OPTIMIZATION OF THE ATABEY PIPE IRRIGATION NETWORK BY USING SUFEN NETWORK SOFTWARE

A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
OF
ATILIM UNIVERSITY

BY

WALEED ALHENDI

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR
THE DEGREE OF MASTER OF SCIENCE
IN
THE DEPARTMENT OF CIVIL ENGINEERING

JANUARY 2019

Approval of the Graduate School of Natural and Applied Sciences, Atilim University.

____

Prof. Dr. Ali KARA
Director

I certify that this thesis satisfies all the requirements as a thesis for the degree of **Master of Science in Civil Engineering, Atilim University**.

____

Asst. Prof. Dr. Gökhan TUNÇ
Head of Department

This is to certify that we have read the thesis OPTIMIZATION OF THE ATABEY PIPE IRRIGATION NETWORK BY USING SUFEN NETWORK SOFTWARE submitted by WALEED ALHENDI and that in our opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science.

____

Assoc. Prof. Dr. Yakup DARAMA
Supervisor

Examining Committee Members:

Prof. Dr. Zafer BOZKUŞ
Civil Engineering Department, METU
____

Assoc. Prof. Dr. Yakup DARAMA
Civil Engineering Department, Atilim University
____

Assist. Prof. Dr. Aslı GENÇ
Civil Engineering Department, Atilim University
____

Date: 11 January 2019

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Name, Last Name: Waleed Alhendi

Signature :

ABSTRACT

OPTIMIZATION OF THE ATABEY PIPE IRRIGATION NETWORK BY USING SUFEN NETWORK SOFTWARE

Alhendi , Waleed
M.S., Civil Engineering Department
Supervisor: Assoc. Prof. Dr.Yakup Darama

January 2019, 73 pages

Agricultural sector in the many developing countries of the world consumes about 70% of their total water resources. In Turkey, 73% of the total water resources is consumed by the agricultural sector. During the last decade, classical irrigation systems have been replaced by modern pipe irrigation networks to conserve water and increase agricultural production. The Atabey irrigation scheme is one of the fertile plains located in the central Mediterranean region known as lakes district of Turkey, was designed and constructed as the classical irrigation system between 1980 and 1990. Due to the change of climate and decrease in total amount of precipitation in the region, water level of the Eğridir Lake which is the main water source of irrigation in the area started to decrease, thus the existing irrigation system was transformed into pipe irrigation network. In this study pipe irrigation network of the Atabey irrigation system was optimized in terms of optimizing pipe diameter and hydraulic conditions by using SUFEN Network software which is based on the simplex algorithm for optimization. Using the SUFEN Network, pipe diameters of the main pipeline, and sub main pipeline were optimized, pressure in the pipe and velocity criterion specified by the State Hydraulic Works (DSI) was achieved. It is determined from the analysis that the operating pressure head in the main pipe varied between 25 m to 35 m for the high pressure zone and between 10 m to 25 m for low pressure zones in the area. Moreover flow velocity in the main pipe varied between 0.6 m/s which is greater than minimum allowable velocity of V_{min}=0.5 m/s and 1.45

m/s which is also smaller than maximum allowable velocity of V_{max}=3.0m/s. These values conform with the hydraulic criteria defined by DSI. Similar results were also obtained for the other branch sub pipe 1. The operating pressure head in this pipe varied between 25 m to 35 m for the high pressure zone and between 10 m to 25 m for low pressure zone and velocity values varied between 0.6 m/s which is greater than allowable minimum velocity (V_{min}=0.5m/s) and 1.9 m/s which is less than maximum allowable velocity (V_{max}=3 m/s). Based on the optimization results the coordinates of the pipes and the final layout of the irrigation network were determined by using Auto CAD application of the SUFEN Network Software. Accuracy of the result obtained from this study was compared with the results of DSI Network solution for the Atabey pipe network and it was found that both results were almost identical. Thus, it was concluded that the optimization performed for the Atabey pipe irrigation network is adequate. .

Keywords: Atabey irrigation, pipe network, optimization, SUFEN Network Software

ÖZ

ATABEY BORULU SULAMA ŞEBEKESİNİN SUFEN ŞEBEKE YAZILIMI KULLANILARAK OPTİMİZASYONU

Alhendi, WALEED
Derece, İnşaat Mühendisliği Bölümü
Tez Yöneticisi : Doç. Dr. Yakup DARAMA

Ocak 2019, 73 sayfa

Gelişmekte olan ülkelerde tarım sektörü ülkenin su kaynağının %70' ini kullanmaktadır. Türkiye'de tarım sektörü toplam su kaynaklarının %73' ünü kullanmaktadır. Geçen on yıllık sürede suyu tasarruflu kullanmak ve zırai ürün miktarını arttırmak için klasik sulama sistemleri modern borulu şebekelerle değiştirilmiştir. Orta Akdeniz göller bölgesinde bulunan Atabey ovası verimli bir ova olup 1980 ve 1990 yılları arasında sulama sistemi klasik sulama sistemi olarak inşaa edilmiştir. Son yıllarda iklim değişikliği ve yağış miktarında meydana gelen azalmayla birlikte ana su kaynağı olan Egridir gölündeki seviye azalması nedeniyle sulama sistemi borulu sulama şebekesine dönüştürülmüştür. Bu çalışmada, Simplex algoritmasını kullanarak geliştirilen SUFEN Şebeke yazılımı kullanılarak Atabey borulu sulama şebekesinin boru çapları ve hidrolik koşulları için optimizasyonu yapılmıştır. SUFEN Şebeke yazılımı kullanılarak ana boru hattının ve anayedek1 boru hattının çapları optimize edilmiş, boru hattında meydana gelecek basınç ve akım hızı değerleri DSİ tarafından belirlenen kriterlere uygun hale hetirilmiştir. Optimizasyon sonuçlarının analizinden ana boru hattında ve ana yedek 1 boru hattında işletme basınç yükü 25 m ile 35 m arasında akım hızı ise V=0.6 m/s>V_{min}=0.5m/s ile V=1.9 m/s <V_{max}=3m/s arasında değişmiş olup bu değerler DSİ tarafından belirlenen hidrolik kriterlere uygun olarak belirlenmiştir. Atabey borulu sulama şebekesinin hesaplanan hidrolik verileri ve hidrolik yük eğimi verileri Auto

CAD yazılımı kullanılarak boruların yerleşim koordinatları ve projenin nihai genel yerleşim planı hazırlanmıştır. Bu çalışmada elde edilen sonuçlar, DSİ tarafından geliştirilen şebeke yazılımının aynı projeye uygulanmasıyla elde edilen sonuçlarla karşılaştırılmış ve her iki optimizasyon çalışmasında elde edilen sonuçların birbirleriyle örtüştükleri belirlenmiştir. Bu doğrulama neticesinde Atabey borulu sulama şebekesinin optimizasyonunun doğru olduğu sonucuna ulaşılmıştır.

Anahtar Kelimeler: Atabey sulaması, borulu şebeke, optimizasyon, SUFEN Şebeke Yazılımı

To My Parents

To My Beloved Fiancé

ACKNOWLEDGMENTS

First of all, I would like to thank Assoc. Prof. Dr. Yakup Darama for his continuous support, help, guidance and insight throughout my thesis study. During this period, he showed great enthusiasm and patience.

I would like to thank Engineer Gökhan Marim, the manager of Sufen Company for his valuable knowledge and support in accessing information for my thesis subject.

I shall also like to express my gratidude to Engineer Ali Şahin the design specialist in Sufen Company for his patience in teaching me the Sufen software.

I also would like to express my gratitude to the manager of the 1.st Planning Section of the Planning Investigation and Allocation Department of the State Hydraulic Works for providing Hydrological, soil and irrigation data for the study area.

Furthermore, I thank the members of the examination committee Prof. Dr. Zafer Bozkuş and Assist. Prof. Dr. Aslı Numanoğlu Genç for their valuable time, comments and suggestions.

Last but not least; I would like to give a huge thank you to my parents and family for the all support they gave me. They have given me great encouragement throughout my thesis studies. Their belief in me is definitely what has made this thesis possible.

Table of Contents

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

DSI: the General Directorate of State Hydraulic Works

WHO: World Health Organization

HDNs: Heuristics Derived from Nature

Gas: Genetic Algorithms

SFLA: Shuffled Frog-Leaping Algorithm

ACO: Ant Colony Optimization

C: the cost vector of pipes per meter

X: the length vector of pipes

L_i: i numbered pipe length

L_{ij} =j element of i numbered pipe

A_j: elevation (m).

E_0: the pressure at the beginning of network (m).

ΔH: the hydraulic loss (m).

U: the coefficient corresponding 95% probability level

^{0}C: Celsius degree

J: the hydraulic slope (m/m)

Q: the discharge (m^3/s)

D is the pipe diameter (m)

L, M, and N are the coefficients depend on roughness coefficient

K: Coefficient of Darcy Weisbach equation.

CHAPTER 1

INTRODUCTION

1.1 Importance of the study

Pipe networks are an essential part of world's infrastructure. The construction and operation of these networks are very costly as for gas, sewerage, irrigation and municipal potable water networks. A relatively small decrease in construction and component cost of these networks therefore leads to huge total saving. These can be considerably reduced through optimal design of networks. Optimization of pipe networks is a multidisciplinary task involving hydraulics, quality and reliability requirements. Pipe network optimization is a combinatorial optimization problem as the pipe diameters can only be selected from a discrete set of commercially available sizes. In spite of all the progress made the optimization of pipe networks fulfilling all these requirements seem to be out of reach at the present time. Most of the current investigations are, therefore restricted to considering the hydraulic and availability requirements, leading to the so-called optimal pipe sizing of the pipe networks.

In agricultural sector the use of pipe irrigation schemes have been increasing due to limited water resources. Around 40% of the world´s food crops are produced by irrigated agriculture and remaining 60% comes from rainwater. Shilpa and Damgir [1]. Over the year 2050, Worlds water will have to support the agricultural system that will feed and create livelihood for an additional 2.7 billion people. The ultimate goals in managing irrigation water are efficiency, equity and sustainability. Among the distribution systems, the pressurized system has been developed during the last decades with considerable advantages with respect to classical open canals. The conveyance losses in open canal system is generally of the order of 40-50%.

In case of closed pipe system, the conveyance loss is much less than 10%, thus efficiency of pipe irrigation system is more than 90%. Therefore, a greater surface may be irrigated with a fixed quantity of water. They overcome the topographic constraints and make it easier to establish water fees based on volume of water consumed because it is easy to measure the volume of water delivered. Being computationally efficient, able in finding global design and capable in solving large problems are the marked aims in developing new models. In general, Optimization methods applied to design of pipe networks are classified as mathematical and natural inspired evolutionary methods. Many researches have shifted the focus of water distribution network optimization from traditional optimization techniques based on linear and non-linear programming to the implementation of heuristics derived from nature (HDNs) namely; Genetic Algorithms (GAs),Simulated Annealing, the Shuffled Frog-Leaping Algorithm (SFLA) and Ant Colony Optimization (ACO) Wang and Dal [2]. Dragon et al [3] developed computer model for least cost optimization problems for water distribution network system optimization.

Due to water scarcity, especially agriculture which is the major water-consuming sector leads the researchers to focus on using water-conserving system. In this sector. There are many studies states that more than demanded amount of water is lost in surface irrigation methods. These researches leaded to invention of modern irrigation methods such as sprinkler irrigation and drip irrigation. This variety irrigation method was invented in the 1960s. Both systems require pressurized irrigation network for their outlets to work efficiently. The sprinkler and the drip irrigation are still the most efficient irrigation methods for water savings and water use by crops. Engineers in water sector tried different types of irrigation methods but seeking the most efficient method and the closest to the natural irrigation leaded to invention of the pipe irrigation system. In an irrigation project, there is no way to shortage the amount of water that is demanded by the crop. So, the water conservation is needed to be involved in: storage, delivery, distribution, operation and application of water by irrigation system are more efficient than the traditional surface irrigation methods. The main advantages of the pressurized systems are less water consumption due to high irrigation systems, less labor need, productivity, erosion control and crop protection against to draught and frost Darama [4]. Transition to automation i.e. remote monitoring and controlling, is applicable to the pressurized system especially in need of metered water distribution. Wang and Dal [2].

In Turkey, the General Directorate of State Hydraulic Works (DSI) defines the irrigation as supplying the water that is necessary for the agricultural crops growth in the effective rooting depth without damaging the soil structure so that higher efficiency with minimum loss of water and soil and with minimum labor could be achieved. This shows that the irrigation should be planned very well because the water is an essential element for crop growth although it could also be harmful in the case of excess watering. In addition to that, the water loss should be minimized and an operational irrigation system should be well planned to deliver the demanded amount of water at the right time. Since 2010, all the irrigation projects designed and implemented by DSI in Turkey and classical open channel irrigation systems fulfill their economic life have been converted pipe irrigation networks.

1.2 Scope of the study and objective

Millions of dollars are spent each year on water distribution supply infrastructure. Computer analysis of pipe networks in irrigation is now common place; however, the use of pipe optimization techniques has been limited. The use of optimization techniques provides an opportunity for potential savings in costs for water supply authorities Dandy et al [5].

In this study, SUFEN Network [6] which is an optimization software used to optimize the Atabey pipe irrigation project in the Isparta province of Turkey in terms of optimum pipe diameter and pressure required for the network for water conservation and money as much as possible and a clearly identify of the optimization steps, a conclusion and recommendation will be given based on the optimization result.

This study is carried out in three phases. In the first phase of the study, studies for pipe irrigation networks optimization are reviewed and hydrology, climate, water and land resources of the study area are discussed. In the second phase of the study, SUFEN Network [6], which is a pipe irrigation network optimization program, is used for optimization of the irrigation network of the Atabey pipe irrigation network in the Isparta Province of Turkey

In the third phase, analysis of the results obtained from the SUFEN Network [6] applied to the Atabey pipe irrigation network in Isparta Province is discussed, the study is summarized, and conclusions are presented.

CHAPTER 2

LITERATURE REVIEW

Agriculture is the largest consumer of water resources and accounts for 80-90 % of all freshwater Shiklomanov [7]. The continuous increase of water consumption in connection with rapid human population growth leads to reduction of water consumption per capita. Unfortunately, only 20 % of human population has access to the freshwater. According to the World Health Organization (WHO), water supply per capita is going to be 1/3 of today's supply in 10 years, approximately half of the world population, will not have an access to clean water resources. Onda et al [8].The irrigation method is very important not only for producing of agricultural crop but also for conserving water resources.

Irrigation networks are the most essential systems in crop production in the agricultural fields of the countries. Today, agriculture is the major water consuming sector in most counties of the world for securing crop production in adequate quantity and quality. Due to increase in population, agricultural areas have also increased to meet the increased food demand. This also increased the amount of water usage in agricultural sector. Since water is limited resource and not only increased amount of agricultural sector water need but also other sectors water need must be met in sustainable manner. Among these sectors, agriculture uses about 70% of fresh water potential of the most countries as shown in Fig. 1 Çakmak et al, [9]. Situation in Turkey is not different than in other countries. Nowadays, 69.4% irrigated land of Turkey consumes 73% of available water resources potential of Turkey. Marım et al [10].

The main objective of the irrigation system is to provide the demanded water at peak level. However, the construction cost for modern irrigation systems to the land can be very problematic. Therefore, seeking suitable irrigation system has enforced the development of advanced and modern irrigation technologies and optimization methods. By the production of cheap high-density polyethylene pipes in 1970s, the pressurized irrigation systems spread all over the world and lead to innovate new optimization methods. The main expense of any pressurized irrigation network is the cost of pipes, because the size of pipes is directly related with pipe prices, this requires to the optimization of pipe sizes. Therefore, many researchers formulated an objective function leading to minimize the construction cost and operation cost of the irrigation network. However, the optimal design of the irrigation distribution systems is a process involving not only cost but also performance Feni et al., [11].

Pipe irrigation system contains hydrants to withdraw water from the system. Generally demand method is used for the operation of hydrants, thus the operation of the hydrants in pipe irrigation should be optimized. Marım et al,[10]. The demand of the irrigation system also depends on the probability of the number of user simultaneously using a hydrant. Clément [12] used the probability of the imitation network capacity being exceeded or fall behind when a user operates the hydrant. According to his method, the number of hydrants being open simultaneously is considered to follow a binomial distribution. Actually, operating a hydrant, which is the outlet of the irrigation system, at different time and at different place is uncertain. Furthermore, the downstream hydrants on demand pressurized irrigation systems should be affected more than the upstream hydrants Feni et. al., [11].

The increase of on demand and large-scale irrigation systems in the early 1960s in France, leaded the development of statistical models to compute the design flows. The most used models were the first and the second formulas of Clément [12]. But only the first formula of Clément has been widely used because of its simplicity and accuracy Lamaddalena and Sagardoy, [13]. The main step of designing demand irrigation network is the discharge calculation in each section Labye et al.[14].

In order to obtain the design flow, Clément [12] used the average water demand in the irrigation system. Designing each line and hydrant by their own crop and the water demand could be possible in a small area but generally, these network systems are designed for large-scale croplands. Moreover, in a district, all farmers generally grow same or similar type of crop. Thus, instead calculating each line and each parcel by different flow demand, using an average water demand in an irrigation project is logical. Wang and Dal [2]. This work purposed to perfectly understand the hydraulics calculations required for pressurized irrigation network. There are numerous hydraulics formulations necessary for optimization and hydraulic calculations. By realizing there is not a contemporary program for solving the pressurized irrigation network, an Excel VBA program is named as EPNO (Excel Pressurized Network Optimization) used in the Mediterranean countries including Turkey, Wang and Dal [2].

During the past years and also nowadays, global warming and drought have been serious problems especially in the middle part of Turkey. .

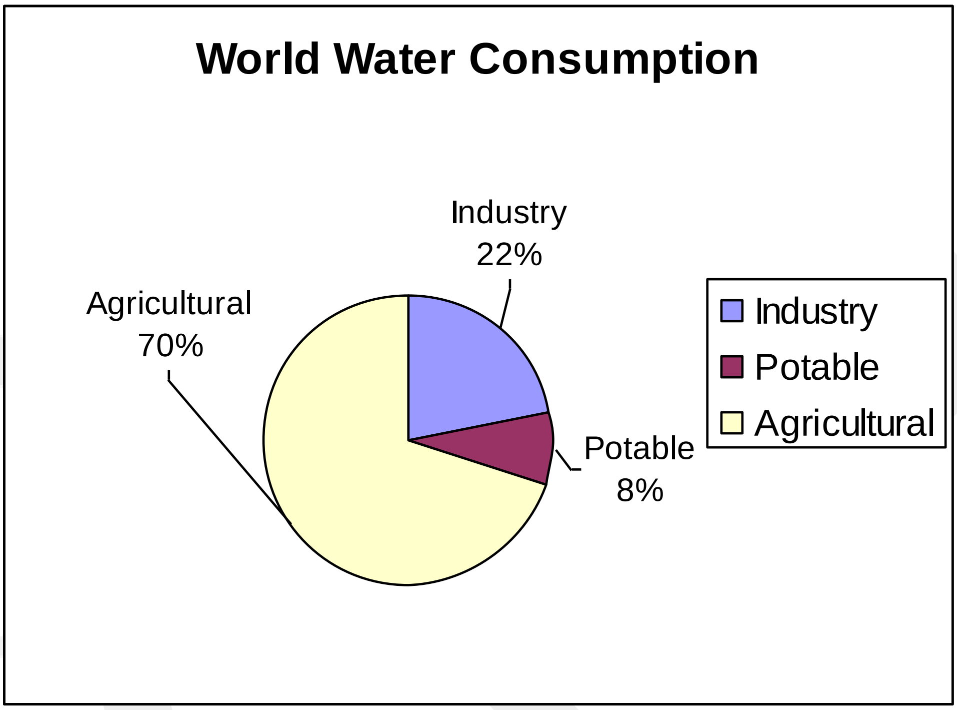


Figure 2-1 World water consumption

As it is shown in Fig.2-2, in high and low-income countries there is a dramatically difference in sectorial water consumption. Agricultural water consumption in high-income countries is 2.5 times less than agricultural water consumption in low-income countries. Whereas industrial water use in high income countries is three times higher than industrial water use in low-income countries. The situation in Turkey is almost same with the world's percentages as seen in Fig. 2-3 DSI [15]. Yearly 32 billion m^3 (%73) is consumed by agricultural activities. Yearly 5 billion m^3 (11%) is used by industry and 7 billion m^3 (11%) is used as a potable water. The behavior of water consumption is similar to world distribution. In Turkey, economically cultivable area for agricultural crop growth is 8.5 million hectare, and to date 65% of this area have been irrigated by irrigation system DSI [16].

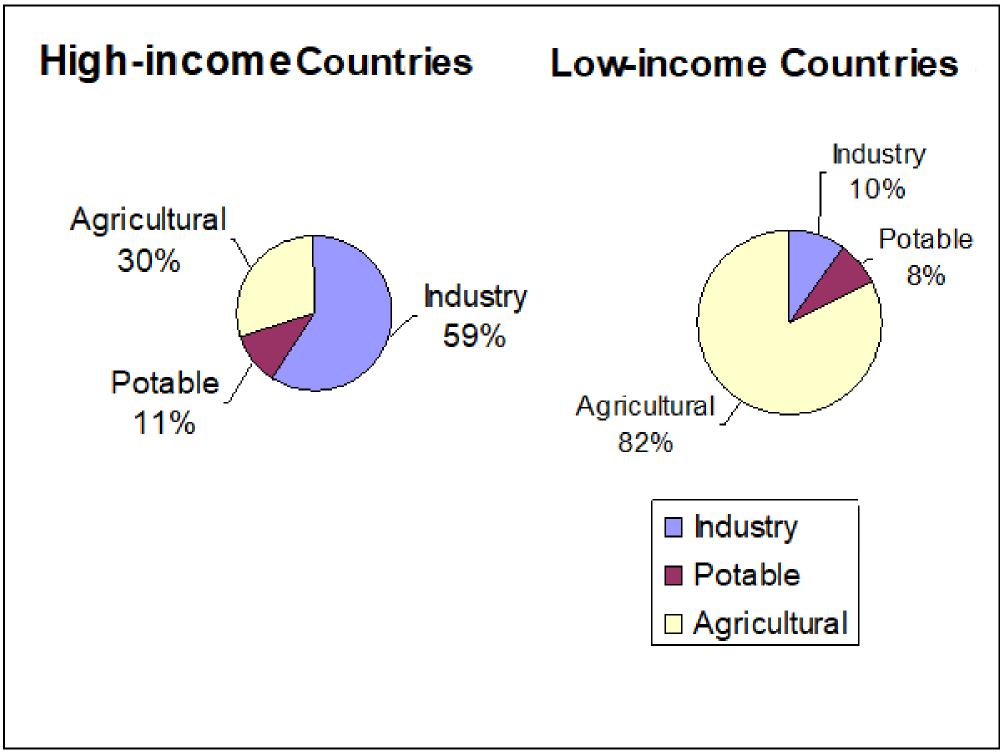


Figure 2-2 Sectorial water consumption in high and low income countries

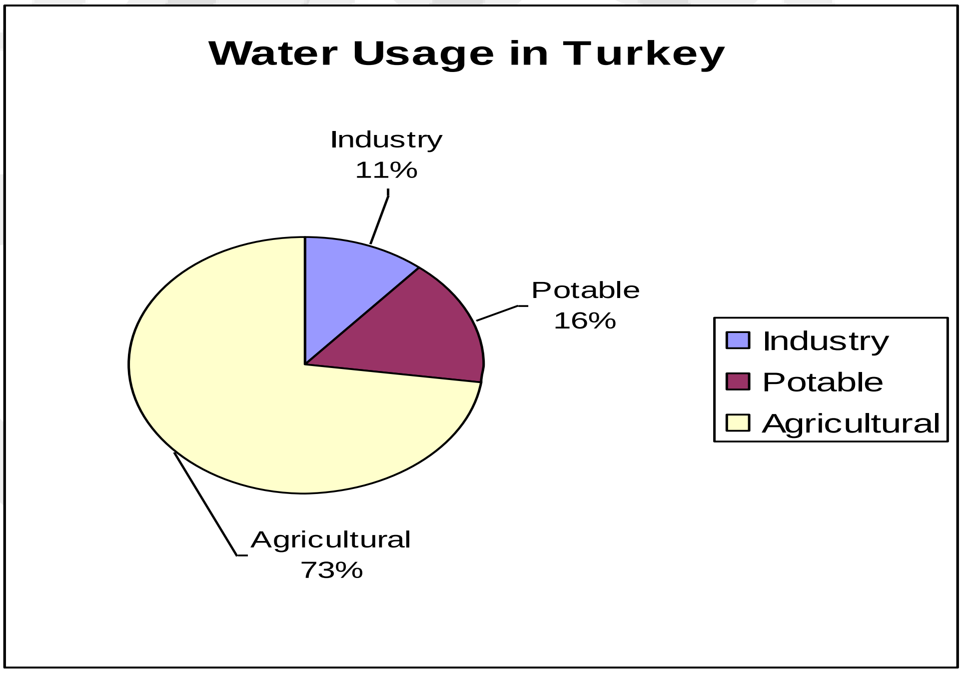


Figure 2-3 Sectorial water consumption in Turkey

CHAPTER 3

STUDY AREA AND HYDROLOGICAL DATA

The Isparta-Atabey plain irrigation project area is located in eastern Mediterranean Region of Turkey known as the Lakes District where the Aegean, Mediterranean and Inner Anatolian regions meet. The size of the irrigation area in the Atabey plain is 13467,70 hectare situated the north of the city center of Isparta (Fig 3-1) which is known as the "City of Roses". The altitude of the Atabey plain is 1035m a.s.l. The area is well connected to other parts of Turkey by roads and highways. Antalya lies 130 km to the south and Eskisehir is 350 km to the north as show in Fig. 3-1.

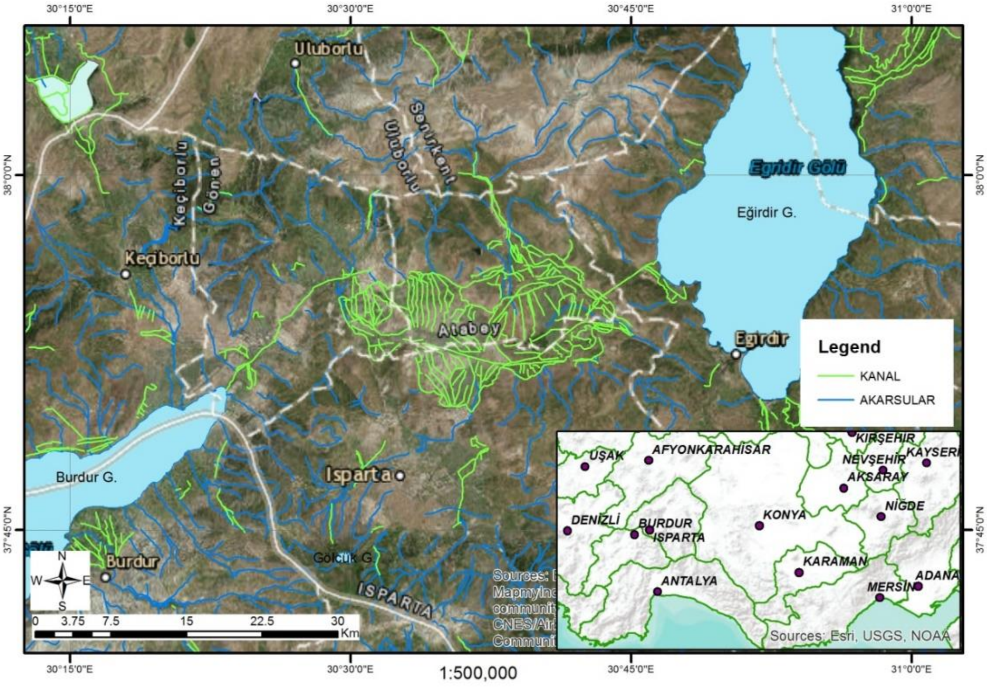


Figure 3-1 Study area location

3.1 Climate and water resources in the study area

The climatic characteristic of the project area is similar to the upper plateau of the Mediterranean Climate, summers hot and dry winters cold and rainy. There are four meteorological and hydro meteorological stations namely Gümüşgün and Kuleönü meteorological stations established by DSI, and Eğirdir, and Atabey meteorological stations established by the General Directorate of Meteorology (MGM) in the project area. These four stations measure the precipitation in the study area. The data of the Atabey station covering the period between 1964-2005 showed that average precipitation of those 41 year is 478 mm, the data of the Eğirdir meteorological station covering the period between 1930-2005 showed that the average precipitation of those 65 years is 757 mm. Table 3-1 shows the monthly average precipitation values of those four meteorological stations. Complete monthly precipitation values measured from four stations during the measurement period is given in the Appendix DSI [15] . Fig. 3-2 shows the seasonal variation of monthly average temperature in the study area. Values shown in Figure 3-2 was determined by averaging the average monthly precipitation values of those 4 precipitation, namely Atabey, Eğirdir, Baladız and Kaleönü.

Table 3-1 Monthly average precipitation values of four meteorological stations

Month	J	F	M	A	M	J	J	A	S	O	N	D
Atabey	62.6	51.8	49.7	56.1	47.4	23.3	11.2	10.3	14.4	32.2	46.1	73
Eğirdir	131.4	105.7	78.2	77.9	48	22.9	8.9	6.9	18.6	44	71.9	142.7
Baladız	57.3	43.8	45.6	49.3	42.3	23.6	14.4	9.6	11.5	36.9	37.6	55.2
Kaleönü	51.9	47.3	54.4	50.3	37.8	28.8	14.4	9.0	9.4	35.8	43.6	58.2
Average	75.8	62.3	57	58.4	43.9	24.7	12.2	9	13.5	37.2	49.8	82.3

Isparta meteorological station temperature measurements represent the average temperature of the study area. The data for temperature measurement covers the period between 1929-2005 given in Appendix B, and the annual average temperature for those 76 years is 11.9 ^{0}C. Temperature data for those years showed that the maximum average temperature is 23.4 ^{0}C measured in July and the minimum average temperature is 1.9 ^{0}C measured in January DSI [15] .

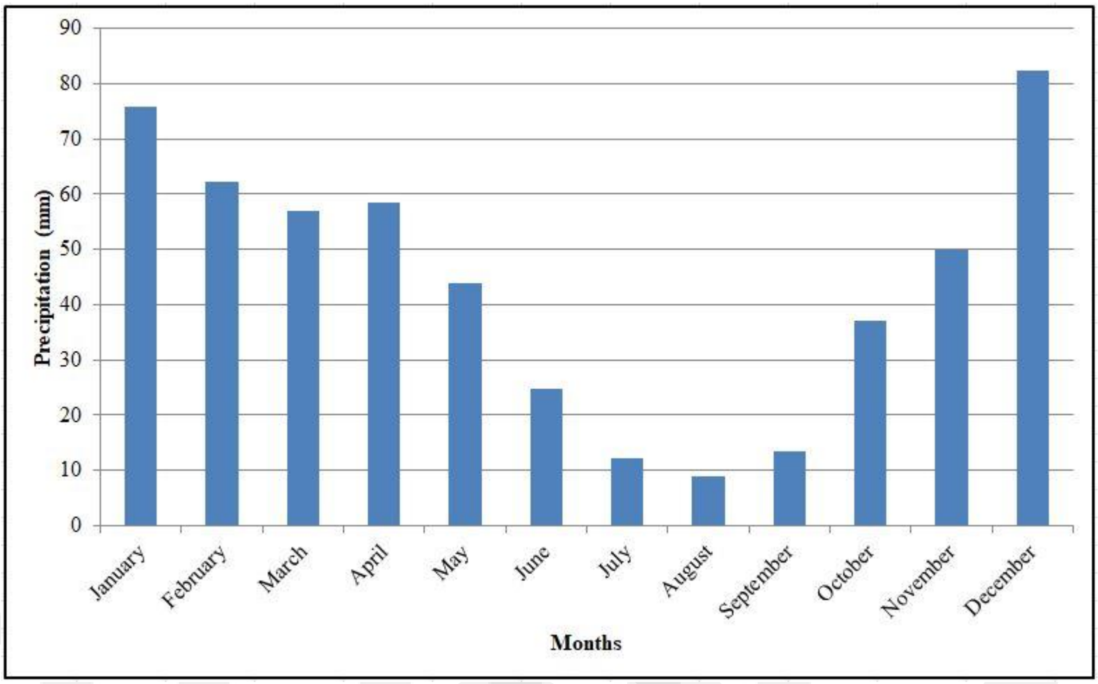


Figure 3-2 Seasonal variation of monthly average precipitation in the study area

Water source of the Atabey irrigation project is the Egridir Lake shown in Fig.3-3. The drainage area of this lake is 3309 km^2. Major streams and creeks feeding the Eğridir Lake are the Gelendost, the Pupa streams and the Çaydere and the Hoyrat creeks. Besides these sources, small creeks and spring in the lake also feeding the Eğridir Lake. Since this lake is the major fresh water source for the region, detailed hydrological study of this lake was conducted to determine the long-term water budget of this lake. Water budget study of the lake showed that inflow to the Eğridir Lake is 841.41 hm^3. Outflows from the lake are 264.16 hm^3 for hydropower, 67.54 hm^3 for irrigation, 12.89 hm^3 for potable water, and 503.78 hm^3 for evaporation. The difference between the inflow and outflow is 6.96 hm^3 showed that lake level increases in each year. Thus a regulator was constructed at the exit of the lake in order to control the lake level DSI [15].

Figure 3-3 Egridir Lake to irrigate Atabey project

3.2 Agricultural activity and topography in the study area

Variety of agricultural crops has been grown in the Isparta-Atabey plain. Some of these crops are; apple, cherry, grape, peach, apricot and sour cherry, these crops are mainly fruits and they grow in the Isparta province and exported and marketed in other cities of Turkey during harvest time, while some are stored in cold stores and supplied to local markets. Some of these fruits are used as fruit juices and dried fruits Sargin and Okudum [18]. There are many impressive caves in and around the Isparta province, and high plateaus that consists of about 45% of Isparta, thus making it one of the prettiest cities in the Mediterranean region.

CHAPTER 4

OPTIMIZATION METHOD IN IRRIGATION NETWORK

4.1 General definition of optimization

In this study, designing of irrigation network is limited until to the hydrant. The main problem of designing irrigation network is deciding pipe diameters, thickness of the pipe and also excavation depth of pipe. The depth of excavation cannot be more than

4 m. Because of the operational issues, it is not preferable to place the pipes in deep depth. This study focuses on optimization of the cost of piping systems. The cost of irrigation network can be divided into two main components: pipeline and ancillary structures; hydrants. The number of hydrant depends on crop pattern, topography at irrigation system based on pressure.

According to pressure and demand constraints, the pipe diameter and thickness will be designed. The primary cost of the network is the cost of pipes. This is the subject of another optimization problem. The depth of the excavation can be optimized according to the comparing cost of suction, drain valves and excavation cost. Table 4-1 shows various pipe irrigation networks in different regions of Turkey. According to the planning report of these irrigation project pipe cost and excavation cost constitutes about 60 % of total cost of the project. Thus, optimization of the pipe cost in the Atabey irrigation project is studied in this work.

Table 4-1 Comparison cost of irrigation network Marım et al, [10].

The name of project	Project stage	Total irrigation area (gross)	The cost of pipe and excavation	Percentage in total cost	The cost of hydrant and ancillary structure	% in total cost
Edime-Kesan Bahcekoy small dams and irrigation	Final design	284.76	937.357	62	569.585	38
Isparta yalvac cakircal small dam and irrigation	Final design	132	405.117	52	375.287	48
Karaman ermenek Sarivadi small dam and irrigation	Final design	16	41.339	36	75.007	64
Tunceli Hozet Uzundal small dams and irrigation	Final design	706.9	7.875.318	78	2.230.471	22
Bingol merkiz Goltepesi small dams and irrigation	Final design	325	1.709.711	65	923.042	35
Elazig Karakocan Bazlama small dam and irrigation	Final design	224	1.418.897	65	771.681	35
Karaman-Ermenek Kazanci small dam and irrigation	Final design	42	206.241	53	183.818	47
Konya Huyuk Goceri small dam and irrigation	Final design	20	38.085	48	41.506	52
Konya Huyuk Mutlu small dam and irrigation	Final design	94.4	274.665	71	109.874	29
Konya Huyuk Burunsuz small dam and iriigation	Final design	37	109.641	68	50.508	32

As seen from Table 4-1, as the irrigation area increases the percentages of the cost of pipes and excavation increases. The cost of the system is function of pipe price and amount of excavation. The smaller the diameter, the lower the price. However, when the pipe diameter decreases, the head at the hydrants also decreases. Therefore, the problem is to decrease pipes cost under pressure constraints at hydrants. There are several optimization techniques to solve such a problem. Literature survey is done on these optimization techniques suitable for irrigation network optimization. In this study, optimization problem of price of pipes is called the network optimization problem. However, optimization of excavation depth is not in the scope of this study.

The most suitable optimization technique has been tried to be found in literature studies. The solution time, algorithm performance and results are evaluated for the selection of the most appropriate optimization study. In this study the "Network Optimization" software also accepted by DSI.

4.2. Optimization of irrigation pipe network

4.2.1. Simplex Method

Simplex method is defined as linear programming method which gives the fastest solution , Optimization of the cost of the pipes in the irrigation network is ensured by optimizing the pipe diameters according to the network length determined by providing the desired network pressures. Variables affecting the mains pipe costs are network length, pipe diameters and hydraulic losses. Pipe diameters are values that are listed at certain diameters relative to pipe type. The lowest cost providing the required pressure on the network can be achieved with the lowest cost function as given in Equation (2). The objective function is as in Equation (1).

$$f(x) = CX \tag{1}$$

Where C is the cost vector of pipes per meter, and X is the length vector of pipes. The constraints of the problem are specific functional and non-negativity constraints. The functional constraints are the pipe length and friction loses. The non-negativity defined as all pipe lengths are non-zero. The minimization of objective function can be achieved by simplex method. The constraints of the simplex algorithm can be expressed as follows. The total pipe length in the branch network is fixed and introduced as an input to the algorithm.

$$\sum_{j=1}^{n} L_{ij} = L_i \tag{2}$$

L_i: i numbered pipe length, L_{ij} =j element of i numbered pipe.

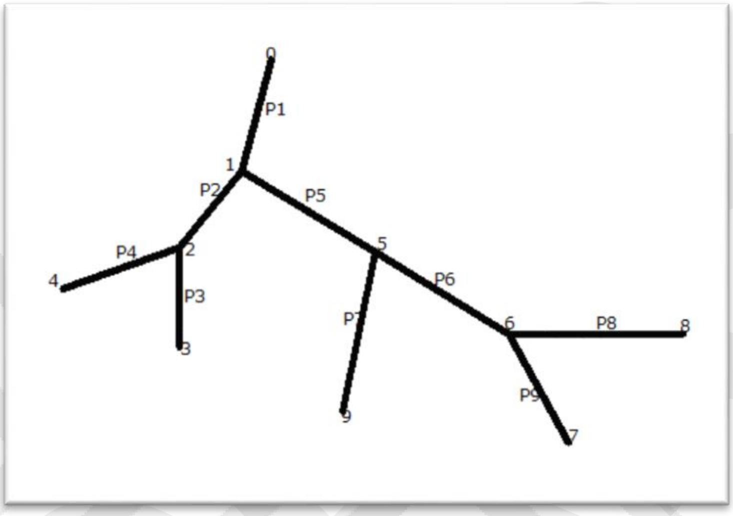
The problem constraint can provide Equation (3) inequality while the objective function is minimized. The desired pressure in each hydrant in the network will be calculated by calculating the hydraulic loss in each pipe segment and subtracting it from the initial pressure according to the branch system in the grid. The network plan will also be introduced to the optimization algorithm with a specific algorithm. The introduction of the network plan will be provided by the road matrix Wij. The final state transformed by the road matrix of the inequality of equation (3) is equation (4). In equations (3) and (4), the minimum pressure in meters of water column that must be provided at the hydrant is 25 m.

$$E_0 - \sum_{j=1}^{n} L_{ij} H_{ij} > \sum_{j=1}^{n} A_j + 25 \tag{3}$$

Where A_j is elevation (m), E_0 is the pressure at the beginning of network (m) and ΔH is the hydraulic loss (m).

$$E_0 - \sum_{j=1}^{n} A_J + 25 > \sum_{j=1}^{n} LW_{ij} \Delta H \times W_{ij} \tag{4}$$

The road matrix Wij (for example 9 pipes) representing the hydraulic loss of the network is given in Fig 2. Here, pipe 9 is located between points 6 and 7. The definition in the matrices is seen where the line goes from 1 to -1. When the 6th row is reached, the 6th pipe is defined as the 5th point to the 6th point. Figure 2 shows the merging of the two main branches at the first row, because of that there are the number “1” more than one in the first row. Thus, the network plan has been defined by entering all 9 pipes. The network of irrigation is introduced to the algorithm with the road matrix shown in Fig.4-1



	0	1	2	3	4	5	6	7	8	9
1	-1	1	1	0	0	1	0	0	0	0
2	0	-1	1	0	0	0	0	0	0	0
3	0	0	-1	1	0	0	0	0	0	0
4	0	0	-1	0	1	0	0	0	0	0
5	0	-1	0	0	0	0	1	0	0	0
6	0	0	0	0	0	-1	1	0	0	0
7	0	0	0	0	0	-1	0	0	0	1
8	0	0	0	0	0	0	-1	0	1	0
9	0	0	0	0	0	0	-1	1	0	0

Figure 4-1 Path matrix for the network (Marım et al, [10])

4.2.2. Discharge and Demand Calculation**.**

In classical irrigation network the discharge is determined as follows: First irrigation module is calculated from maximum crop water consumptive use. Maximum crop water consumptive use is calculated based on crop pattern, soil and climatic conditions in the area. Determination of irrigation module in this study accurately is very important step and it is known parameter in the optimization method.

Total discharge of the irrigation system is determined according to demand method. This method is based on continuous supply of water at every point in the project area. According to this method, capacities of the main, secondary and tertiary pipes are determined based on assumption that maximum demand in the field is continuously available in the irrigation system. However, only desired amount of water is supplied to the field during the operation of the system. The capacities of pipes in the network can be computed using the following analysis. Let n be number of turnouts (hydrants) operating at the same time on a tertiary. If q is withdrawn from each turnout at the same time, then the required total discharge Q_t=n.q. On the other hand,. Since continuous water application in 24 hr based is is practically impossible, then irrigation water is to be given periodically such that $Q_t>Q_c$ or $nq>Aq_{max}$. This inequality can be converted to an equality form by incorporating a multiplicative coefficient to the right hand side such that nq =AFq_{max} (Kızılkaya, [19]; Yanmaz, [20]; Darama, [4]). Total discharge is decreased by a flexibility number. Irrigation module, q_{max}, is calculated according to maximum monthly water demand. Depending on classical or pipeline system discharge can be written as;

$$Q_t = nq = AFq_{max} \qquad (5)$$

The discharge to be delivered to an area of size A by the tertiary concerned based on continuous application of maximum demand would be

$$Q_c = Aq_{max} \qquad (6)$$

Here q_{max} is the irrigation modulus (lt/s/ha) based on the crop pattern in the tertiary area. Since practically the maximum discharge can not be provided during 24 hour period, then assuming $Q_t>Q_c$ or $nq>Aq_{max}$, maximum discharge periodically given to the area. This inequality can be made to equality by multiplying right hand side of the inequality.

$$Q = nq = AFq_{max} \qquad (7)$$

And the flexibility coefficient F can be written as:

$$\mathrm{F} = \frac{\mathrm{nq}}{\mathrm{A}.q_{max}} \qquad (8)$$

Here n is the number of hydrants operating at the same time with discharge q (lt/s), A is the irrigation area in hectare. The flexibility coefficient is greater than 1, and approaches to 1 as the area size increases Darama [4]. This coefficient can be written for pipe irrigation system as (Marım et al, [10]):

$$\mathrm{F} = \mathrm{H}\left(1 + U\sqrt{\frac{1}{H} - \frac{1}{N}}\right) \tag{9a}$$

$$H = \frac{Eq}{rd}\sum S_e \tag{9b}$$

$$r = \frac{T'}{T} \tag{9c}$$

$$\mathrm{N} = \frac{\mathrm{Q_i}}{\mathrm{q}} \tag{9d}$$

Here U, is the coefficient corresponding 95% probability level from Gauss Normal Distribution i.e, Prob(U)=0.05 will give value of U=1.645. T is daily working hour and equals to 24 hour, T' irrigation period, E is the ratio of net area to total area, q is the theoretic parcel discharge, S_e is the total area, H is the number of hydrants working at the same time, Q_i is total discharge of the pipe and N is the total number of hydrant in the pipe. Using equations (7a, 7b, 7c and 7d) how the irrigation discharge can be reduced in a hypothetical irrigation network. All the calculations formulated in EXCEL and the results are presented in Table 4-2. In this table, the input for this example hypothetic system is irrigational module ,q_{max}, is 0.40 lt/s/ha, irrigation time, T, is 20 hour and high pressure pipe system the required discharge for theoretical parcel, q, is 10 lt/s/8ha, the total area is 1742 hectare, and total number of hydrant in the pipe network is 218. If these 218 hydrants were operating at the same time then the required discharge would be equal to (1742/8)x10 (lt/s)x218=2180 lt/s. As seen from Table 4-2 that this amount of discharge is reduced to 868 lt/s by applying statistical method.

Table 4-2 Discharge calculations of pipe irrigation network (Marım et al [10])

Variable	Input data	Unit	Explanation
q_{max}	0,40	lt/s/ha	Irrigation Modulus
U	1,645		Gauss probability (U=1.645)
E	0,9		net area /total area
T'	20	hour	Irrigation period
T	24	hour	
r	0,833		
q	10	lt/s/8ha	theoretic hydrant area discharge
ΣSe	1742	ha	Total area
	1567	ha	net area
N	218		Total number of hydrants
H	75,3		Number of hydrants working at the same time
F	86,8		Flexibility coefficient
Q	868	lt/s	Total discharge

4.2.3. Hydraulic Calculations

Hydraulic In irrigation piping systems, Colebrook equation is used in order to calculate hydraulic losses.

$$J = L * Q^{M} * D^{-N}/1000 \tag{8}$$

Where J is the hydraulic slope (m/m), Q is the discharge (m^3/s), D is the pipe diameter (m), L,M, and N are the coefficient depend on roughness coefficient , K. Coefficient of Dairy Weisbach equation can be calculated by Moody Chart. In 1944, L.F. Moody generated Moody Chart in order to find accurate friction coefficient. According to DSI assumptions k is taken as 0.5 mm for irrigation networks. The comparison of different formulas are done and given below. Dairy Weisbach, Colebrook, Manning and Hazen Williams equations are compared for 1000 km pipe, 100 m head.

4.3. Application of Sufen optimization program

The software that will be used in this study is Sufen Network [21] shown in Fig. 4-2. The software is developed by Sufen Project Software Engineering Construction Ltd. Company which is based in Ankara, Turkey working on project in water sector. Using SUFEN Network [21] pipe irrigation optimization program optimum hydraulic conditions for the design of the Atabey Province pipe irrigation network in terms of cost and desired operation pressure could be determined. Sufen softwares has also interface feature which gives an advantage to designers to incorporate AUTOCAD drawing program to draw plans and final drawing of the project layout, profiles and cross sections.

The Sufen Network software with the specifications briefly described above is applied to the Atabey pipe irrigation project and the layout plan shown in Fig. 5-1. There are five main steps for the application of Sufen Network software for the optimization of pipe diameter and pressure of the Atabey pipe irrigation project. These five steps will be explained in detail in chapter 5 and 6.

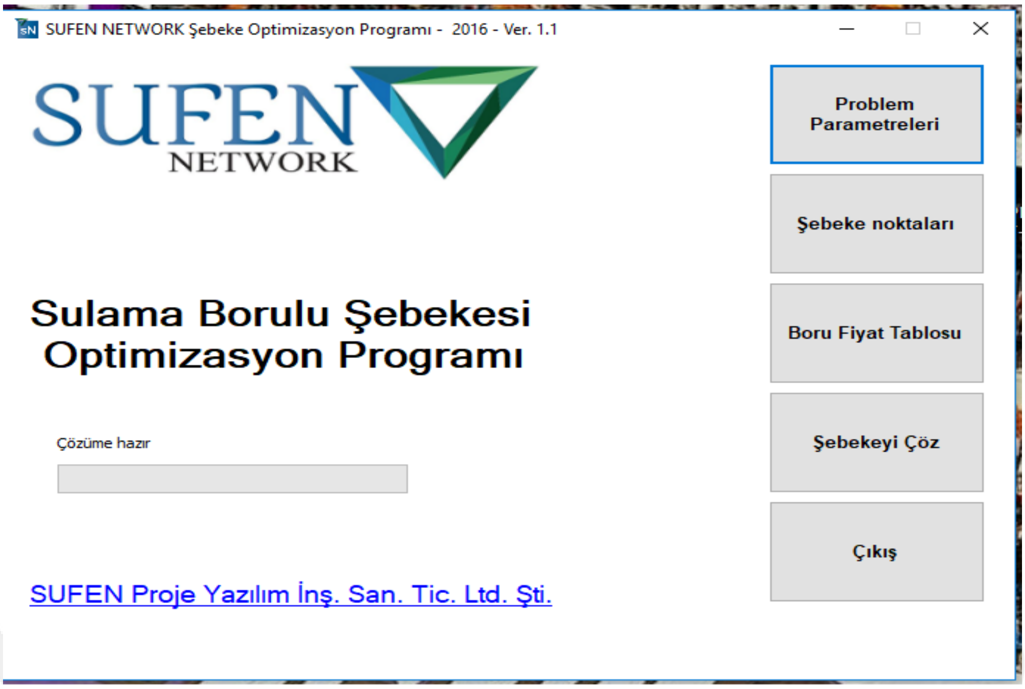


Figure 4-2 Sufen Network program window

CHAPTER 5

ANALYSIS OF THE RESULTS

As stated above, there are five steps that Sufen Network software is applied to the Atabey pipe irrigation project to obtain desired results and the solutions of optimization problems. First, a plan for the project area shown in Fig. 5-1 is drawn by using AutoCAD software.

Figure 5-1 Area plan view of the Atabey project layout drawn by AutoCAD

The total area shown in Fig. 5-1 was divided into parcels so that the number and location of hydrants serving those parcels could be determined. The base of the area of the Atabey pipe irrigation system was obtained from the Google Earth map view showing the locations of main and secondary pipes in the project area (Fig. 5-2)

Figure 5-2 Google Earth Map view of the project area.

The second step consist of field surveys to determine the locations, elevations and ground level of the main pipe and secondary pipes in project area as shown in Table 5-1 and Table 5-2, so that profiles and plans of the Atabey irrigation area could be drawn by using AutoCAD software.

Table 5-1 Elevations and ground level for the main pipe

Area			
Km	Code	Km	Code
0+000,00	979,85	4+332,15	965,41
0+015,00	979,79	4+348,14	965,08
0+031,54	979,49	4+351,22	964,93
0+040,42	979,56	4+369,59	964,30
0+052,73	979,25	4+387,41	963,86
0+067,19	978,20	4+409,76	963,56
0+079,99	978,27	4+417,23	963,40

Table 5-2 Elevations and ground level for the sub pipe 1

Area			
Km	code	km	code
0+000,00	976,98	3+112,63	955,07
0+015,72	973,47	3+126,06	954,78
0+028,36	970,64	3+138,72	954,37
0+029,72	970,43	3+152,12	954,10
0+031,49	970,46	3+161,91	954,00
0+035,49	969,62	3+167,66	953,90
0+046,95	968,60	3+170,14	953,93

The third step is the optimization. Excel spread sheet is used to prepare the input data into Sufen Network program. These Excel sheets data contains information for the main pipe and secondary pipe 1 such as pipe name, hydrant area, pipe length, elevation, etc. as shown in Tables 5-3 and 5-4.

The fifth column in table 5-3 is the structure type where S indicates to separation, H for hydrant, SP for start point and F for flow way out. As shown in Table 5-3, the first values for length, hydrant area are set be zero in order to define starting point of the main pipe so that the starting point of the irrigation system can be defined.

Table 5-3 Input data of Sufen network for main pipe

	Pipe name	Length (m)	Hydrant area (ha)	S/H/SP/F	Elevation (m)
1	Main pipe	0	0	SP	979,85
2	Main pipe	112,32	4,6	H1	976,99
3	Main pipe	250,50	0	S(pipe1)	976,98
4	Main pipe	906,15	1,5	H2	977,17
5	Main pipe	1166,73	0	S(pipe2)	966,52
6	Main pipe	1594,70	0	S(pipe3)	977,58
7	Main pipe	2080,84	0	S(pipe4)	975,40
8	Main pipe	2640,89	7,9	H3	967,85
9	Main pipe	3007,08	6	H4	969,44
10	Main pipe	3451,83	0	S(pipe5)	968,83
11	Main pipe	3771,47	0	S(pipe6)	969,49
12	Main pipe	4215,50	7,9	H5	967,37
13	Main pipe	4417,23	8,2	H6	963,40

Table 5-4 Hydraulic (input) data for main pipe

Required Head (m)	Inlet Discharge (lt/s)	Imposed Diameter (mm)	Irrigation Modulus (q) l/s/ha	Imposed discharge (lt/s)	Imposed code of BKV/P m
990,97	0	710	0,62	0	0
996,9876698	0	710	0,62	0	0
0	0	710	0,62	0	0
997,167941	0	630	0,62	0	0
0	0	630	0,62	0	0
0	0	630	0,62	0	0
0	0	0	0,62	0	0
987,8531098	0	0	0,62	0	0

Table 5-4 (continued)

989,4444707	0	0	0,62	0	0
0	0	0	0,62	0	0
0	0	0	0,62	0	0
987,3722573	0	0	0,62	0	0
983,4046	0	0	0,62	0	0

Tables 5-5 and 5-6 below show the input data for the sub pipe 1. Here if the structure type is not hydrant the hydrant area will be set to zero. Inlet discharge and imposed discharge is also set to zero before the optimization and after the optimization there will be values for the discharge.

Table 5-5 Pipe Parameter (input) data for the sub pipe 1

	Pipe name	Length (m)	Hydrant area (ha)	S/H/SP/F	Elevation (m)
14	Sub pipe1	161,13	6,6	H1	959,35
15	Sub pipe1	325,82	0	S(pipe1-1)	962,65
16	Sub pipe1	1041,74	6	H2	949,43
17	Sub pipe1	1391,09	11,5	H3	948,46
18	Sub pipe1	1721,19	11,4	H4	950,50
19	Sub pipe1	2208,42	13	H5	954,14
20	Sub pipe1	2413,33	7,8	H6	966,33
21	Sub pipe1	2550,74	0	S(pipe1-2)	967,81
22	Sub pipe1	2686,97	8	H7	962,20
23	Sub pipe1	2854,43	6,9	H8	954,25
24	Sub pipe1	3024,66	8,6	H9	956,57
25	Sub pipe1	3170,14	8,5	H10	953,93

Table 5-6 Hydraulic (input) data for sub-pipe 1

Required Head (m)	Inlet Discharge (lt/s)	Imposed Diameter (mm)	Irrigation Modulus (q) l/s/ha	Imposed discharge (lt/s)	Imposed code of BKV/P (m)
979,3508181	0	630	0,62	0	0
0	0	630	0,62	0	0
969,4346034	0	0	0,62	0	0
968,4628524	0	0	0,62	0	0
970,4974555	0	0	0,62	0	0
974,1414419	0	0	0,62	0	0
986,3338645	0	0	0,62	0	0
0	0	0	0,62	0	0
982,201845	0	0	0,62	0	0
974,2464177	0	0	0,62	0	0
976,566899	0	0	0,62	0	0
973,9297888	0	0	0,62	0	0

Irrigation modulus for all pipes of the Atabey pipe irrigation area is determined as q_{max}=0.62 l/s/ha as shown in Table 5-4 and Table 5-6. After the preparation of the input data, Sufen Network software is executed and program menu containing several options opens. From the menu, “Problem Parameters” option was chosen and Problem Parameters menu appears (Fig. 5-3)

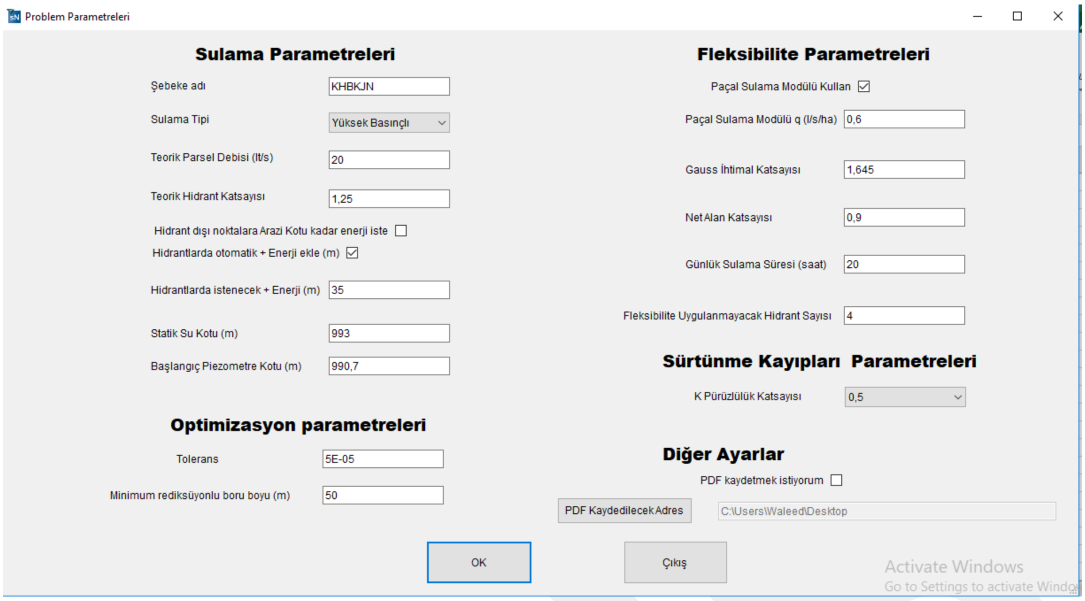


Figure 5-3 Problem Parameters window

Network name is defined as Atabey, irrigation type is chosen as high pressure system, the theoretical flow is defines as 20lt/s, hydrant flexibility coefficient is equals to 1.25, and Gauss Probability value is equal to 1.645. and these parameters are entered into Problem Parameters Window. After this operation, Network Nodes “Şebeke Noktaları” option is selected and data in Tables 5-3 and 5-4 are copied into this page as shown in Fig. 5-4

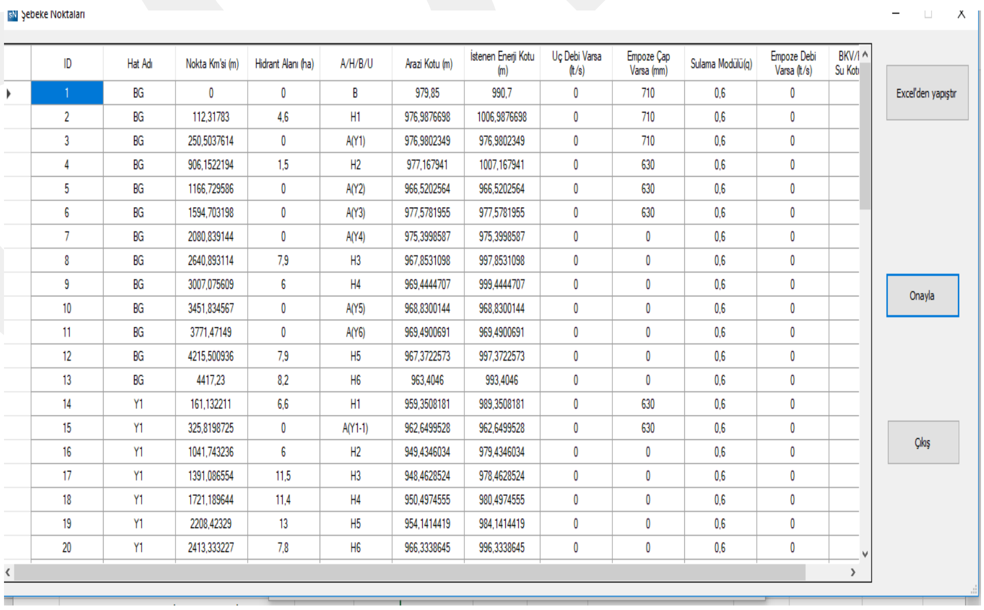


Figure 5-4 Network points window of Sufen Network Software

After this operation, the next option is to prepare pipes price table for main pipe and secondary pipe (sub-pipe 1) containing pipe type, diameter, inner and outer diameter, cost (in TL) and maximum and minimum allowable water velocities (m/s). As shown in Tables 5-7 and 5-8.

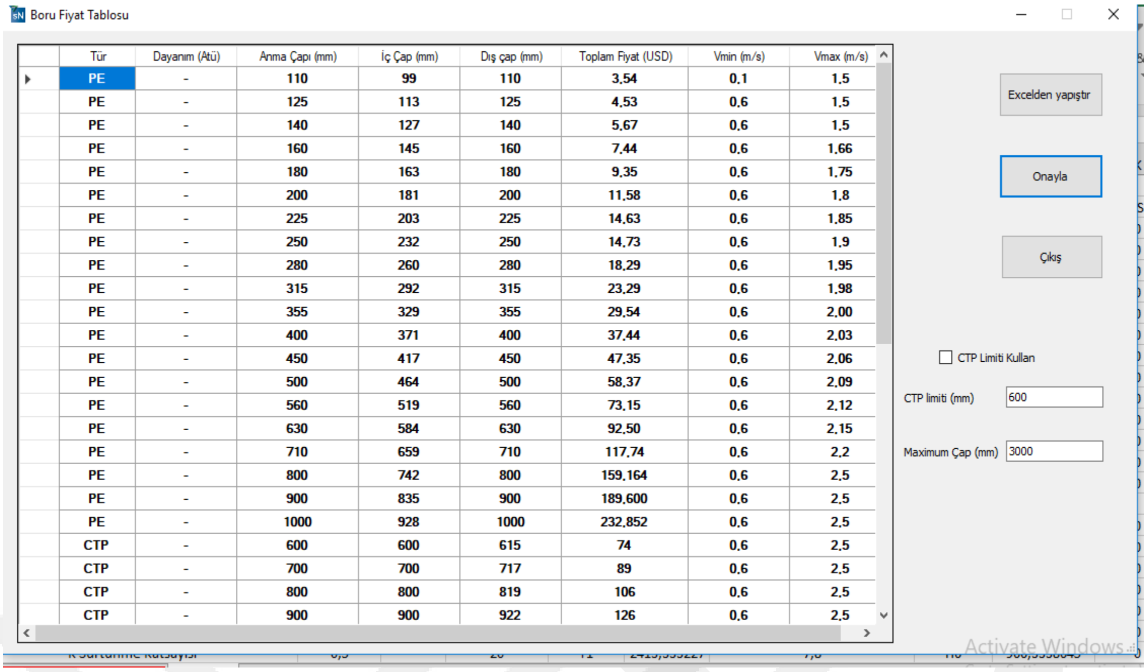
Table 5-7 Default values of the program for the main pipe

type	Pipe diameter (mm)	Inner diameter (mm)	Outer diameter (mm)	Total cost (TL)	V_{min} (m/s)	V_{max} (m/s)
PE	110	99	110	3,54	0,1	1,5
PE	125	113	125	4,53	0,6	1,5
PE	140	127	140	5,67	0,6	1,5
PE	160	145	160	7,44	0,6	1,66
PE	180	163	180	9,35	0,6	1,75
PE	200	181	200	11,58	0,6	1,8
PE	225	203	225	14,63	0,6	1,85
PE	250	232	250	14,73	0,6	1,9
PE	280	260	280	18,29	0,6	1,95
PE	315	292	315	23,29	0,6	1,98
PE	355	329	355	29,54	0,6	2
PE	400	371	400	37,44	0,6	2,03
PE	450	417	450	47,35	0,6	2,06
PE	500	464	500	58,37	0,6	2,09

Table 5-8 Default values of the program for the sub pipe 1

Type	Pipe diameter (mm)	Inner diameter (mm)	Outer diameter (mm)	Total cost (TL)	V_{min} (m/s)	V_{max} (m/s)
PE	560	519	560	73,15	0,6	2,12
PE	630	584	630	92,5	0,6	2,15
PE	710	659	710	117,74	0,6	2,2
PE	800	742	800	159,164	0,6	2,5
PE	900	835	900	189,6	0,6	2,5
PE	1000	928	1000	232,852	0,6	2,5
CTP	600	600	615	74	0,6	2,5
CTP	700	700	717	89	0,6	2,5
CTP	800	800	819	106	0,6	2,5
CTP	900	900	922	126	0,6	2,5
CTP	1000	1000	1024	148	0,6	2,5
CTP	1100	1100	1126	173	0,6	2,5

In Tables 5-7 and 5-8 pipe type PE is polyethylene, and CTP is Glass fiber polystyrene type pipes. Based on these data, the Sufen network software will calculate the pipes cost and the velocity according to the pipes diameters. Tables 5-7 and 5-8 were transferred to copy to Pipe Cost Table menu of the Sufen Network Software (Fig.5-5).



Tür	Dayanım (Atü)	Anma Çapı (mm)	İç Çap (mm)	Dış çap (mm)	Toplam Fiyat (USD)	Vmin (m/s)	Vmax (m/s)
PE	-	110	99	110	3,54	0,1	1,5
PE	-	125	113	125	4,53	0,6	1,5
PE	-	140	127	140	5,67	0,6	1,5
PE	-	160	145	160	7,44	0,6	1,66
PE	-	180	163	180	9,35	0,6	1,75
PE	-	200	181	200	11,58	0,6	1,8
PE	-	225	203	225	14,63	0,6	1,85
PE	-	250	232	250	14,73	0,6	1,9
PE	-	280	260	280	18,29	0,6	1,95
PE	-	315	292	315	23,29	0,6	1,98
PE	-	355	329	355	29,54	0,6	2,00
PE	-	400	371	400	37,44	0,6	2,03
PE	-	450	417	450	47,35	0,6	2,06
PE	-	500	464	500	58,37	0,6	2,09
PE	-	560	519	560	73,15	0,6	2,12
PE	-	630	584	630	92,50	0,6	2,15
PE	-	710	659	710	117,74	0,6	2,2
PE	-	800	742	800	159,164	0,6	2,5
PE	-	900	835	900	189,600	0,6	2,5
PE	-	1000	928	1000	232,852	0,6	2,5
CTP	-	600	600	615	74	0,6	2,5
CTP	-	700	700	717	89	0,6	2,5
CTP	-	800	800	819	106	0,6	2,5
CTP	-	900	900	922	126	0,6	2,5

Figure 5-5 Pipes price window of the Sufen Network

CTP limit was defined as 600 mm and maximum diameter as 3000 mm. At this stage the input data to the Sufen Network Software is completed and the next step is to choose Solve the Network from the main menu of the program (Fig. 4-2).

The fourth step is to transfer the Sufen network solution of optimization results to Excel sheets as seen in Tables 5-9 to 5-15. Table 5-9 shows the length, start and end points of pipe, ground level and land elevation at the end points for the main pipe.

Table 5-9 Length, start and end points, ground level and land elevation at the end point for the main pipe

Start node No	End node No	Pipe name	Structure name	Pipe length (m)	Starting point KM	Land Elevation at the starting point (m)	End point KM	Land Elevation at the end point (m)
1	**2**	MP	H1	112,30	0+000,00	979,85	0+112,32	976,99
2	**3**	MP	S(pipe1)	138,20	0+112,32	976,99	0+250,50	976,98
3	**4**	MP	H2	655,60	0+250,50	976,98	0+906,15	977,17
4	**5**	MP	S(pipe2)	260,60	0+906,15	977,17	1+166,73	966,52
5	**6**	MP	S(pipe3)	428,00	1+166,73	966,52	1+594,70	977,58
6	**7**	MP	S(pipe4)	486,10	1+594,70	977,58	2+080,84	975,40
7	**8**	MP	H3	560,10	2+080,84	975,40	2+640,89	967,85
8	**9**	MP	H4	366,20	2+640,89	967,85	3+007,08	969,44
9	**10**	MP	S(pipe5)	444,80	3+007,08	969,44	3+451,83	968,83
10	**11**	MP	S(pipe6)	319,60	3+451,83	968,83	3+771,47	969,49
11	**12**	MP	H5	444,00	3+771,47	969,49	4+215,50	967,37
12	**13**	MP	H6	201,70	4+215,50	967,37	4+417,23	963,40

Table 5-10 shows the static and dynamic pressure head values, piezometric code and required energy head in meter for the main pipe, Table 5-11 shows the total area, flow rate (lt/s), diameter (mm) ,velocity (m/s) and hydraulic grade line for the main pipe and Table 5-12 shows the hydrant data including hydrant type and pipe cost for the main pipe.

Table 5-10 Pressure values for the main pipe

Static Pressure head (m)	Dynamic pressure head (m)	Piezometric Code (m)	Required Energy head (m)
16,01	13,64	990,62	990,62
16,02	13,23	990,21	0,00
16,02	12,13	989,29	989,29
26,48	22,41	988,94	0,00
26,48	10,93	988,51	0,00
17,60	12,64	988,04	0,00
25,15	19,66	987,52	987,52
25,15	17,57	987,01	987,01
24,17	17,65	986,48	0,00
24,17	16,51	986,00	0,00
25,63	17,58	984,96	984,96
29,60	20,00	983,40	983,40

Table 5-11 Total area, flow rate, diameter, velocity and hydraulic slope data of the main pipe

Total area (ha)	Flow (lt/s)	Pipe type	Diameter (mm)	Length (m)	Velocity (m/s)	Hydraulic slope (m/m)
500,3	495	PE	710	112,30	1,45	0,0030728
495,7	490,9	PE	710	138,20	1,44	0,0030231
214,5	240,1	PE	630	655,60	0,90	0,0013932
213	238,6	PE	630	260,60	0,89	0,0013762

Table 5-11 (Continued)

173,8	201,8	PE	630	428,00	0,75	0,0009910
116,6	146,4	PE	560	486,10	0,69	0,0009747
77,3	106,2	PE	500	560,10	0,63	0,0009292
69,4	97,9	PE	450	366,20	0,72	0,0013790
63,4	91,3	PE	450	444,80	0,67	0,0012027
31,4	54,5	PE	355	319,60	0,64	0,0014970
16,1	50	PE	315	444,00	0,75	0,0023484
8,2	30	PE	250	71,10	0,71	0,0028471

Table 5-12 Hydrant data for the main pipe

Hydrant area (ha)	Hydrant flow(lt/s)	Hydrant type	Pipe cost (USD)
4,6	20	D	13222,20
0	0	-	16271,67
1,5	10	D	60643,00
0	0	-	24105,50
0	0	-	39590,00
0	0	-	35558,22
7,9	20	H	32693,04
6	20	H	17339,57
0	0	-	21061,28
0	0	-	9440,98
7,9	20	H	10340,76
8,2	30	H	1047,23

Similar analysis was also done for secondary pipe (sub pipe 1) of the Atabey pipe irrigation project. Table 5-13 shows the length, start and end points of pipe, ground level and land elevation at the end points for the sub pipe-1. Table 5-14 shows the static and dynamic pressure head values, piezometric code and required energy head in meter for the sub pipe 1, Table 5-15 shows the total area, flow rate (lt/s), diameter (mm) ,velocity (m/s) and hydraulic grade line for the sub pipe 1 and Table 5-16 shows the hydrant data including hydrant type and pipe cost for the sub pipe 1.

Table 5-13 Length, start and end points, ground level and land elevation at the end point for the sub pipe 1

Start node No	End node No	Pipe name	Structure name	Pipe length (m)	Starting point KM	Land Elevation at the starting point (m)	End point KM	Land Elevation at the end point (m)
13	**14**	SP1	H1	161,10	0+000,00	976,98	0+161,13	959,35
14	**15**	SP1	S(pipe1-1)	164,70	0+161,13	959,35	0+325,82	962,65
15	**16**	SP1	H2	715,90	0+325,82	962,65	1+041,74	949,43
16	**17**	SP1	H3	349,30	1+041,74	949,43	1+391,09	948,46
17	**18**	SP1	H4	330,10	1+391,09	948,46	1+721,19	950,50
18	**19**	SP1	H5	487,20	1+721,19	950,50	2+208,42	954,14
19	**20**	SP1	H6	204,90	2+208,42	954,14	2+413,33	966,33
20	**21**	SP1	S(pipe1-2)	137,40	2+413,33	966,33	2+550,74	967,81
21	**22**	SP1	H7	136,20	2+550,74	967,81	2+686,97	962,20
22	**23**	SP1	H8	167,50	2+686,97	962,20	2+854,43	954,25
23	**24**	SP1	H9	170,20	2+854,43	954,25	3+024,66	956,57
24	**25**	SP1	H10	145,50	3+024,66	956,57	3+170,14	953,93

Table 5-14 Pressure values of the sub pipe 1

Static Pressure head (m)	Dynamic pressure head (m)	Piezometric Code (m)	Required Energy head (m)
33,65	30,51	989,86	979,35
33,65	26,86	989,51	0,00
43,57	39,40	988,83	969,43
44,54	40,06	988,53	968,46
44,54	37,79	988,28	970,50
42,50	33,61	987,75	974,14
38,86	21,24	987,58	986,33
26,67	19,59	987,40	0,00
30,80	22,55	984,75	982,20
38,75	27,24	981,49	974,25
38,75	23,04	979,61	976,57
39,07	23,09	977,02	973,93

Table 5-15 Total area, flow rate, diameter, velocity and hydraulic slope data of the sub pipe 1

Total area (ha)	Flow (lt/s)	Pipe type	Diameter (mm)	Length (m)	Velocity (m/s)	Hydraulic slope (m/m)
281,2	301	PE	630	161,10	1,12	0,0021699
274,6	295	PE	630	164,70	1,10	0,0020859
115,2	144,6	PE	560	715,90	0,68	0,0009513
109,2	138,5	PE	560	349,30	0,65	0,0008743
97,7	127	PE	560	330,10	0,60	0,0007377
86,3	115,4	PE	500	487,20	0,68	0,0010935
73,3	101,7	PE	500	204,90	0,60	0,0008536
65,5	93,4	PE	450	137,40	0,68	0,0012575
32	80	PE	250	136,20	1,89	0,0194676

Table 5-15 (Continued)

24	80	PE	250	167,50	1,89	0,0194671
17,1	60	PE	250	170,20	1,42	0,0110770
8,5	30	PE	180	145,50	1,44	0,0177841

Table 5-16 Hydrant data for the sub pipe 1

Hydrant area (ha)	Hydrant flow (lt/s)	Hydrant type	Pipe cost USD
6,6	20	H	14901,75
0	0	-	15234,75
6	20	H	52368,09
11,5	30	H	25551,30
11,4	30	H	24146,82
13	40	H	28437,86
7,8	20	H	11960,01
0	0	-	6505,89
8	20	H	2006,23
6,9	20	H	2467,28
8,6	30	H	2507,05
8,5	30	H	1360,43

The last step of the optimization is to prepare the final drawing application project of the study area. Sufen network engineers and programmers developed a software that can draw the final drawings of the project using AutoCAD software as shown in Figures 5-6 and 5-7.

As indicated in Chapter 4 that Sufen Network program uses Simplex algorithm and heuristic based dynamic programming techniques for optimization. Simplex algorithm option was used for the optimization of the Atabey pipe irrigation network in this study. The results shown in Tables 5-9, 5-10 , 5-11 and 5-12 for the main pipe and Tables 5-13, 5-14, 5-15 and 5-16 for the Sub-pipe 1, found to be similar with the results obtained from the DSI Network Programming developed by French BRL

GELSAR in 1986 (Marım et al., [10] and the results of DSI Software for the main pipe are given in the Appendix C. Therefore, the pipe irrigation network application project of the Atabey plain (Fig. 5-7) developed based on the optimization results obtained from this study can be applied to the field.

Figure 5-6 Software used to draw the final drawings

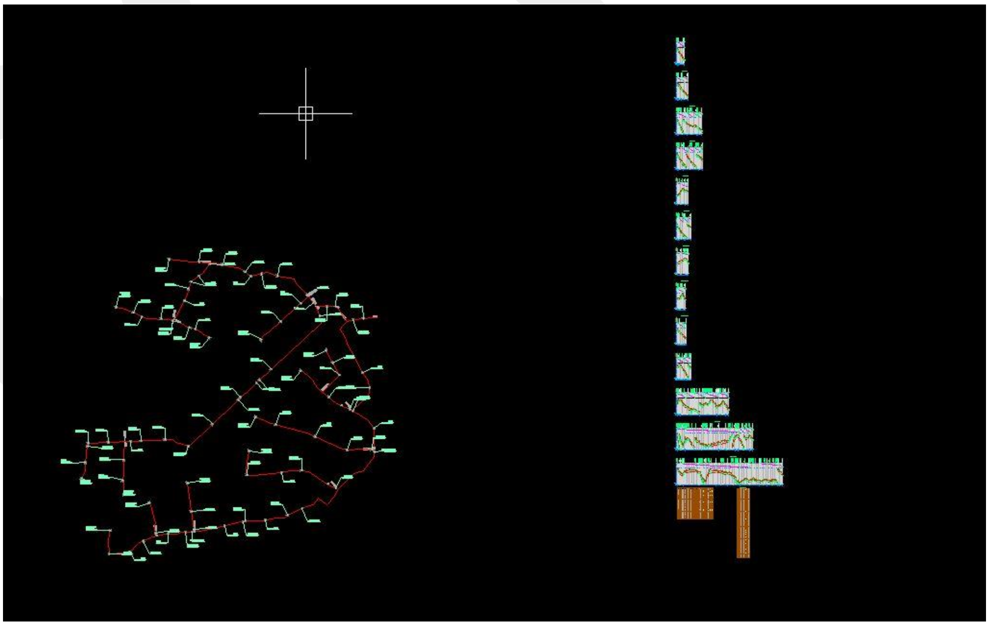


Figure 5-7 Final application drawings of Atabey pipe irrigation project

CHAPTER 6

DISCUSSION OF RESULTS

Sufen network program also calculates the coordinates for the pipes so that the designers could draw the pipe profile for each pipe and sub pipe in the project by using AutoCAD. This work was also done for the Atabey pipe irrigation network for the main pipe, sub-pipe 1 and the results are presented in Table 6-1 and 6-2 respectively, and using the data in these table longitudinal profiles of main pipe and sub pipe 1 is plotted using AutoCAD program.

Table 6-1 Coordinates for the main pipe

(r, θ) Values		KM	Y-Coordinate	X-Coordinate
Length	Angle	0+000,00	563.825,797	4.195.290,985
31,540	300,307	0+031,54	563.794,257	4.195.291,137
76,680	296,448	0+108,22	563.717,697	4.195.286,861
80,210	294,706	0+188,43	563.637,764	4.195.280,198
62,060	279,637	0+250,49	563.578,851	4.195.260,685
72,140	251,472	0+322,63	563.526,675	4.195.210,867
24,540	225,363	0+347,17	563.517,155	4.195.188,249
58,530	157,581	0+405,70	563.553,331	4.195.142,238
117,870	177,182	0+523,57	563.594,680	4.195.031,859
58,060	163,364	0+581,63	563.626,278	4.194.983,150
176,010	171,177	0+757,64	563.703,273	4.194.824,874

Table 6-2 Coordinates for the sub pipe 1

(r, θ) Values		KM	Y-Coordinate	X-Coordinate
Length	Angle	0+000,00	563.578,838	4.195.260,683
153,340	361,121	0+153,34	563.490,906	4.195.386,306
155,450	301,807	0+308,79	563.335,519	4.195.390,717
17,030	264,459	0+325,82	563.321,074	4.195.381,696
39,920	173,492	0+365,74	563.337,221	4.195.345,187
37,460	184,696	0+403,20	563.346,140	4.195.308,804
64,810	190,605	0+468,01	563.355,669	4.195.244,698
743,160	252,111	1+211,17	562.813,044	4.194.736,914
784,490	251,244	1+995,66	562.247,597	4.194.193,137
114,310	319,485	2+109,97	562.138,599	4.194.227,581

After determination of the coordinates, profiles of the main pipe and the sub pipe can be drawn as shown in Figures 6-1 and 6-2. These tables and profile plots are very useful for the design engineer working in the office for detail drawing of design and layout of the project and the construction engineers working in the field for implementing the project.

In the profile shown in Figure 6-1, it is noticed that there is water discharge in the main pipe of Atabey network project, the blue line is the ground level, the two red line is the maximum and minimum grading boundary, and the yellow line is the safety line. The vertical purple line is the separation and the green one is the hydrant. In sub pipe 1 profile (Fig 6-2) there is air discharge (air valves) installed in this pipe

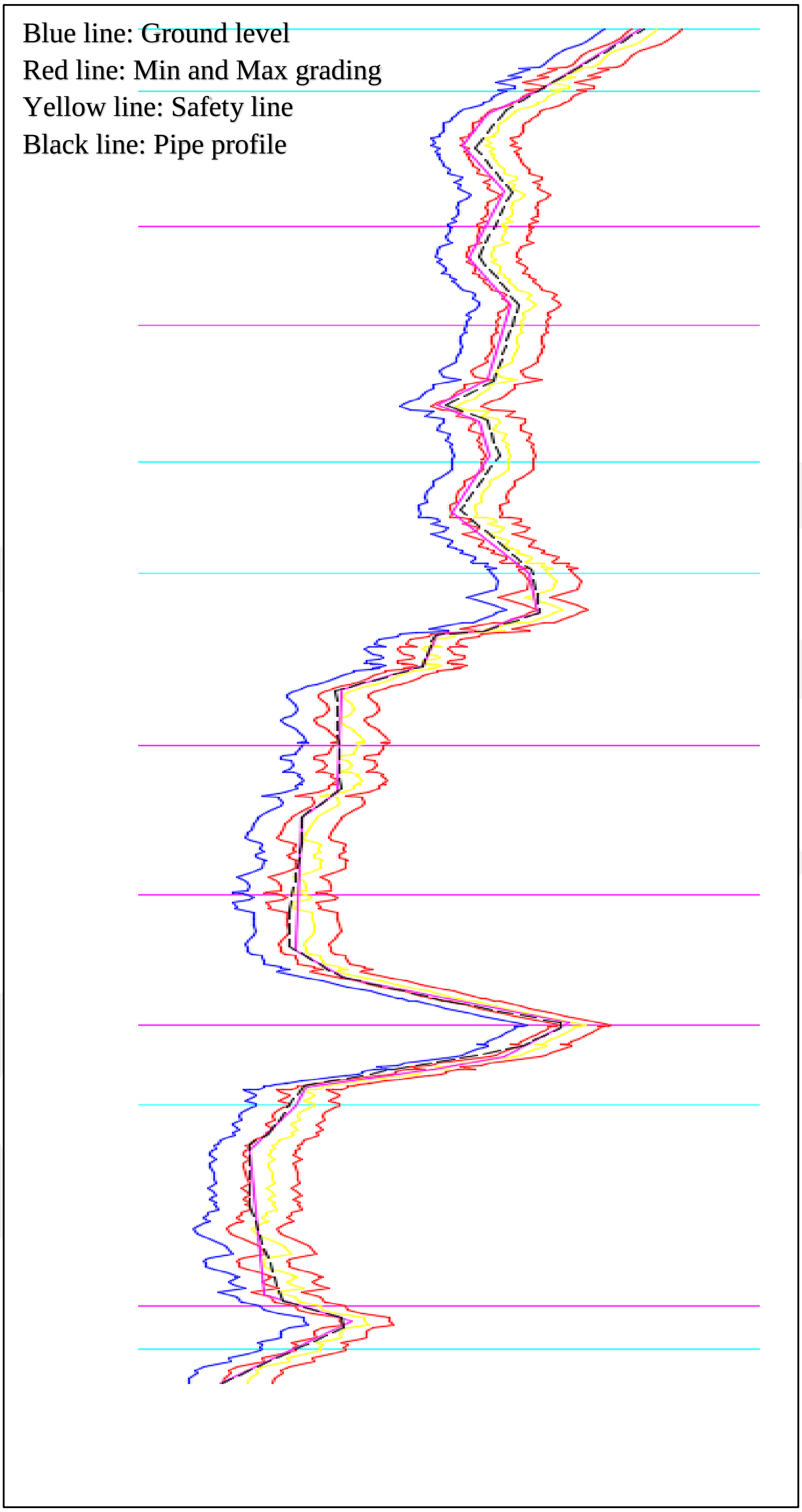


Figure 6-1 Profile of the Main pipe

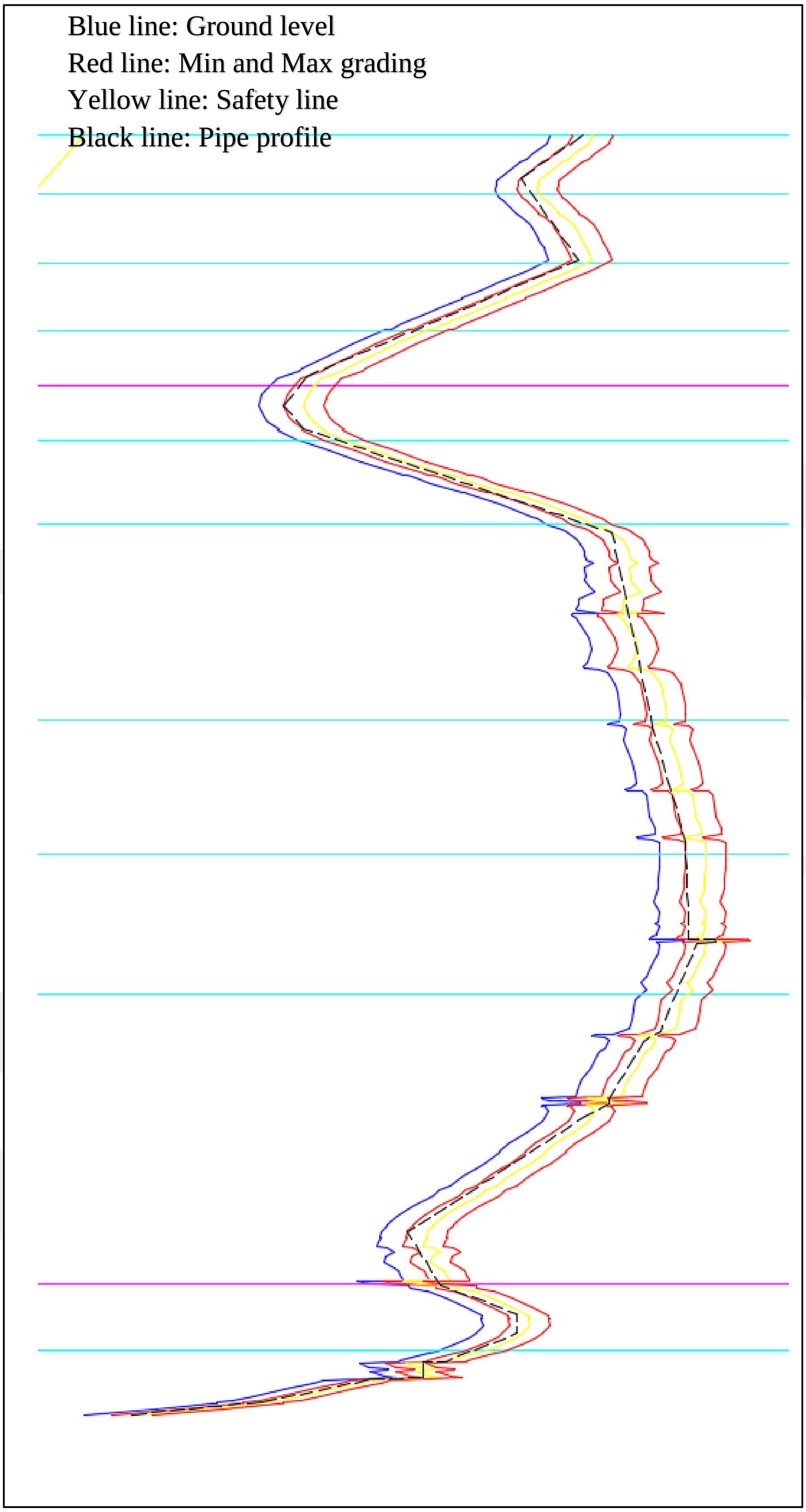


Figure 6-2 Profile of the Sub pipe 1

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

Pipe irrigation networks are the most essential systems in crop production in the agricultural fields of the countries. Agriculture is the major water consuming sector in most countries of the world for securing crop production in adequate quantity. It is determined that agriculture uses 70% of fresh water potential of the most countries to meet the increased demand of food due to increase in population. Since water is limited resource it is viable not only for agriculture but also crucial for municipal and industrial sector, thus it must be managed and used in sustainable manner. In order to reduce the percentage of water consumption in agriculture, pipe irrigation networks have been replaced in place of classical irrigation networks in most countries of the world. Since 2010, classical irrigation networks have been replaced by pipe irrigation networks in Turkey. During this replacement period, optimization techniques have been used to determine optimum hydraulic conditions before the design of application projects. In this study, optimization of the Atabey pipe irrigation network located in Isparta province of Turkey, was studied by using Sufen Network software which employs simplex optimization algorithm. An optimum hydraulic condition in terms of cost and desired operation pressure was investigated.

It was determined from the analysis that the operating pressure head in the main pipe varied between 25 meter to 35 meter for the high pressure and between 10 meter to 25 meter for mid and low pressure and flow velocity in the main pipe varied between 0.6 m/s which is greater than minimum allowable velocity of v_{min}=0.5 m/s and 1.45 m/s which is also smaller than maximum allowable velocity of v_{max}=3.0m/s. These values conforms the hydraulic criteria defined by DSI. Similar results were also obtained for the other branch sub pipe 1. The operating pressure head in this pipe varied between 25 meter to 35 meter for the high pressure and for mid and low pressure between 10 meter to 25 meter and velocity values varied between 0.6 m/s which is greater than allowable minimum velocity (v_{min}=0.5m/s) and 1.9 m/s which is less than maximum allowable velocity (v_{max}=3 m/s). Based on these hydraulic data and hydraulic grade line data of the network of the Atabey pipe irrigation system, coordinates and final layout of the system was determined by using the AutoCAD application file of the SUFEN Network.

Optimization results of the Atabey pipe irrigation network obtained from the SUFEN Network software were compared with DSI results obtained from Network Programming developed by French BRL GELSAR in order to check the accuracy and it was determined that SUFEN Network software results for the Atabey pipe irrigation network is the same as the DSI results determined by French BRL GELSAR software. Thus it is assumed that the results of the optimization by using SUFEN Network for the Atabey pipe irrigation are accurate.

In order to compensate error that might possibly occur during the construction of the network discharge values were increased by 10%, so that possible leakage has taken into consideration. The peak pressure of 29.6 meter is assured at the farthest point in the main pipe.

7.2 Recommendations

Simplex method was used for the optimization of the Atabey pipe irrigation network in order to compare the results of optimization with those results obtained from DSI. Other optimization methods such as Nonlinear, Heuristic optimization techniques, Fast Multiple Method and The Metropolis Algorithm can also be used for this irrigation network. Due to the lack of data, optimization of the excavation depth of pipes is not included in this study and when data is available; this option can be included into the analysis.

REFERENCES

[1] Shilpa, Bhale and R.M.Damgir, (2016) “Optimization of irrigation network” International Journal of Advanced Computational Engineering and Networking, ISSN: 2320-2106, Volume-4, Issue-12, Dec.-2016

[2] Wang, Keh-Han, Mustafa DAL, (2017) “Optimization and modelling of pressurized irrigation network” Ministry of Forestry and Water Affairs General Directorate of Water Management, 06510, Yenimahalle-Ankara-Turkey

[3] Dragon, Savic and Walter “Genetic Algorithms for Least-Cost Design of Water Distribution Networks”Journal of water resource planning and management March /April 1997

[4] Darama, Y.,(2009), “Introduction to Irrigation and Drainage Engineering”, Lecture notes, METU, Civil Engineering Department,, 3rd Edition, Ankara, Turkey.

[5] Dandy. O.C. ,Simpson. A.R. and Murphy, LJ. (1993). "A Review of Pipe Network Optimization Techniques." Proc •• WoJucomp '9J. Melbourne. Australia, 30 March - 1 April

[6] SUFEN Network (2016), Users Manual of the Pipe Irrigation Network Optimization Software, V1.1., Sufen Project and Engineering Consulting Ltd. Ankara, Turkey

[7] Shiklomanov, I. (1998). “World Water Resources: A New Appraisal and Assessment for the 21st Century”. (UNESCO, Ed.), Paris

[8] Onda, K., LoBuglio, J. & Bartram, J. (2012). Global Access to Safe Water: Accountig for Water Quality and the Resulting Impact on MDG Progress. International Journal of Environmental Research and Public Health 9 (3), 880-894.

[9] Çakmak B., Yıldırım M., Aküzüm T, "Türkiye'de Tarımsal Sulama Yönetimi, Sorunlar ve Çözüm Önerileri", TMMOB 2. Su Politikaları Kongresi, 2008

[10] Marım, G. Darama, Y. and Z. Bozkus, (2018), "Optimization of Pipe Irrigation Network", Teknik Dergi, TMMOB, Chambers of Civil Engineering, Vol.29, No:5, pp. 1831-1850,doi:10.18400/tekderg.306880

[11] Feni, M., Khadra, R. & LaMaddalena, N. (2014). Hydraulic and agronomic constraints of on demand pressurized irrigation networks optimization. Geophysical Research Abstracts , Vol.16-6741. EGU General Assembly 2014, Vienna, Austria

[12] Clement R (1966) "Calcul des débits dans les rèseaur d'irrigation fonctionnant àla demande La Houille Blanche (5), 553-576.

[13] LaMaddalena, N. & Sagardoy, J. A. (2000). Performance analysis of on-demand pressurized irrigation systems. FAO Irrigation and Drainage Paper (59).

[14] Labye, Y., Galand, A., Olson, M. & Tsiourtis, N. (1988). Design and Optimization of Irrigation Distribution Networks. FAO Irrigation and Drainage Papers, Vol. 44, Rome.

[15] DSI, (2008) "Isparta Atabey plain irrigation project planning revised report", State Hydraulic Works, 18. Regional Directorate, Isparta Turkey , Aralık 2008 (In Turkish)

[16] DSI (2008) "DSI In Brief-2008", General Directorate of State Hydraulic Works Publication, Ankara, Turkey

[17] DSI (2014) "DSI In Brief-20014", General Directorate of State Hydraulic Works Publication, Ankara, Turkey.

[18] Sargin, S. and Okudum, R., 2014: Current analysis of orcharding in the Isparta Province (Turkey). In: Szymańska, D. and Biegańska, J. editors, Bulletin of Geography. Socio-economic Series, No. 23, Toruń: Nicolaus Copernicus University Press, pp. 119–134.

[19] Kizilkaya, T., (1988) "Irrigation and Drainage State Hayraulic Works (DSI) Publication, Ankara, Turkey (in Turkish)

[20] Yanmaz, A. M., (2001) Applied Water Resources Engineering, Second Edition, METU Press, Ankara, Turkey.

[21] Http/www.Sufen.com.TR

APPENDIX A

ATABEY STATION MONTHLY TOTAL PRECIPITATION(mm)													
Years	MONTHS												Annual Average
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
1964	0.1	86.4	87.4	2.9	45.1	87.0	9.7	0.0	7.4	0.2	51.3	116.3	493.8
1965	32.5	98.2	80.1	61.5	78.0	30.3	.	0.0	.	19.7	68.8	104.2	573.3
1966	161.0	26.8	47.7	79.6	30.3	13.5	25.3	3.1	17.4	6.9	26.9	207.8	646.3
1967	54.8	28.4	17.4	111.3	35.0	5.8	0.0	0.0	76.1	56.4	41.0	80.6	506.8
1968	106.7	40.4	84.3	18.3	43.2	18.3	.	16.2	13.7	32.1	96.6	131.2	601.0
1969	181.6	87.8	73.0	64.5	96.1	6.0	27.2	4.5	3.5	24.0	47.0	160.1	775.3
1970	67.0	55.6	30.6	34.8	24.2	26.7	11.0	.	3.7	22.7	16.2	52.8	345.3
1971	35.7	51.2	77.9	48.0	78.1	20.7	23.5	38.1	45.6	28.7	53.9	43.8	545.2
1972	17.7	45.7	21.0	52.7	64.7	44.4	14.3	3.1	6.3	62.5	25.6	6.7	364.7
1973	76.4	46.5	49.2	32.1	41.0	12.2	18.2	0.0	0.0	41.5	16.6	34.5	368.2
1974	64.7	103.7	31.8	47.7	55.3	8.9	9.4	18.2	9.3	24.3	24.3	58.8	456.4
1975	83.8	53.8	17.3	74.2	180.4	45.1	19.1	18.5	.	44.9	68.6	63.9	669.6
1976	92.0	39.3	28.9	93.8	82.7	13.0	7.8	0.5	1.0	69.6	30.2	43.3	502.1
1977	26.5	51.5	38.6	85.0	16.4	33.0	15.5	.	27.4	34.6	12.0	67.1	407.6
1978	87.1	134.0	88.0	52.1	.	1.0	2.0	.	46.7	124.6	3.9	69.9	609.3
1979	136.0	37.2	40.5	27.7	104.7	39.5	1.5	7.0	.	67.3	107.3	68.7	637.4
1980	71.7	51.3	53.4	54.4	35.8	25.9	.	1.3	3.8	31.8	40.3	44.0	413.7
1981	129.3	98.8	30.7	24.4	62.3	8.8	8.0	.	2.0	8.9	25.8	142.7	541.7
1982	63.5	51.8	24.9	91.6	29.4	33.6	9.2	14.2	6.0	56.2	28.7	25.0	434.1
1983	101.1	29.4	33.9	56.9	12.2	31.3	3.9	15.6	14.4	18.2	118.6	63.2	498.7
1984	31.2	48.8	96.1	116.3	13.0	3.0	5.2	14.7	4.5	.	38.4	22.2	393.4
1985	105.3	83.9	50.1	42.0	43.8	15.6	0.0	18.5	3.8	62.7	77.8	58.0	561.5
1986	68.9	84.0	7.0	23.0	33.9	8.7	0.0	2.0	46.9	6.6	22.2	66.4	369.6
1987	68.7	74.2	77.0	72.6	38.8	69.2	11.5	42.5	22.7	12.9	65.8	36.2	592.1
1988	12.6	99.7	101.7	78.2	25.5	9.9	17.3	5.9	4.3	36.8	135.8	56.9	584.6
1989	8.9	18.3	58.8	13.5	50.2	2.5	12.8	1.0	2.9	66.9	80.8	62.2	378.8
1990	6.4	17.4	15.7	54.7	39.6	43.7	5.1	.	3.9	10.3	13.5	98.3	308.6
1991	34.7	35.5	16.4	79.5	100.5	6.2	10.7	5.0	23.9	46.2	10.0	136.3	504.9
1992	.	9.5	69.5	47.5	27.5	53.1	22.9	13.0	.	8.7	46.3	54.3	352.3
1993	49.6	16.7	38.1	40.0	74.5	1.6	.	0.0	.	4.0	63.9	38.0	326.4
1994	68.3	46.3	44.8	22.1	26.0	23.6	16.4	4.0	.	71.0	38.2	38.8	399.5
1995	49.1	20.2	137.1	14.5	24.6	26.7	61.8	.	2.5	23.5	54.1	22.7	436.8
1996	29.7	47.9	48.6	63.1	21.1	9.2	34.6	0.0	17.6	12.4	.	134.3	418.5

1997	29.6	19.4	18.3	82.2	35.0	39.6	0.0	62.3	24.4	69.0	50.4	94.9	525.1
1998	59.7	37.7	88.3	37.4	78.1	32.3	.	.	3.3	23.9	54.7	92.3	507.7
1999	52.7	65.6	65.5	36.6	10.7	14.8	11.9	87.7	19.9	9.1	5.6	16.1	396.2
2000	56.8	35.5	32.4	66.4	61.1	24.4	.	.	27.3	19.3	35.0	31.5	389.7
2001	46.8	24.4	18.7	43.4	58.9	19.9	13.5	2.1	.	.	110.5	148.3	486.5
2002	28.9	9.2	34.3	77.9	38.7	1.7	16.7	14.2	96.0	6.4	35.9	106.3	466.2
2003	34.4	79.7	26.7	110.1	48.8	36.0	.	.	5.3	57.9	7.0	129.6	535.5
2004	143.5	42.8	10.1	76.6	15.2	14.6	.	3.2	0.0	5.6	50.2	14.8	376.6
2005	53.4	42.4	76.1	43.4	12.3	15.9	24.8	15.2	9.4	23.3	36.5	22.5	375.2
Total	2628.4	2176.9	2087.9	2354.5	1992.7	977.2	470.8	431.6	602.9	1351.6	1936.2	3065.5	20076.2
Average	62.6	51.8	49.7	56.1	47.4	23.3	11.2	10.3	14.4	32.2	46.1	73.0	478.0

EĞİRDİR METEOROLOGICAL STATION PRECIPITATION VALUES (mm)

Years	MONTHS												Average
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
1930	37.8	86.0	54.1	19.5	81.5	35.5	4.3	1.7	41.2	74.4	21.2	219.4	676.6
1931	230.7	152.1	149.0	101.6	102.9	44.9	0.0	5.7	21.3	17.7	14.0	100.9	940.8
1958	102.6	15.4	80.9	33.5	19.5	34.6	1.9	.	85.4	49.8	23.5	87.2	534.3
1959	169.2	6.6	16.6	43.6	31.6	32.5	23.1	21.4	2.1	17.7	75.8	178.5	618.7
1960	76.2	50.8	99.2	48.2	46.5	70.3	7.3	.	18.9	7.7	31.7	120.8	577.6
1962	86.9	172.1	113.6	44.9	21.9	5.6	0.0	8.3	48.2	58.5	14.0	212.2	786.2
1963	75.0	144.4	71.7	96.2	44.3	22.6	6.4	.	0.4	20.8	17.4	13.1	512.3
1964	0.9	119.3	74.6	4.8	53.3	51.4	0.7	.	41.7	.	51.7	77.8	476.2
1965	102.3	164.1	65.9	81.8	50.3	16.6	.	2.5	.	14.2	70.0	237.6	805.3
1966	259.4	34.7	82.4	54.1	30.5	15.8	8.8	0.0	31.0	0.3	21.7	285.6	824.3
1967	64.5	41.5	41.2	93.4	25.6	3.3	5.4	.	12.0	76.9	51.3	100.3	515.4
1968	225.4	52.6	84.8	12.9	20.9	30.2	0.0	25.3	43.7	30.8	106.6	172.4	805.6
1969	209.5	95.1	63.8	83.9	42.7	11.3	1.9	1.6	8.2	24.9	46.7	260.3	849.9
1970	103.4	92.4	46.0	53.6	42.4	8.5	3.5	.	20.8	27.0	35.0	45.4	478.0
1971	38.0	92.9	106.9	68.3	44.0	14.6	21.2	17.3	10.9	30.2	96.3	152.0	692.6
1972	15.1	102.8	23.2	38.0	66.7	26.9	20.8	2.4	3.6	92.5	21.2	3.9	417.1
1973	108.8	140.4	55.2	23.2	32.0	10.0	5.3	.	0.0	57.6	8.1	29.6	470.2
1974	37.1	235.6	59.1	25.1	49.7	2.6	1.9	30.0	9.0	45.6	20.6	107.7	624.0
1975	287.4	86.8	46.2	124.5	163.2	28.6	4.8	19.9	3.3	31.5	113.3	87.5	997.0
1976	133.6	44.5	38.1	98.5	87.7	35.4	10.2	9.1	0.3	101.3	33.8	122.6	715.1
1977	20.3	54.7	67.6	149.9	1.4	61.3	6.3	.	22.2	67.3	16.5	159.8	627.3
1978	260.2	250.5	207.8	84.7	14.6	10.1	0.7	.	54.9	167.1	151.2	202.9	1404.7
1979	432.2	80.8	37.7	67.0	58.3	35.0	4.7	0.5	3.5	109.8	176.2	165.8	1171.5
1980	200.3	57.2	80.1	86.0	44.2	21.6	.	1.2	15.2	84.0	72.5	201.6	863.9
1981	560.7	214.0	60.9	12.9	42.8	6.6	0.9	.	0.0	19.9	139.4	256.8	1314.9
1982	48.3	84.6	82.1	188.9	26.3	30.8	32.9	11.2	3.8	57.0	64.3	60.5	690.7
1983	181.5	104.2	38.4	162.8	18.6	47.7	14.9	15.8	26.4	21.2	103.2	136.7	871.4
1984	138.5	222.2	122.2	145.0	10.8	2.7	9.4	4.3	10.3	.	86.4	28.7	780.5
1985	248.5	135.6	52.4	31.2	51.1	22.5	0.0	2.5	4.2	45.3	103.1	59.0	755.4
1986	176.8	153.0	10.8	34.3	25.2	9.5	.	6.1	26.4	12.6	12.5	172.0	639.2
1987	145.7	70.0	109.9	53.6	52.5	94.2	23.7	4.0	0.8	19.5	136.5	71.1	781.5
1988	32.5	120.0	175.3	117.0	64.5	10.0	5.0	3.3	2.6	35.9	169.7	178.5	914.3
1989	9.2	40.4	87.2	73.7	67.8	7.0	0.6	.	0.7	122.5	164.7	73.7	647.5
1990	15.7	79.0	65.0	52.4	42.3	42.3	2.0	3.8	10.3	21.2	16.5	188.9	539.4
1991	42.4	59.0	10.9	133.9	107.4	2.8	38.2	2.5	6.1	90.0	19.2	325.6	838.0
1992	0.8	27.8	154.9	44.8	25.6	26.5	22.1	10.4	1.9	10.4	140.1	99.9	565.2
1993	83.1	205.6	83.9	24.2	78.8	0.7	.	.	0.4	9.2	68.7	117.2	671.8
1994	120.7	56.6	65.6	30.7	59.4	9.5	21.5	21.1	13.4	95.1	81.7	80.2	655.5
1995	135.4	57.8	194.0	121.6	49.5	8.4	31.2	4.6	17.4	51.5	130.1	50.3	851.8
1996	87.9	155.6	87.5	92.0	37.5	19.2	26.8	5.6	28.1	21.9	62.6	283.0	907.7
1997	91.7	29.2	43.3	162.6	25.3	49.9	0.4	31.5	27.2	95.8	89.2	194.9	841.0

1998	123.6	58.6	190.1	70.2	72.9	58.5	0.9	.	33.3	35.9	82.4	172.7	899.1
1999	116.1	197.9	61.5	9.8	18.4	6.3	15.7	31.2	7.1	7.8	28.9	96.0	596.7
2000	64.1	129.1	70.1	60.1	83.7	3.6	4.9	0.5	7.4	45.9	85.6	78.4	633.4
2001	88.9	86.3	28.1	115.7	82.7	.	0.5	5.5	60.4	1.8	210.0	354.8	1034.7
2002	57.5	11.7	91.9	160.2	25.4	1.0	22.0	18.9	75.0	8.5	57.7	230.3	760.1
2003	75.1	231.7	53.6	133.7	72.8	14.9	.	1.6	15.7	55.8	23.6	240.7	919.2
2004	334.6	79.0	21.5	113.9	25.9	11.0	11.1	3.6	.	17.8	73.3	24.8	716.5
2005	180.5	195.2	103.3	132.7	9.7	6.1	14.1	1.4	35.6	48.3	84.4	73.2	884.5
Total	6436.6	5177.4	3830.1	3815.1	2352.6	1120.9	438.0	336.3	912.3	2158.4	3524.1	6992.8	37094.6
Average	131.4	105.7	78.2	77.9	48.0	22.9	8.9	6.9	18.6	44.0	71.9	142.7	757.0

BALADIZ METEOROLOGICAL STATION MONTHLY TOTAL PRECIPITATION (mm)													
Years	MONTHS												Sum
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
1967						Missing	record						
1968	80.6	43.3	53.2	19.0	32.7	40.3	0.0	7.0	32.6	51.6	68.3	120.1	548.7
1969	191.0	73.2	60.6	46.8	32.8	9.2	3.0	9.0	8.4	22.3	41.4	123.5	621.2
1970	28.6	42.1	30.6	33.4	46.2	16.6	0.9	0.0	10.6	37.3	25.9	53.1	325.3
1971	52.4	42.5	68.9	45.7	37.6	27.5	24.8	20.9	10.0	13.8	35.1	35.9	415.1
1972	21.7	47.6	26.7	27.0	87.6	26.8	15.3	6.1	2.1	46.7	22.8	5.6	336.0
1973	37.9	37.2	42.4	39.2	81.6	9.2	1.1	0.0	0.0	30.1	13.5	27.4	319.6
1974	51.7	63.2	29.6	38.1	65.2	10.2	1.5	6.8	4.3	9.6	12.1	43.2	335.5
1975	57.2	48.9	26.9	34.1	75.5	75.9	14.2	15.0	4.8	34.5	66.5	88.5	542.0
1976	92.5	34.1	25.0	91.3	100.1	46.3	8.1	0.0	0.0	66.7	22.6	47.0	533.7
1977	22.1	39.9	19.6	65.1	13.8	21.6	0.9	1.0	22.5	41.3	8.0	61.6	317.4
1978	79.1	122.1	52.8	53.7	0.7	25.0	11.3	0.0	36.4	60.6	3.2	61.1	506.0
1979	135.8	18.6	39.4	20.3	52.1	17.9	7.8	1.4	6.6	59.7	66.8	66.5	492.9
1980	85.0	42.8	74.9	45.8	44.5	37.6	0.2	0.0	13.2	30.9	40.1	23.5	438.5
1981	102.2	76.6	23.9	14.7	57.7	22.8	19.0	1.4	1.1	12.8	19.9	104.6	456.7
1982	45.1	57.5	34.1	82.3	27.1	47.4	9.6	43.9	11.8	59.3	15.3	23.3	456.7
1983	73.4	45.4	42.4	53.4	41.6	21.6	19.7	12.7	26.7	21.9	73.6	64.3	496.7
1984	34.0	17.6	81.8	102.7	32.3	0.7	10.3	8.0	7.5	0.0	45.7	9.4	350.0
1985	107.2	85.1	48.6	25.9	29.9	15.0	2.3	0.0	11.5	40.5	50.6	53.8	470.4
1986	47.2	48.7	7.5	21.5	31.4	14.4	10.5	14.6	23.2	17.5	6.5	54.5	297.5
1987	58.9	63.9	41.1	70.4	40.9	37.9	17.2	4.3	0.0	48.5	59.7	32.4	475.2
1988	12.0	70.2	84.6	59.4	16.8	18.5	2.0	7.0	8.5	48.0	97.8	15.1	439.9
1989	3.7	8.0	53.2	1.2	31.9	6.5	3.2	6.5	0.0	49.9	70.4	46.4	280.9
1990	3.1	14.3	11.9	49.4	40.0	31.9	2.2	1.0	9.0	13.4	8.2	78.7	263.1
1991	33.5	30.0	30.5	69.7	72.6	1.5	45.0	12.3	11.8	53.3	9.3	60.4	429.9
1992	0.0	11.9	58.9	49.2	27.6	48.6	34.0	12.0	0.0	13.8	37.1	42.4	335.5
1993	66.6	34.7	37.8	51.4	98.3	0.8	0.0	1.2	0.0	5.2	68.3	32.4	396.7
1994	70.7	40.9	74.5	30.1	34.6	50.1	20.2	1.6	1.4	97.2	46.9	44.2	512.4
1995	42.4	23.5	108.0	23.5	19.5	33.0	54.7	6.3	0.0	33.5	58.3	22.2	424.9
1996	41.0	50.4	80.0	55.3	46.9	9.5	46.9	2.9	18.8	18.8	3.0	109.3	482.8
1997	27.0	24.5	21.5	119.2	28.5	28.9	0.0	82.9	22.4	104.8	48.2	75.3	583.2
1998	51.6	57.6	111.5	73.3	68.9	53.1	0.0	0.0	0.0	28.8	43.8	110.4	599.0
1999	40.5	80.1	52.7	30.9	11.8	38.5	3.5	52.9	0.0	18.0	10.5	24.4	363.8
2000	65.5	35.7	46.8	52.4	61.7	20.5	3.6	0.0	33.0	12.8	36.4	40.3	408.7
2001	29.9	24.5	27.3	44.1	43.7	0.0	35.7	5.4	0.0	0.0	91.4	194.1	496.1
2002	36.1	8.8	36.7	95.1	29.5	3.2	23.0	7.9	86.1	16.7	34.6	68.1	445.8
2003	41.1	93.5	24.6	136.0	53.0	17.9	0.0	17.4	8.7	58.3	6.6	36.4	493.5
2004	191.6	37.8	7.0	63.4	16.0	11.0	13.0	1.6	2.2	4.0	46.0	12.2	405.8

2005	39.8	5.2	56.2	28.2	10.8	6.6	36.2	3.0	1.0	15.4	46.8	25.4	274.6
2006	25.8	12.8	44.4	4.4	36.6	13.2	54.6	0.0	22.5	171.4	12.8	0.2	398.7
2007	68.2	37.4	25.6	7.2	11.2	26.4	18.8	9.6	0.0	8.2	30.6	70.8	314.0
2008													0.0
2009													0.0
2010													0.0
Sum	2293.7	1752.1	1823.7	1973.8	1691.2	943.6	574.3	383.6	458.7	1477.1	1504.6	2208.0	17084.4
Average	57.3	43.8	45.6	49.3	42.3	23.6	14.4	9.6	11.5	36.9	37.6	55.2	427.1

KULEÖNÜ METEOROLOGIGAL STATION MONTHLY TOTAL PRECIPITATION (mm)

Years	MONTHS												Total
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
1975						Missing	Record						
1976	73.1	35.0	31.2	66.3	109.1	22.1	6.7	0.0	0.0	78.9	26.5	30.5	479.4
1977	19.4	45.8	24.3	103.1	7.6	20.8	14.9	0.0	12.6	14.1	3.8	85.9	352.3
1978	82.8	115.3	76.7	42.9	1.0	1.4	2.8	0.1	32.9	101.7	5.2	81.0	543.8
1979	138.8	19.1	31.4	28.2	52.5	45.1	8.2	2.0	0.0	79.2	127.0	60.2	591.7
1980	68.6	48.0	46.6	52.4	30.0	26.0	0.0	0.0	0.1	29.0	33.0	43.1	376.8
1981	158.1	109.2	27.2	15.4	24.0	9.2	0.4	0.0	0.0	7.0	23.2	107.0	480.7
1982						Missing	Record						0.0
1983	74.3	38.0	31.2	53.9	27.8	35.5	29.9	13.5	5.0	15.9	96.9	51.5	473.4
1984	30.3	44.6	85.6	152.9	7.8	3.7	1.7	10.7	15.1	0.0	40.7	17.7	410.8
1985	89.5	82.5	45.3	29.5	45.6	36.1	0.0	0.3	4.2	46.3	61.8	59.1	500.2
1986	50.7	67.3	4.8	11.7	20.7	10.1	0.0	5.0	29.6	7.0	10.8	60.8	278.5
1987	27.9	63.5	88.7	67.3	31.5	64.9	8.6	3.0	2.8	11.9	73.0	35.3	478.4
1988	20.9	77.1	101.7	71.3	23.5	26.6	22.5	8.7	8.9	48.7	87.7	58.2	555.8
1989	10.2	12.5	52.9	8.1	25.1	19.7	10.2	0.8	1.3	71.0	54.3	40.3	306.4
1990	7.8	25.3	21.5	37.1	54.5	30.1	9.5	0.3	2.0	41.5	13.4	102.4	345.4
1991	18.6	40.0	18.1	74.9	69.9	10.3	33.3	5.9	10.7	24.7	8.0	8.0	322.4
1992	0.6	7.7	77.4	44.0	35.6	44.1	21.1	4.8	0.4	6.5	48.3	63.7	354.2
1993	43.9	24.7	45.1	28.0	63.6	0.0	0.0	0.0	0.0	5.3	53.0	32.0	295.6
1994	7.0	35.3	50.9	20.0	30.0	34.7	26.5	24.8	3.0	72.6	32.7	30.7	368.2
1995	59.5	31.9	135.7	20.5	23.7	56.6	80.8	0.0	11.5	19.6	54.7	15.1	509.6
1996	33.3	78.7	48.9	56.5	36.9	42.8	38.8	0.1	19.4	19.3	2.5	129.3	506.5
1997	30.5	11.3	26.5	81.1	36.7	59.7	0.0	117.6	37.3	70.6	40.2	68.8	580.3
1998	96.8	28.0	124.3	41.6	74.8	33.0	1.4	0.0	9.4	17.5	63.3	100.4	590.5
1999						Closed							0.0
Total	1142.6	1040.8	1196.0	1106.7	831.9	632.5	317.3	197.6	206.2	788.3	960.0	1281.0	9700.9
Average	51.9	47.3	54.4	50.3	37.8	28.8	14.4	9.0	9.4	35.8	43.6	58.2	441.0

APPENDIX B

ISPARTA METEOROLOGICAL STATION MONTHLY AVERAGE TEMPERATURE (^{0}C)

Years	MONTHS												Yıllık
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
1929	-0.3	-0.5	3.0	11.5	18.2	20.7	23.0	25.7	16.7	12.9	9.8	4.5	12.1
1930	3.2	3.5	8.1	11.4	15.1	19.2	24.2	24.1	19.2	13.7	8.4	6.5	13.1
1931	3.0	4.2	6.5	9.6	15.2	19.0	24.4	24.0	19.9	13.6	5.4	2.7	12.3
1932	-0.2	1.5	5.8	10.0	15.4	21.1	24.0	23.2	20.6	17.6	7.6	2.4	12.4
1933	0.7	3.2	4.0	7.1	13.0	17.8	21.3	22.5	16.7	12.5	10.8	2.1	11.0
1934	1.5	-2.0	8.0	12.6	15.1	19.3	22.4	22.8	17.8	12.9	9.0	3.8	11.9
1935	2.2	3.1	5.4	10.3	18.7	22.2	23.4	23.7	19.9	13.8	6.2	6.4	12.9
1936	4.7	2.9	7.3	12.1	13.5	17.7	23.1	23.4	17.0	13.6	7.3	0.1	11.9
1937	-1.3	4.9	9.0	11.3	14.5	19.8	24.6	23.5	21.3	13.1	9.4	5.2	12.9
1938	0.8	0.8	3.6	9.8	15.1	20.7	23.9	24.0	17.5	13.5	6.7	4.9	11.8
1939	2.9	1.9	4.3	11.7	16.7	18.3	23.2	22.2	20.0	15.3	7.4	5.1	12.4
1940	0.8	4.8	5.4	11.1	13.5	19.3	23.8	23.0	18.6	15.0	8.8	5.0	12.4
1941	3.7	5.7	5.8	12.0	17.6	20.4	23.5	22.9	16.7	10.7	6.2	-1.5	12.0
1942	-0.8	3.8	6.8	11.0	16.7	21.7	22.3	21.5	17.3	11.6	7.4	2.7	11.8
1943	0.7	0.9	3.5	9.1	14.1	19.0	22.3	23.8	19.3	14.6	10.4	4.2	11.8
1944	0.3	3.1	5.4	12.0	14.2	20.1	22.8	21.5	18.2	13.5	7.0	3.9	11.8
1945	1.7	-0.4	2.2	8.8	18.7	19.7	22.6	23.4	18.9	10.8	8.3	2.7	11.5
1946	2.0	2.2	4.0	10.6	14.7	19.4	22.5	22.5	20.0	11.3	10.5	4.6	12.0
1947	1.1	4.7	9.5	13.1	15.9	20.5	22.6	22.3	17.6	11.9	7.6	5.9	12.7
1948	5.2	2.3	1.5	9.2	14.9	18.6	23.8	23.8	18.1	12.8	6.0	-1.8	11.2
1949	-3.2	-0.3	3.3	7.2	16.9	19.5	21.4	21.5	15.4	13.3	10.4	5.2	10.9
1950	-2.1	1.4	5.4	13.6	14.1	18.5	22.2	21.8	19.8	11.2	7.7	6.7	11.7
1951	2.7	4.9	7.6	11.4	15.7	18.7	21.7	22.9	19.0	10.4	7.4	0.8	11.9
1952	3.3	3.8	4.7	11.4	14.4	18.2	22.4	23.4	21.6	14.1	8.4	6.0	12.6
1953	2.9	3.3	1.2	10.6	13.4	18.8	23.4	23.4	18.2	13.2	4.8	0.6	11.2
1954	-0.4	2.8	7.3	9.2	14.7	21.1	24.5	23.6	18.8	13.7	8.4	4.3	12.3
1955	4.8	6.8	7.3	9.1	17.0	12.9	22.5	21.8	18.4	14.9	8.2	4.6	12.4
1956	2.7	2.7	3.3	11.5	14.1	19.7	23.4	21.6	17.6	11.9	7.2	1.1	11.4
1957	0.5	4.9	6.9	11.2	13.6	19.9	23.4	24.2	19.6	15.1	7.6	3.8	12.6
1958	3.2	5.3	7.0	10.5	16.2	19.2	22.4	23.8	17.3	12.8	8.7	5.6	12.7
1959	3.4	-2.6	5.4	10.9	15.6	19.3	22.1	21.6	16.5	11.2	7.3	5.1	11.3

1960	3.3	3.3	5.5	10.6	16.7	18.6	22.7	22.1	18.9	15.6	9.7	6.7	12.8
1961	1.8	2.0	4.8	11.9	16.2	19.7	23.5	23.7	16.3	12.8	8.6	5.1	12.2
1962	3.5	2.5	8.0	9.8	16.4	20.5	24.3	25.1	19.6	13.4	11.5	6.0	13.4
1963	4.0	5.5	4.2	10.4	13.4	19.7	23.0	24.1	19.2	13.7	9.2	4.5	12.6
1964	-1.1	1.8	7.0	10.3	13.8	18.8	23.4	22.0	17.7	14.7	8.0	4.8	11.8
1965	2.4	1.7	6.5	9.7	14.5	21.2	24.3	23.7	20.5	11.3	7.6	4.5	12.3
1966	3.7	6.3	6.2	11.8	15.3	20.1	24.1	24.5	18.6	15.5	11.9	4.2	13.5
1967	1.3	0.5	4.7	9.8	15.0	18.8	22.4	23.2	18.1	12.7	6.3	4.6	11.5

ISPARTA METEOROLOGICAL STATION MONTHLY AVERAGE TEMPERATURE (^{0}C)

Years	A Y L A R												Average
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
1968	0.8	3.8	5.5	13.8	18.4	19.2	24.4	21.5	17.7	12.6	8.7	5.1	12.6
1969	1.4	4.2	7.5	7.7	17.4	21.2	21.9	24.0	20.2	13.4	8.4	5.9	12.8
1970	4.9	5.5	8.0	13.0	14.7	21.0	24.0	22.6	17.9	11.1	7.6	1.8	12.7
1971	5.2	2.8	5.9	9.4	15.4	19.9	22.5	21.5	18.5	11.0	7.4	1.2	11.7
1972	-0.6	0.7	6.5	12.0	15.6	19.6	22.0	22.1	19.2	12.3	5.9	0.7	11.3
1973	0.5	3.4	4.7	9.7	16.7	18.9	23.8	23.0	20.1	13.5	4.8	3.5	11.9
1974	-3.2	1.1	8.1	9.2	14.8	20.7	23.1	21.7	17.0	15.0	7.2	2.0	11.4
1975	0.6	1.2	7.1	11.7	14.2	18.8	23.1	21.6	18.2	12.2	6.4	0.2	11.3
1976	0.5	-0.2	6.3	9.8	14.9	18.7	21.3	21.1	16.9	13.2	7.8	3.3	11.1
1977	1.4	5.5	5.9	10.5	16.2	20.1	23.9	24.0	18.4	10.3	9.2	1.8	12.3
1978	3.1	5.2	6.1	10.2	16.6	19.7	24.4	21.4	16.4	13.6	5.5	3.6	12.2
1979	2.4	5.2	7.4	10.5	14.6	19.5	21.9	22.3	18.5	13.2	7.5	3.0	12.2
1980	0.3	1.6	4.7	9.6	14.6	19.8	24.1	22.8	17.0	12.7	7.9	4.0	11.6
1981	2.4	2.0	7.6	10.5	13.5	20.2	23.2	22.3	18.4	14.2	5.2	6.1	12.1
1982	3.4	0.2	4.2	10.1	14.4	18.5	20.2	21.7	17.7	11.9	4.6	2.3	10.8
1983	-1.8	0.0	5.1	10.6	15.4	18.0	21.6	20.3	17.2	10.7	8.1	3.8	10.8
1984	3.3	4.4	5.8	8.3	16.3	20.1	21.9	19.6	17.8	12.0	6.6	0.7	11.4
1985	4.6	-1.4	5.3	11.2	16.4	19.8	21.7	23.4	18.2	9.8	8.7	2.9	11.7
1986	3.6	4.1	7.6	12.8	13.4	19.4	24.3	23.9	18.7	11.8	3.9	1.7	12.1
1987	3.8	4.3	1.6	8.3	14.5	19.3	23.3	21.6	18.9	11.6	5.9	3.7	11.4
1988	2.6	2.8	3.5	10.7	16.2	20.0	24.2	22.7	18.2	11.5	4.5	3.6	11.7
1989	-0.9	1.9	7.8	14.7	15.7	19.5	24.0	23.5	18.9	11.1	7.1	1.6	12.1
1990	-0.5	2.9	7.1	10.6	14.5	19.6	24.4	22.9	18.1	13.7	8.9	4.6	12.2

1991	1.1	2.2	8.8	10.5	13.4	20.9	23.1	23.4	19.0	13.1	6.7	0.3	11.9
1992	-2.9	-2.0	3.5	10.5	15.0	19.3	21.2	23.2	17.7	15.2	6.3	-0.1	10.6
1993	-0.9	0.7	5.3	10.5	13.9	20.4	23.5	24.1	19.2	14.6	5.7	4.7	11.8
1994	4.3	3.5	6.1	12.7	16.7	20.2	23.7	23.5	21.7	14.9	6.0	2.0	12.9
1995	3.6	5.0	5.8	9.3	16.6	22.2	22.1	23.5	19.4	12.2	3.6	3.9	12.3
1996	0.7	4.6	4.7	8.9	17.3	21.2	24.6	23.7	17.7	11.4	8.7	6.2	12.5
1997	2.9	1.8	3.8	6.4	17.6	20.4	23.4	20.8	17.2	12.9	7.9	4.4	11.6
1998	1.8	4.5	3.4	12.2	15.2	20.7	25.1	25.6	18.9	14.6	9.7	4.4	13.0
1999	3.9	3.5	6.5	11.5	17.8	20.7	24.5	23.8	19.1	14.5	8.0	5.4	13.3
2000	-1.6	1.9	4.5	11.6	15.4	21.1	26.1	23.6	18.9	12.2	8.8	3.4	12.2
2001	4.1	4.1	11.0	11.3	15.6	22.0	25.9	24.9	19.8	13.6	7.3	3.7	13.6
2002	0.4	6.1	8.4	10.2	15.9	21.1	23.7	22.5	16.6	13.1	8.2	0.9	12.3
2003	6.3	0.2	3.9	9.7	17.1	21.4	24.0	23.9	18.1	14.2	7.4	2.5	12.4
2004	0.7	2.9	7.6	10.9	15.5	20.4	24.0	23.1	19.2	14.7	7.6	3.5	12.5
2005	3.3	2.5	6.7	11.0	16.1	20.6	24.8	24.3	18.1	11.4	6.2	4.0	12.4
Average	1.7	2.7	5.8	10.6	15.5	19.8	23.2	23.0	18.5	13.0	7.6	3.5	12.1

APPENDIX C

Table C1. Pressure values for the main pipe (DSI Software solution results)

Static Pressure head (m)	Dynamic pressure head (m)	Piezometric Code (m)	Required Energy head (m)
16,01	13,64	990,62	990,62
16,02	13,23	990,21	0,00
16,02	12,13	989,29	989,29
26,48	22,41	988,94	0,00
26,48	10,93	988,51	0,00
17,60	12,64	988,04	0,00
25,15	19,66	987,52	987,52
25,15	17,57	987,01	987,01
24,17	17,65	986,48	0,00
24,17	16,51	986,00	0,00
25,63	17,58	984,96	984,96
29,60	20,00	983,40	983,40

Table C2. Total area, flow rate, diameter, velocity and hydraulic slope data of the main pipe (DSI Software Solution)

Total area (ha)	Flow (lt/s)	Pipe type	Diameter (mm)	Length (m)	Velocity (m/s)	Hydraulic slope (m/m)
500,3	495	PE	710	112,30	1,45	0,0030728
495,7	490,9	PE	710	138,20	1,44	0,0030231
214,5	240,1	PE	630	655,60	0,90	0,0013932
213	238,6	PE	630	260,60	0,89	0,0013762
173,8	201,8	PE	630	428,00	0,75	0,0009910
116,6	146,4	PE	560	486,10	0,69	0,0009747
77,3	106,2	PE	500	560,10	0,63	0,0009292
69,4	97,9	PE	450	366,20	0,72	0,0013790
63,4	91,3	PE	450	444,80	0,67	0,0012027
31,4	54,5	PE	355	319,60	0,64	0,0014970
16,1	50	PE	315	444,00	0,75	0,0023484
8,2	30	PE	250	71,10	0,71	0,0028471

Table C3. Hydrant data for the main pipe (DSI Software Solution Results)

Hydrant area (ha)	Hydrant flow(lt/s)	Hydrant type	Pipe cost (USD)
4,6	20	D	13222,20
0	0	-	16271,67
1,5	10	D	60643,00
0	0	-	24105,50
0	0	-	39590,00
0	0	-	35558,22
7,9	20	H	32693,04
6	20	H	17339,57
0	0	-	21061,28
0	0	-	9440,98
7,9	20	H	10340,76
8,2	30	H	1047,23