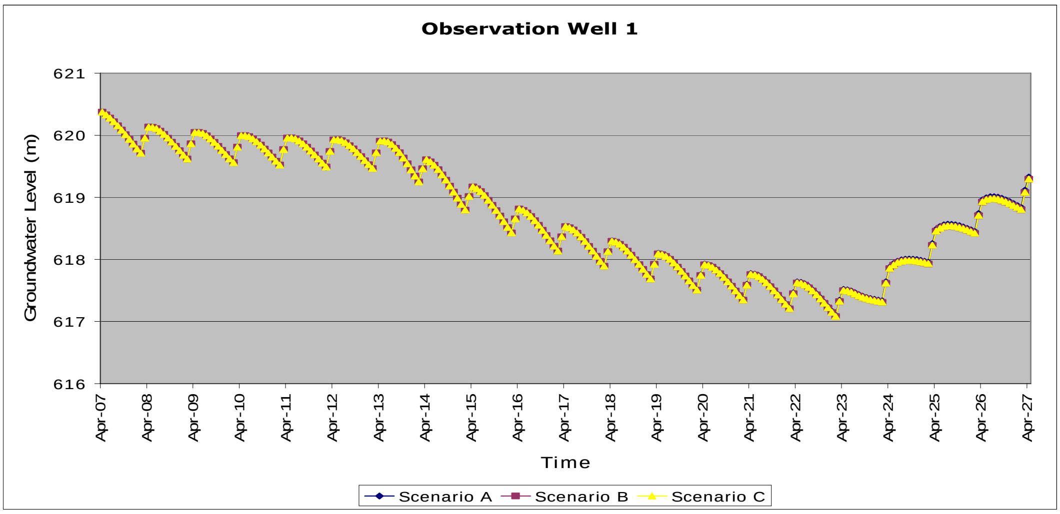


Figure 6.4 Hydrographs for Scenarios A, B and C (continued)





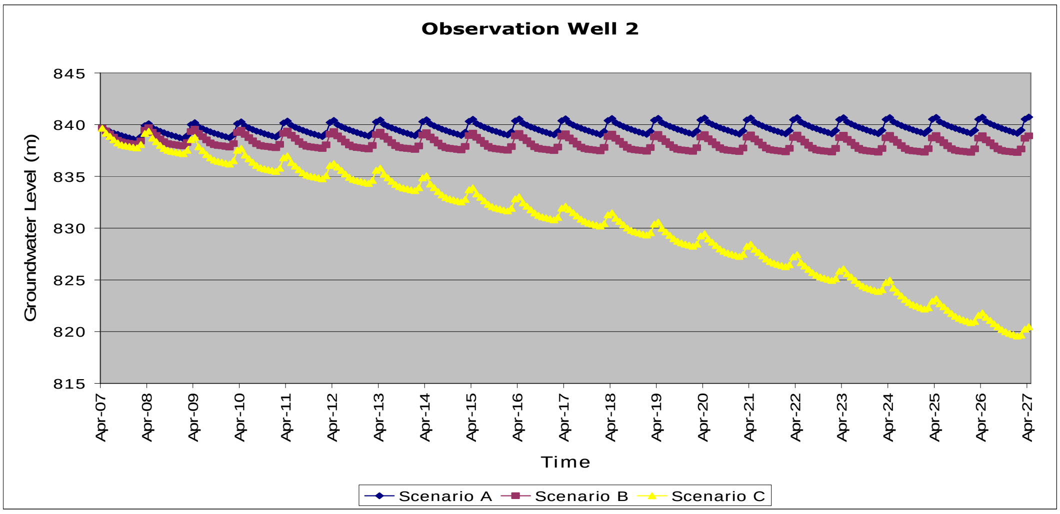


Figure 6.4 Hydrographs for Scenarios A, B and C (continued)

Table 6.2 Annual budget and reserve change of Ulubey aquifer for Scenario A for 20 years planning period (hm^3/year)

Year	RECHARGE						DISCHARGE							Change in Reserve
	Precipitation	Subsurface Inflow	Surface Inflow	Streams	Asartepe-Alluvium	Total	Wells	Subsurface Outflow	Springs	Streams	Adıgüzel Dam	Asartepe-Alluvium	Total	
1	64.35	63.11	10.11	0.47	53.61	191.65	5.98	53.66	5.35	102.70	10.83	10.27	188.80	2.86
2	64.19	62.50	10.08	0.46	53.47	190.69	5.97	53.78	5.35	102.84	10.89	10.14	188.97	1.73
3	64.19	62.38	10.08	0.45	53.47	190.57	5.97	53.88	5.36	102.99	10.91	10.07	189.19	1.39
4	64.19	62.32	10.08	0.45	53.47	190.51	5.97	53.95	5.36	103.09	10.93	10.04	189.33	1.18
5	64.35	62.46	10.11	0.45	53.62	190.98	5.98	54.13	5.38	103.43	10.96	10.06	189.94	1.04
6	64.19	62.26	10.08	0.44	53.48	190.45	5.97	54.02	5.36	103.20	10.94	10.02	189.50	0.95
7	64.19	62.24	10.08	0.44	53.48	190.43	7.05	54.03	5.36	103.24	10.94	10.02	190.65	-0.22
8	64.19	62.22	10.08	0.44	53.48	190.41	7.05	54.05	5.36	103.27	10.95	10.02	190.69	-0.28
9	64.35	62.38	10.11	0.44	53.62	190.91	7.07	54.21	5.35	103.57	10.98	10.04	191.23	-0.32
10	64.19	62.20	10.08	0.44	53.48	190.39	7.05	54.07	5.31	103.31	10.96	10.01	190.71	-0.32
11	64.19	62.19	10.08	0.44	53.48	190.38	7.05	54.08	5.29	103.31	10.96	10.01	190.71	-0.32
12	64.19	62.18	10.08	0.44	53.48	190.37	7.05	54.09	5.27	103.32	10.96	10.02	190.70	-0.32
13	64.35	62.35	10.11	0.44	53.62	190.87	7.07	54.24	5.26	103.59	10.99	10.04	191.20	-0.33
14	64.19	62.17	10.08	0.44	53.48	190.36	7.05	54.10	5.23	103.31	10.97	10.02	190.67	-0.31
15	64.19	62.16	10.08	0.44	53.48	190.35	7.05	54.10	5.21	103.31	10.97	10.02	190.66	-0.31
16	64.19	62.16	10.08	0.44	53.49	190.36	7.05	54.11	5.20	103.30	10.97	10.02	190.64	-0.28
17	64.35	62.33	10.11	0.44	53.63	190.86	5.27	54.26	5.20	103.57	11.00	10.04	189.35	1.51
18	64.19	62.15	10.08	0.44	53.49	190.35	5.26	54.11	5.18	103.29	10.97	10.02	188.83	1.51
19	64.19	62.15	10.08	0.44	53.49	190.34	5.26	54.12	5.20	103.29	10.98	10.02	188.86	1.48
20	64.19	62.15	10.08	0.44	53.48	190.34	5.26	54.12	5.23	103.31	10.98	10.02	188.91	1.43
Average	64.23	62.30	10.09	0.44	53.51	190.58	6.37	54.06	5.29	103.26	10.95	10.05	189.98	0.60

6.3 Scenario B

Scenario B simulates the effects of additional pumping from the wells of irrigational cooperatives in addition to the pumping schedule of Scenario A. Table 6.3 represents the planned areas to be irrigated and predicted monthly pumping schedule of these cooperative wells within the study area which will extract groundwater from Ulubey aquifer. Water requirement of the areas to be irrigated by cooperative wells is determined as 0.61 L/s/ha according to the DSİ reports. Irrigational water demand is assumed to be at its maximum in June, July and August, while it is equal to one third of it in May and September. It is assumed that no groundwater is extracted from these cooperative wells in the other seven months. As a result, annual amount of groundwater extracted from these cooperative wells is predicted as 4.62 hm^3 to irrigate an area of 780 hectares.

Table 6.3 predicted monthly pumping schedule and planned areas to be irrigated by cooperative wells

Name of the Cooperative	Area (ha)	Water Requirement (L/s)	Amount of Groundwater Supplied					
			May	June	July	August	September	Total (hm^3/year)
İkisaray	40	24.4	0.022	0.063	0.065	0.065	0.021	0.237
Selikler	100	61	0.054	0.158	0.163	0.163	0.053	0.592
Susuzören	200	122	0.109	0.316	0.327	0.327	0.105	1.184
Çoğuplu	40	24.4	0.022	0.063	0.065	0.065	0.021	0.237
Budaklar	100	61	0.054	0.158	0.163	0.163	0.053	0.592
Yayalar	100	61	0.054	0.158	0.163	0.163	0.053	0.592
Ovademirler	100	61	0.054	0.158	0.163	0.163	0.053	0.592
Yavu	100	61	0.054	0.158	0.163	0.163	0.053	0.592
	Total	475.8	0.425	1.233	1.274	1.274	0.411	4.618

Additional pumping from the wells of irrigational cooperatives in addition to the current pumping schedule, caused additional drawdowns in different amounts (Figures 6.5 and 6.6). According to the drawdown maps of August 2026 and April 2027, at the locality where cooperative wells are concentrated maximum drawdown is about 17 m in August 2026 and about 4 m in April 2027. Drawdowns at the end of August represent the conditions by the end of irrigation season. That is why in order to make a comparison between the initial and final conditions, the areal drawdowns should be calculated considering the groundwater levels of April 2007 and April 2027. Drawdowns at the end of April 2027 spread to a larger area. However, these drawdowns are insignificant, as they range between 1-2 m. Drawdowns at the end of April 2027 are about 4 m, even at the locality of Susuzören cooperative where maximum drawdowns are observed due to E-W aligned faults (Figures 6.5 and 6.6).

According to the groundwater level hydrographs presented in Figure 6.4, seasonal groundwater level fluctuations of Scenario B are more than that of Scenario A due to pumping during the irrigation season. At the Observation Well 1 in the locality of Tüprag wells, there is no difference in the results of Scenario A and B (Figure 6.4). As a result, it can be concluded that there is no interaction between the extractions from Tüprag wells and cooperative wells and they do not create an overlapping cone of depression.

Table 6.4 represents the annual water budget of Ulubey aquifer for 20 years planning period for Scenario B. According to this table, change in groundwater reserve indicates an average decrease of 1.62 hm^3/year. Groundwater discharge into the Banaz Stream decreases about 1.5 hm^3/year compared to the results of Scenario A due to the pumping from cooperative wells. However these are insignificant declines compared to the present situation. As a result, under average recharge conditions, additional pumping from cooperative wells will not create a significant change in groundwater levels, groundwater discharge into Banaz Stream and reserve of Ulubey aquifer.

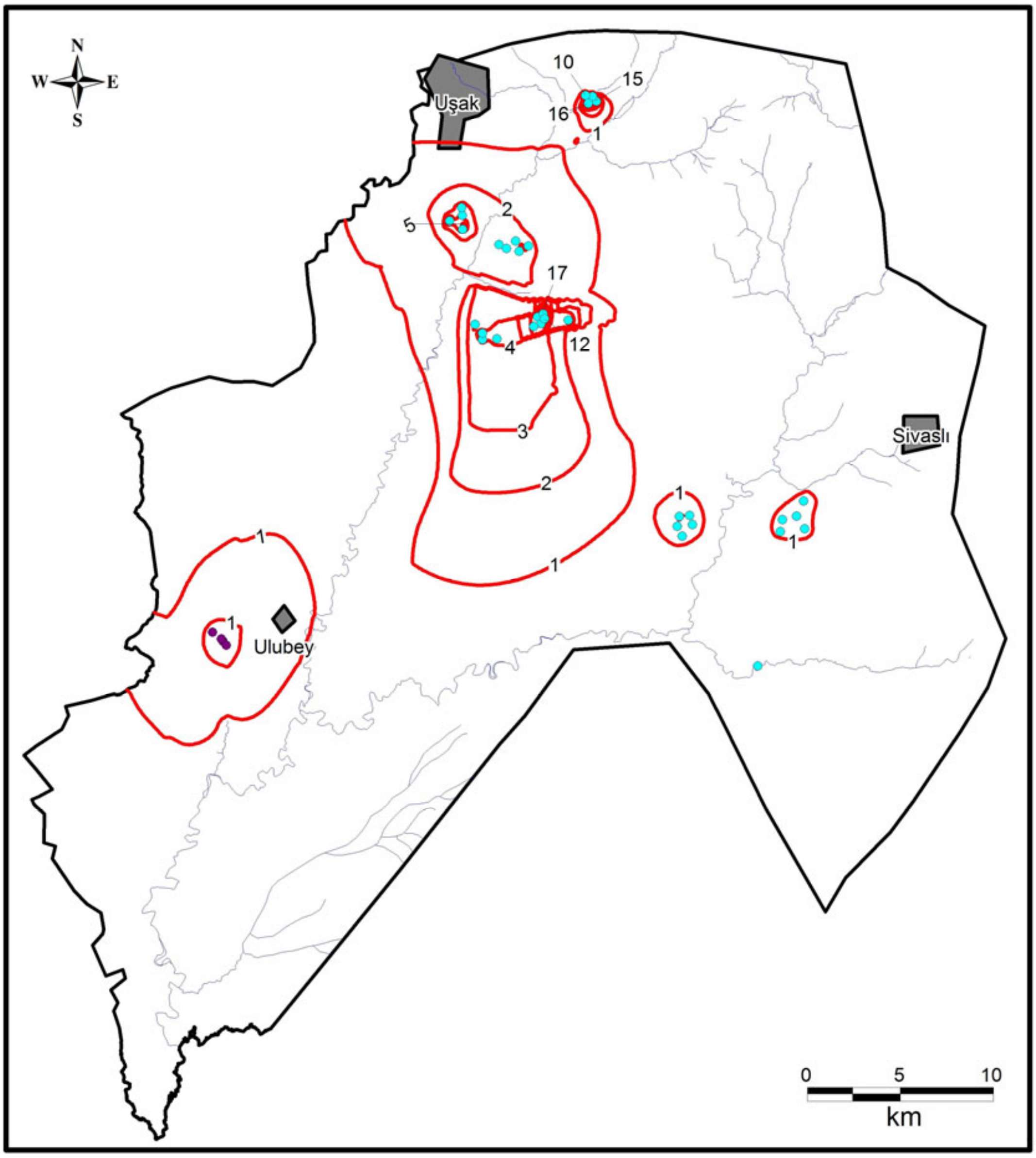


Figure 6.5 Drawdown map resulted from the pumping schedule predicted for Scenario B, in August 2026

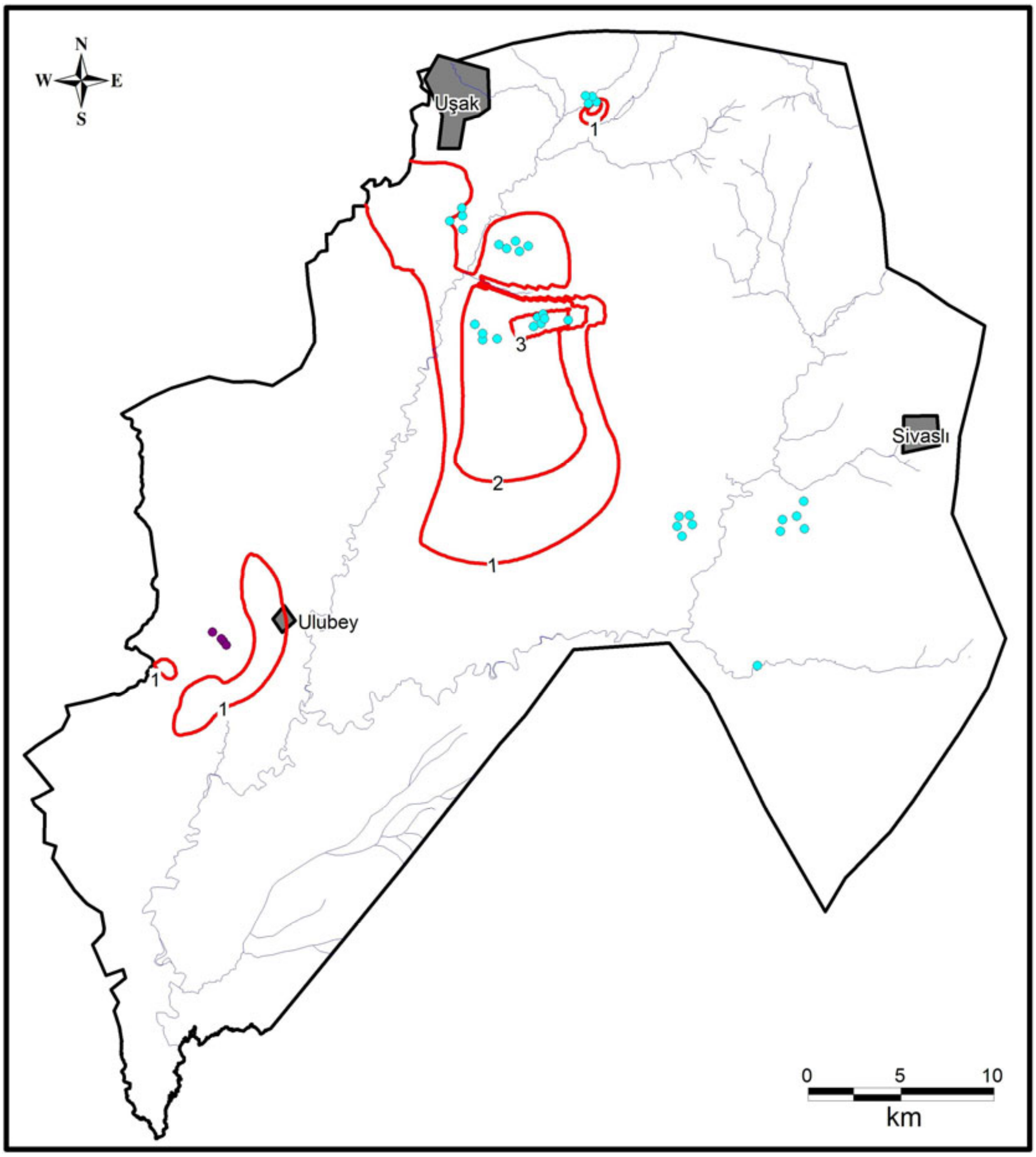


Figure 6.6 Drawdown map resulted from the pumping schedule predicted for Scenario B, in April 2027

Table 6.4 Annual budget and reserve change of Ulubey aquifer for Scenario B for 20 years planning period (hm^3/year)

Year	RECHARGE						DISCHARGE							Change in Reserve
	Precipitation	Subsurface Inflow	Surface Inflow	Streams	Asartepe-Alluvium	Total	Wells	Subsurface Outflow	Springs	Streams	Adigüzel Dam	Asartepe-Alluvium	Total	
1	64.35	63.11	10.11	0.48	53.79	191.84	10.60	53.57	5.35	102.45	10.83	10.25	193.04	-1.20
2	64.19	62.52	10.08	0.48	53.69	190.97	10.58	53.61	5.35	102.33	10.89	10.11	192.88	-1.92
3	64.19	62.44	10.08	0.48	53.72	190.91	10.58	53.65	5.36	102.31	10.91	10.06	192.87	-1.96
4	64.19	62.40	10.08	0.49	53.74	190.90	10.58	53.67	5.36	102.25	10.93	10.03	192.82	-1.92
5	64.35	62.56	10.11	0.50	53.89	191.41	10.60	53.82	5.38	102.46	10.96	10.05	193.26	-1.86
6	64.19	62.38	10.08	0.50	53.76	190.91	10.58	53.67	5.36	102.10	10.94	10.02	192.67	-1.77
7	64.19	62.37	10.08	0.51	53.76	190.91	11.67	53.67	5.36	102.02	10.94	10.02	193.68	-2.76
8	64.19	62.37	10.08	0.51	53.77	190.92	11.67	53.67	5.36	101.93	10.95	10.01	193.59	-2.66
9	64.35	62.54	10.11	0.52	53.92	191.44	11.69	53.81	5.35	102.12	10.98	10.04	193.99	-2.55
10	64.19	62.37	10.08	0.52	53.78	190.94	11.67	53.66	5.31	101.76	10.95	10.01	193.37	-2.42
11	64.19	62.37	10.08	0.52	53.79	190.95	11.67	53.66	5.29	101.67	10.96	10.01	193.26	-2.30
12	64.19	62.37	10.08	0.53	53.79	190.96	11.67	53.66	5.27	101.58	10.96	10.01	193.15	-2.18
13	64.35	62.54	10.11	0.53	53.94	191.48	11.69	53.80	5.26	101.77	10.99	10.04	193.55	-2.07
14	64.19	62.37	10.08	0.53	53.80	190.98	11.67	53.65	5.23	101.41	10.96	10.01	192.94	-1.96
15	64.19	62.37	10.08	0.54	53.80	190.99	11.67	53.65	5.21	101.34	10.97	10.01	192.84	-1.86
16	64.19	62.38	10.08	0.54	53.80	190.99	11.67	53.65	5.19	101.26	10.97	10.01	192.75	-1.76
17	64.35	62.55	10.11	0.54	53.95	191.51	9.89	53.79	5.19	101.47	11.00	10.04	191.38	0.13
18	64.19	62.38	10.08	0.55	53.81	191.00	9.88	53.64	5.18	101.13	10.97	10.01	190.82	0.19
19	64.19	62.38	10.08	0.55	53.81	191.01	9.88	53.64	5.20	101.08	10.97	10.01	190.78	0.23
20	64.19	62.38	10.08	0.55	53.81	191.02	9.88	53.64	5.23	101.04	10.97	10.01	190.77	0.25
Average	64.23	62.46	10.09	0.52	53.81	191.10	10.99	53.68	5.29	101.77	10.95	10.04	192.72	-1.62

6.4 Scenario C

Scenario C simulates the effects of additional pumping in order to supply increasing demand on water depending on a potential population increase of Uşak town, in addition to the pumping schedule of Scenario B. For population projection, each method applied by Teksan Temel A.Ş. (1996) using the results 1990 census, the latest census of that time, are checked with the results 2000 census. Finally, the method of compound interest is chosen (Equation 6.1).

$$N_f = N_o\left(1+\frac{C}{100}\right)^n \tag{6.1}$$

N_o : Result of old census

N_f : Result of the final census

C : Coefficient of increase

n : Number of years between the two censuses

After testing several values, Teksan Temel A.Ş. determined the coefficient of increase as 3. However, population calculated for the year 2000 using the coefficient of increase as 3, results in a smaller value than it actually is. So, it is concluded that population of Uşak town increased less than it was predicted. As a result, by comparing data of census 1990 and 2000, the coefficient of increase is determined as 2.7. The next step is the determination of water demand per day per capita. In this stage, the values predicted by Teksan Temel A.Ş. are utilized. In this prediction the fact that water demand per day per capita would also increase in time was taken into account and increasing water demand for periods of five years was calculated (Teksan, 1996). After population projection is finalized and future water demand per day per capita is calculated, water demand of Uşak town is determined on annual basis. It is assumed that present water supply meets the present demand of Uşak town and same amount of water will be supplied from these sources in the next years. Present sources supplying water to Uşak town are (Çokuran Spring: 100 L/s, Karabol Spring: 45 L/s, wells of asphalt worksite: 60 L/s, wells of airport site: 120 L/s, Bölme wells: 90 L/s). According to these assumptions, the gap between the present water supply and the future water demand will grow continuously, and reach to 373 L/s by 2027 at the end of the planning period of 20 years. Finally, it is recommended that additional water demand is to be supplied from the wells that would be drilled in Ulubey aquifer during 20 years, such that five wells to be drilled in each five years. Table 6.5 represents the results of population projection, water demand per day per capita, total water demand and pumping schedule of the proposed wells. Locations of the wells proposed are determined considering several factors, such as distance to the present distribution network, depth to groundwater table, saturated thickness, hydraulic conductivity and distance to the present wells and potential cooperative wells. Resulting well field proposed is located 3 km north of Ovademirler and Yavu villages. Proposed wells are located 300 m apart from each other and it is assumed that five wells would be drilled in each five years. Location of these wells is shown on Figure 6.7.

Resulting drawdowns due to the pumping from the wells proposed to supply the increasing demand during the planning period (in addition to pumping from current wells and potential cooperative wells) in August 2026 and April 2027 are shown on Figures 6.7 and 6.8, respectively. According to these drawdown maps, at the locality where proposed wells are located maximum drawdown is about 19 m in August 2026 and in April 2027. Due to the fact that these wells, which are proposed to meet the increasing water demand, are operated continuously, change in groundwater levels of these wells between August and April is only about 5-10 cm. This small seasonal fluctuation can not be detected from the areal drawdown maps (Figures 6.7 and 6.8).

Table 6.5 Population projection of Uşak town for the next 20 years, water demand, pumping schedule of the proposed wells

Years	Population	Water demand per person (L/s)	Total water demand (L/s)	Gap that has to be supplied (L/s)	Total number of wells from which gap will be supplied	Pumping rate of each well (L/s)
2007	165089	219	418.5	0.0	0	0.00
2008	169546	219	429.8	11.3	5	2.26
2009	174124	219	441.4	22.9	5	4.58
2010	178825	226	467.8	49.3	5	9.86
2011	183653	226	480.4	61.9	5	12.39
2012	188612	226	493.4	74.9	5	14.98
2013	193704	226	506.7	88.2	10	8.82
2014	198934	226	520.4	101.9	10	10.19
2015	204306	232	548.6	130.1	10	13.01
2016	209822	232	563.4	145.0	10	14.50
2017	215487	232	578.6	160.2	10	16.02
2018	221305	232	594.2	175.8	15	11.72
2019	227280	232	610.3	191.8	15	12.79
2020	233417	235	634.9	216.4	15	14.43
2021	239719	235	652.0	233.6	15	15.57
2022	246192	235	669.6	251.2	15	16.74
2023	252839	235	687.7	269.2	20	13.46
2024	259666	235	706.3	287.8	20	14.39
2025	266677	243	750.0	331.6	20	16.58
2026	273877	243	770.3	351.8	20	17.59
2027	281271	243	791.1	372.6	20	18.63

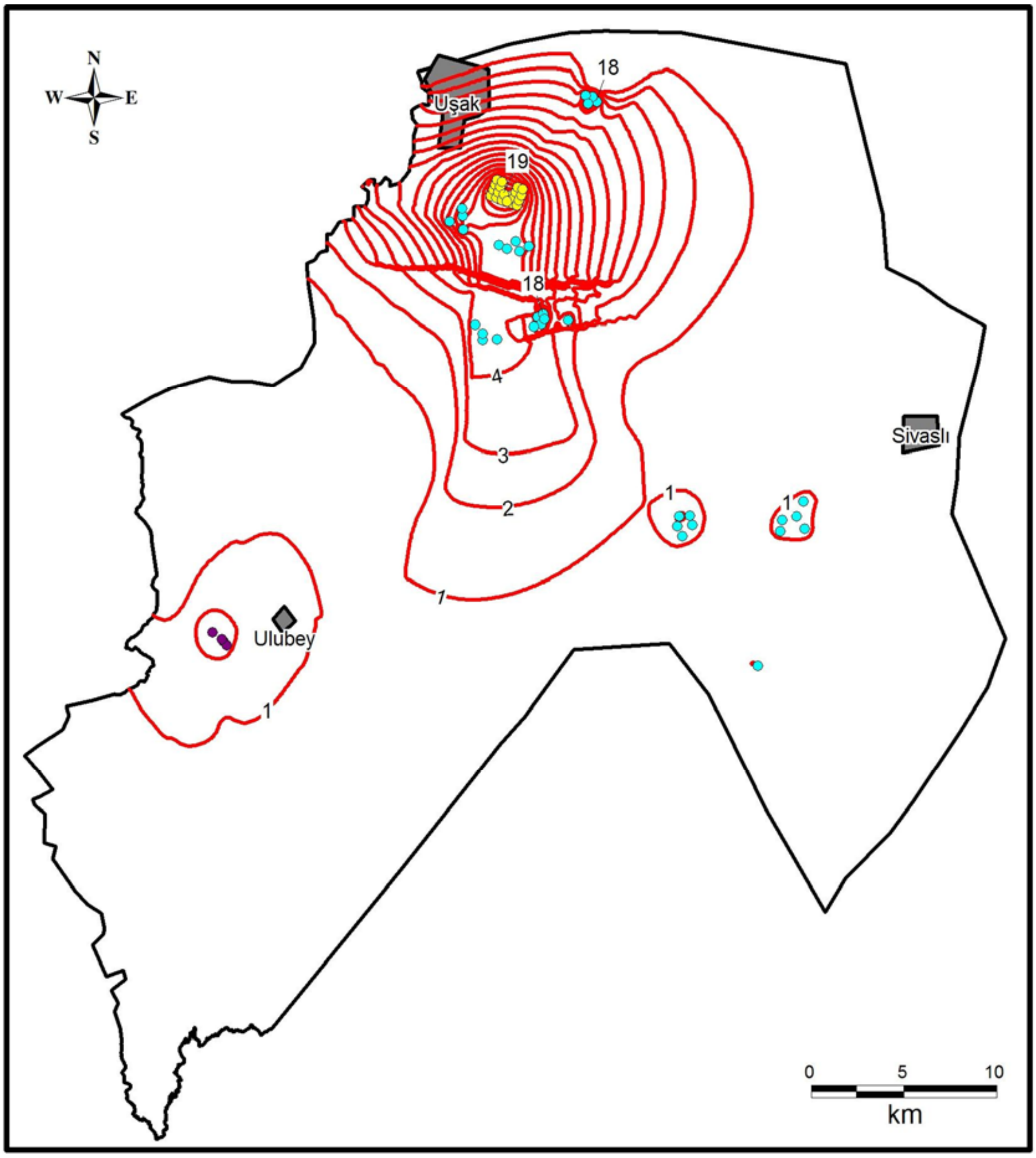


Figure 6.7 Drawdown map resulted from the pumping schedule predicted for Scenario C, in August 2026

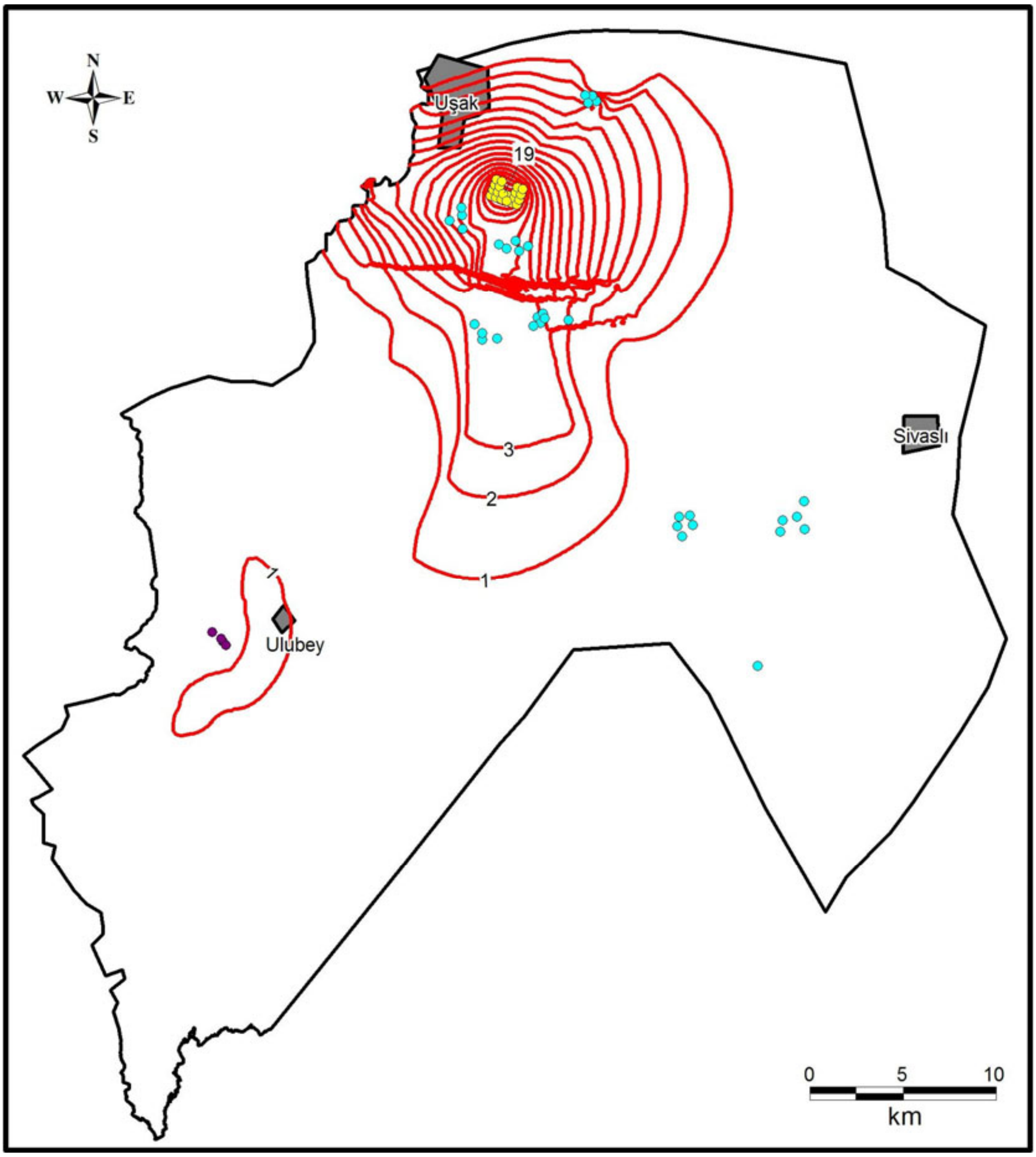


Figure 6.8 Drawdown map resulted from the pumping schedule predicted for Scenario C, in April 2027

According to the groundwater level hydrographs presented in Figure 6.4, due the pumping at the proposed well field (Observation Well 2), drawdowns continuously increase during the planning period and reach to 20 m at the end of 20 years. However, as it is mentioned earlier, drawdowns calculated by the model at these wells only represent areal drawdowns and actual dynamic groundwater level would be deeper.

At the end of 20 years, an additional drawdown of 12 m is observed at the wells of the Ovademirler (58799) and Yavu (56956) Cooperatives, due to the pumping from the wells proposed to supply the increasing water demand of Uşak town (Figure 6.4). However, these additional drawdowns comprise only about the 7% of the saturated thickness in these localities, so they are assumed to be insignificant. Other than these two cooperatives, in İkisaray and Susuzören cooperatives additional drawdowns of 3 m and 1 m are observed, respectively. At any other locality, either a cooperative or the Observation Well 1, no additional drawdown is observed.

Table 6.6 represents the annual water budget of Ulubey aquifer for 20 years planning period for Scenario C. According to this table, change in groundwater reserve decreases from 1.35 hm^3/year to 6.22 hm^3/year at the end of the planning period and an average decrease of 4.94 hm^3/year in groundwater reserve is predicted. Due to the pumping from the wells proposed for cooperative irrigation and for future water supply of Uşak town, groundwater discharge to Banaz Stream decreases about 2.4 hm^3/year in average compared to the results of Scenario A. However, these changes are insignificant with respect to the present situation. Consequently, it is concluded that pumping from the wells proposed for cooperative irrigation and for future water supply of Uşak town in addition to the current pumping rates, will not affect the groundwater reserve of Ulubey aquifer and discharges into the Banaz Stream significantly.

Table 6.6 Annual budget and reserve change of Ulubey aquifer for Scenario C for 20 years planning period (hm^3/year)

Year	RECHARGE						DISCHARGE							Change in Reserve
	Precipitation	Subsurface Inflow	Surface Inflow	Streams	Asartepe-Alluvium	Total	Wells	Subsurface Outflow	Springs	Streams	Adıgüzel Dam	Asartepe-Alluvium	Total	
1	64.37	62.75	10.11	0.49	54.04	191.76	10.96	53.39	5.34	102.23	10.84	10.35	193.11	-1.35
2	64.21	62.17	10.08	0.49	53.97	190.91	11.31	53.43	5.35	102.10	10.90	10.21	193.28	-2.37
3	64.21	62.10	10.08	0.49	54.03	190.91	12.14	53.45	5.35	102.02	10.92	10.15	194.03	-3.13
4	64.21	62.09	10.08	0.50	54.10	190.97	12.54	53.44	5.35	101.91	10.93	10.12	194.29	-3.31
5	64.37	62.28	10.11	0.50	54.30	191.56	12.97	53.56	5.37	102.05	10.97	10.13	195.05	-3.49
6	64.21	62.13	10.08	0.51	54.21	191.14	13.37	53.38	5.36	101.64	10.95	10.09	194.78	-3.63
7	64.21	62.17	10.08	0.51	54.26	191.24	14.88	53.34	5.36	101.49	10.95	10.09	196.11	-4.87
8	64.22	62.21	10.08	0.52	54.33	191.36	15.77	53.29	5.35	101.32	10.96	10.08	196.77	-5.42
9	64.38	62.44	10.11	0.52	54.55	192.00	16.27	53.39	5.35	101.42	10.99	10.10	197.51	-5.51
10	64.22	62.32	10.08	0.52	54.47	191.62	16.72	53.19	5.31	100.97	10.96	10.07	197.21	-5.60
11	64.22	62.38	10.08	0.53	54.53	191.74	17.21	53.13	5.28	100.78	10.96	10.07	197.44	-5.70
12	64.23	62.44	10.08	0.53	54.59	191.87	17.72	53.08	5.26	100.60	10.97	10.07	197.69	-5.82
13	64.39	62.67	10.11	0.54	54.80	192.52	18.53	53.17	5.26	100.68	11.00	10.09	198.71	-6.20
14	64.24	62.56	10.08	0.54	54.73	192.15	19.03	52.96	5.22	100.21	10.97	10.05	198.45	-6.30
15	64.24	62.63	10.08	0.54	54.81	192.31	19.59	52.90	5.21	100.02	10.97	10.05	198.73	-6.42
16	64.25	62.71	10.08	0.55	54.88	192.46	20.16	52.83	5.19	99.82	10.98	10.05	199.03	-6.57
17	64.41	62.95	10.11	0.55	55.10	193.13	18.99	52.92	5.19	99.90	11.01	10.07	198.08	-4.95
18	64.25	62.85	10.08	0.55	55.05	192.79	20.33	52.71	5.17	99.42	10.98	10.04	198.64	-5.86
19	64.25	62.94	10.08	0.55	55.16	192.99	20.97	52.63	5.19	99.20	10.98	10.03	199.00	-6.01
20	64.25	63.04	10.08	0.56	55.26	193.19	21.63	52.55	5.22	99.00	10.98	10.03	199.41	-6.22
Average	64.27	62.49	10.09	0.52	54.56	191.93	16.55	53.14	5.28	100.84	10.96	10.10	196.87	-4.94

CHAPTER 7

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

7.1 Summary

The aim of this study was to develop a management plan for Ulubey aquifer system in Uşak province, where groundwater is the main source of fresh water. All the available data regarding physiography, meteorology, geology and hydrogeology of the system have been collected, evaluated and utilized to develop a conceptual hydrologic budget and a conceptual model for the system. However, due to lack of data, all of the components of the groundwater budget could not be precisely determined. Consequently, a mathematical groundwater flow model based on the conceptual model has been utilized to determine the groundwater budget and also to test alternative management scenarios. Lithological units having good aquifer properties that were simulated in the mathematical model were selected considering their hydrogeological properties and regional extends within the study area. According to the detailed hydrogeological classification of the units within the Banaz Stream Basin, Ulubey Formation, Asartepe Formation, alluvium and marbles were determined as the most important units having good aquifer properties on regional basis. Other units either form the base due to their impermeable characteristics or do not have regional significance due to limited or disconnected outcrops. Although, marbles were classified as good aquifer, there was not enough data to define their regional geometry, groundwater levels, boundary conditions and hydraulic properties. Consequently, marbles were not included in mathematical model, instead, lateral flows between marbles and other simulated units were considered in modeling stage. Moreover, having similar hydraulic properties and overlapping extensions, Asartepe Formation and alluvium were considered as a single unit. As a result, Ulubey Formation and Asartepe Formation that was considered as a single unit with alluvium were defined separately on mathematical model. Finally, a model of two layers, upper one simulating Asartepe Formation and alluvium, and lower one simulating Ulubey Formation, was designed and lateral flow from marbles to the system was considered in the simulation.

The first stage of groundwater flow model design was determination of the model domain and setting up the finite difference grid. Model boundaries were determined considering geological and hydrogeological characteristics of the basin. Then, this model domain was splitted into blocks in which hydrogeological parameters were assumed to be uniform. After, domain and finite difference grid of the model was set up; hydraulic parameters as well as recharge/discharge parameters of the system were input into the model and boundary conditions were determined by considering geological structure and hydrogeological characteristics of the system.

In the next stage, the model was calibrated under steady state conditions, until a good correlation of groundwater levels observed in the field and calculated by the model was achieved. During calibration process, input parameters of the model, such as hydraulic conductivity, recharge, anisotropy and conductances of drains and rivers, were changed by trial and error. Correlation between observed and calculated groundwater levels was checked by Root Mean Square Error (RMS). Match of data measured in the field and calculated by the model, such as spring discharges and baseflow rates, was also considered. At the end of calibration process a good match was achieved for each factor considered and it was concluded that calibrated model was capable of simulating the hydraulic heads with 5.1 % tolerance. During calibration, at the end of each run of the model, calculated groundwater budget was compared with the conceptual budget. Calculated groundwater budget was separated into two, such that each sub-budget would belong to different model layers, in order to determine recharge and discharge mechanisms of each layer one by one and to observe the interactions between these layers. It was also concluded that at the end of calibration, groundwater budget calculated by the model was consistent with the conceptual budget of the system.

The model calibrated under steady state conditions was then utilized in sensitivity analysis, which was very beneficial in determination of the parameter or parameters which were effective on the model results. A series of simulations were performed in order to test the sensitivity of the model to changes in several parameters, such as recharge from precipitation, hydraulic conductivity and anisotropy and also to test the effects of changes in these parameters to model results. At the end of sensitivity analysis, it was observed that the model was very sensitive to increase and decrease in hydraulic conductivity and increase in the recharge from precipitation, whereas it was not as sensitive to the changes in anisotropy as the other two parameters.

Groundwater flow model calibrated under steady state conditions, which was proved to be capable of representing the field conditions, could be used to test the effects of several future pumping schedules on Ulubey aquifer system. For this purpose, three management scenarios were set up under transient conditions and their effects were tested. A planning period of 20 years, from May 2007 to April 2027, was simulated in the model. Each of these three management scenarios, together with their results and conclusions based on these results were summarized below:

Scenario A was based on the assumption that current pumping rates will continue throughout the planning period of the next 20 years. According to the results of this simulation, maximum residual drawdown was about 1.5 m in August 2026 and about 1 m in April 2027 in the locality of Tüprag wells. As a result, continuation of current pumping schedule will not create a significant change in groundwater levels and reserve of Ulubey aquifer compared to the present situation under average recharge conditions.

Scenario B simulated the effects of additional pumping from the wells of irrigational cooperatives in addition to the pumping schedule of Scenario A. As a result, annual amount of groundwater extracted from these cooperative wells was predicted as 4.62 hm^3 to irrigate an area of 780 hectares. Additional pumping from the wells of irrigational cooperatives in addition to the current pumping schedule caused additional drawdowns in different amounts. At the locality where cooperative wells are concentrated, maximum drawdown was about 17 m in August 2026 and about 4 m in April 2027. According to the groundwater level hydrographs, seasonal groundwater level fluctuations of Scenario B were more than that of Scenario A due to pumping during the irrigation season. At the Observation Well 1 in the locality of Tüprag wells, there was no difference in the results of Scenario A and B. As a result, it can be concluded that there is no interaction between the extractions from Tüprag wells and cooperative wells and they do not create an overlapping cone of depression. According to the annual water budget of Ulubey aquifer for 20 years planning period, change in groundwater reserve indicated an average decrease of 1.62 hm^3/year, for Scenario B. Groundwater discharge into the Banaz Stream decreased about 1.5 hm^3/year compared to the results of Scenario A due to the pumping from cooperative wells. However these are insignificant declines compared to the present situation. As a result, under average recharge conditions, additional pumping from cooperative wells will not create a significant change in groundwater levels, groundwater discharge into Banaz Stream and reserve of Ulubey aquifer.

Scenario C simulated the effects of additional pumping in order to supply increasing demand on water depending on a potential population increase of Uşak town, in addition to the pumping schedule of Scenario B. According to population projections and future water demand analysis, the gap between the present water supply and the future water demand was predicted to grow continuously, and reach to 373 L/s by 2027 at the end of the planning period of 20 years. Finally, it was recommended that additional water demand is to be supplied from the wells that would be drilled in Ulubey aquifer during 20 years, such that five wells to be drilled in each five years. Locations of the wells proposed were determined considering several factors, such as distance to the present distribution network, depth to groundwater table, saturated thickness, hydraulic conductivity and distance to the present wells and potential cooperative wells. Proposed well field is located 3 km north of Ovademirler and Yavu villages. Proposed wells are located 300 m apart from each other and it was assumed that five wells would be drilled in each five years. Due to the pumping from the wells proposed to supply the increasing demand during the planning period (in addition to pumping from current wells and potential cooperative wells), a maximum drawdown of 19 m was predicted in August 2026 and April 2027. At the end of 20 years, an additional drawdown of 12 m was noted at the wells of the Ovademirler and Yavu Cooperatives, which are located close to the proposed well field. However, these additional drawdowns comprised only about the 7% of the saturated thickness in these localities, so they were assumed to be insignificant. Change in groundwater reserve decreased from 1.35 hm^3/year to 6.22 hm^3/year at the end of the planning period and average decrease of 4.94 hm^3/year in groundwater reserve was predicted. Due to the pumping from the wells proposed for cooperative irrigation and for future water supply of Uşak town, groundwater discharge to Banaz Stream decreased about 2.4 hm^3/year in average compared to the results of Scenario A. However, these changes were insignificant with respect to the present situation. Consequently, it was concluded that pumping from the wells proposed for cooperative irrigation and for future water supply of Uşak town in addition to the current pumping rates, will not affect the groundwater reserve of Ulubey aquifer and discharges into the Banaz Stream significantly.

7.2 Conclusions

Based on the results of this study following conclusions can be made:

- Groundwater levels of Ulubey aquifer are slightly affected by the recent wet and dry period. Moreover, during the past 17 years there has been no decline in groundwater levels due to pumping from wells. These facts indicate that due to non increasing pumping rates, equilibrium conditions of Ulubey aquifer still persist.

- According to the conceptual groundwater budget of Ulubey aquifer system, the gap between the calculated recharge (48 hm^3/yr) and discharge (104.9 hm^3/year) of Ulubey aquifer implies that approximately 57 hm^3 of groundwater has to be reduced from the reserve and groundwater levels have to decline continuously. However, groundwater levels of Ulubey aquifer has been stabilized since 1990. This fact proves that aquifer is recharged from other units (Asartepe Formation, marbles) and it may also discharge to other units. That is why a mathematical groundwater flow model has to be utilized in order to determine the missing components of groundwater flow budget of the system and to determine the interactions between the Ulubey aquifer and the other units.
- Effects of cooperative irrigations planned by DSI and also effects of possible increase in groundwater demand due to population increase are simulated by different scenarios. As a result, neither of these scenarios create significant drawdown or change in groundwater reserve, which implies that Ulubey aquifer system is capable of supplying the required amount of groundwater for cooperative irrigations and also in case of a potential population increase.

7.3 Recommendations

Moreover, based on the results of this study following recommendations which might aid in the determination of a groundwater management plan for the Ulubey aquifer system can be made:

- Predicted amounts of additional pumping from cooperative wells will not create a significant change in groundwater levels, groundwater discharge into Banaz Stream and reserve of Ulubey aquifer, under average recharge conditions. Thus, cooperative irrigation should be encouraged and incited instead of individual irrigation.

- Although pumping from the wells proposed to supply the growing water demand due to the possible population increase, will cause drawdowns; under average recharge conditions, it will not affect the groundwater reserve of Ulubey aquifer and discharges into the Banaz Stream significantly. However, the proposed well field has the highest relative contamination potential because of the shallow groundwater levels, high conductivity values and high recharge rates around this locality (Yazıcıgil et al., 2008). As a result, this locality should be protected.

- This model is set up and calibrated on the basis of the available data which are not distributed uniformly throughout the area comprising the aquifer. Especially in the east of Karahallı and in the south of Bulkaz River data are insufficient. In order to better characterize the system and improve the model, new monitoring wells distributed evenly and regular monitoring from these wells are recommended.

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