REHABILITATION STUDIES ABOUT STORAGE TANKS: A CASE STUDY

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ABSTRACT

REHABILITATION STUDIES ABOUT STORAGE TANKS: A CASE STUDY

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One of the most important factors, while designing a water distribution system, is the storage tank capacity in terms of costs. When the storage tank volume is increased, more water can be stored, the water distribution system works more efficiently, and energy costs can be decreased. Population growth, interest rate, the cost of the water distribution system elements and energy prices have major effects on the storage tank capacity. The software model of the study area, N8.3, was optimized, and the daily energy costs of the 24 hour period simulation analysis were analysed.

Costs of 24 hours period simulation of the scenarios, daily energy costs, were calculated for the years between 2015 and 2085. Results showed that the daily energy costs of the network decreased if the storage tank size increased. When the storage tank capacity is large enough, the storage tank can store more water in the lowest price intervals, and feeds the network for a longer period in the highest cost intervals.

The requirement of the largest storage tank, which is selected within the scope of this study, occurred at the year 2055 when the interest rates are low. When the interest rate are high, the annual cost of the storage tank is greater than the annual costs of low interest rates. As a result of this, the largest storage tank requirement occurred later, after the year 2075, when the interest rates are high.

Keywords: Rehabilitation Studies, Storage Tanks, Water Supply System, Pump Scheduling, Annual Cost Calculations

ÖZ

SU DEPOLARI HAKKINDA REHABİLİTASYON ÇALIŞMALARI: BİR UYGULAMA

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Su şebekeleri tasarlanırken maliyetler açısından en önemli unsurlardan birisi su deposu kapasitesidir. Su depolama tankının kapasitesi arttırıldığında daha fazla su depolanabilmekte, su şebekesi daha verimli çalışmakta ve enerji maliyetleri düşmektedir. Nüfus artışı, faiz oranı, sistem elemanlarının maliyeti ve enerji fiyatları depolama tankı üzerinde önemli etkilere sahiptir. N8.3 basınç bölgesinin bilgisayar modeli optimize edilmiş ve 24 saatlik simülasyon analizi sonucunda çıkan enerji maliyetleri analiz edilmiştir.

Çeşitli senaryoların 24 saatlik maliyetleri yani günlük enerji maliyetleri 2015 ile 2085 yılları arasında hesaplanmıştır. Sonuçlar, su şebekesi maliyetlerinin, depolama tankı kapasitesi büyüdüğü zaman düştüğünü göstermektedir. Depolama tankının kapasitesi yeterince büyük olduğunda, depolama tankı, enerji maliyeti düşük olan zamanlarda daha fazla su depolayabilmekte ve enerji maliyeti yüksek olan zamanlarda şebekeyi daha uzun süre boyunca besleyebilmektedir.

Faizler düşük olduğu zaman, bu çalışma kapsamında seçilen en büyük kapasiteli depoya olan gereksinim 2055 yılında görülmüştür. Faizler yüksek olduğunda, depolama tankının yıllık maliyeti, düşük faiz oranının maliyetine göre daha fazla olmaktadır. Bunun sonucunda, yüksek faiz oranlı yerlerde en büyük kapasiteli depoya olan gereksinim daha geç, 2075 yılından sonra, ortaya çıkmaktadır.

Anahtar Kelimeler: Rehabilitasyon Çalışmaları, Su Depoları, Su Temini Sistemleri, Pompa Programlaması, Yıllık Maliyet Hesaplamaları

This thesis is dedicated to my family…

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TABLE OF CONTENTS

LIST OF TABLES

TABLES

LIST OF FIGURES

FIGURES

LIST OF SYMBOLS

SYMBOLS

A: Annual payment or cost

c: Growth Rate

C: Hazen – Williams coefficient

$C_n(t)$: Unit energy cost of pump n at schedule time

$C_n(bp)$: Maximum demand charge for pump n during billing period bp

D: Diameter (m)

$Emax_n^{bp}$: Maximum energy consumption of pump n during billing period bp

$E_n(t)$: Energy consumption during the schedule time interval

F: Future value

h_f: Head loss (m)

H_p: Pump head (m)

H_s: Head difference

i: Interest rate

L: Length of Pipe (m)

n: Number of years

N: Number of pumps

NBPn: Designates the number of billing periods for pump n

N_g: Future population

N_y: New census

PV: Present value or worth

T: Control time span

$P_{min,j}$: Minimum pressure limit

$P_{max,j}$: Maximum pressure limit at node j and at time t

P_j: Pressure at the node j

V_{max}: Maximum velocity limit

V_j (t): Velocity of any pipe j during the time interval t

TL^{final}: Final water level in the storage tank k

$TL^{initial}$: Initial water level in the storage tank

TL_k (t): Water level in storage k at time interval t

TL_{max}: Maximum allowable tank level

TL_{min}: Minimum allowable tank level

PS_k: Number of pump switch for pump k

$PSmax_k$: Maximum allowable number of pump switched permitted for pump k

S_k (t): Control setting of pump k at the time interval t

Q: Discharge (m^3/s)

Q_{annual}: Annual Daily Demand (lt/s)

Q_{max}: The Average Discharge on the Day of the Highest Amount of the Water Used at the end of the Economic Life (lt/s)

V_{daily} = Daily Required Water Volume (m^3/day)

ΔTL_k: Allowable tolerance of the final water level for the storage tank k

CHAPTER 1

INTRODUCTION

1.1. General

Water is an essential need for every living organism in the world and used in every stage of life. Water distribution networks (WDN) are built for having access to potable water. The operation of the construction of water distribution networks is carried out by water authorities in most of the cities. Authorities must plan, design and operate the water distribution systems by considering the water's quality, quantity and cost. Water quality is the usability of water according to any human need or purpose. If the quality of water is not good or there is instability between the per capita income and water prices, people cannot use the water that is their fundamental need.

The cost of people's requirements is one of the most important things for people. Engineering studies should be carried out by considering these costs. New projects should be developed according to people's water needs. Developed projects are constructed with taxes taken from the community by the government. Several projects must be developed in order to find the most accurate and most economical design. More alternatives mean more chances to catch the feasible solution. Engineers are responsible for determining the most feasible solution among the alternatives of the project.

In the planning phase of the water distribution network, the areas in need of water are determined. Economic life and population of that area must be taken into account in the next step. At the design stage, water distribution network system elements such as the pipes, valves, reservoirs or pumps are chosen with respect to the calculations. The water distribution network must be constructed according to the design projects. The water distribution system cannot function properly if there is any mistake or inconsistency between construction works and design stages.

Optimization process must be started at the planning stage of the water distribution network in order to minimize the costs. Rehabilitation studies as pump scheduling, extended period simulation analysis and selection of water storage tank capacity are the parts of the optimization process. Requirements of the water distribution network must be taken into account during the rehabilitation studies. The main purpose of the rehabilitation is to make the water distribution network more efficient against the new conditions of the area. Rehabilitation work consists of determining and replacing the defective parts of the water distribution network. Water price can be reduced by changing the WDN system components in accordance with the rehabilitation strategy.

The tank capacity is one of the most important factors in lowering the costs of water. More water can be stored by increasing the water storage tank capacity. On the other hand, the initial investment of a smaller water tank will be lower. The water storage tank capacity must be chosen according to conditions of the study area. Also, water storage tank can be replaced to adapt the system to the new conditions and provide the water to users economically.

1.2. Purpose of the Study

The purpose of the study is focused on storage tank rehabilitation of a particular part of Ankara WDN. The rehabilitation is made by comparing the total annual costs of daily energy, storage tank and pump. The N8.3 region consists of six zones that are North Sancaktepe, South Sancaktepe, Şehit Kubilay, East Çiğdemtepe, West Çiğdemtepe and Yayla. The area is located in the north of Ankara.

The computer based model of the N8.3 region water distribution network is taken from the previous researches (Şendil, 2013).

In this study, the energy prices of the water distribution network of N8.3 region are examined. Daily pump energy costs and tank costs were taken into account in the determination of energy prices. Energy prices can be reduced by changing the water tank of the WDN at the right time. In addition, the water tank will be insufficient due to the population growth. The tank must be changed in order to overcome this issue. Generally, the study aims to compare the time-varying energy prices by considering the daily pump costs and annual tank replacement costs.

The second chapter of the study is about the water distribution system components. In this section, brief information about the WDN components is given. Also, this chapter includes the information about the population of the N8.3 area.

In the third chapter, the terms of the economy which are used in the study are explained. Interest rates of Turkey, economic life, annual, present and future cost calculations are expressed. Explanation of these terms will provide a better understanding of the study.

In the fourth chapter, the genetic algorithm mechanism and optimization technique are discussed. This section also contains the parameters and definitions of the genetic algorithm technique.

The case study is presented in the fifth chapter. This section covers the major part of the study. Population projection and water requirement analysis, graphs and calculations due to the pump and water tank annual costs are explained in this chapter. Besides these, the results of the study are discussed in this chapter.

In the sixth chapter, conclusions of the study are presented and suggestions are made for future studies.

CHAPTER 2

THEORETICAL CONSIDERATIONS

2.1. Population and Population Growth

Requirement of water must be estimated to design the water supply system. In Turkey, the population projection is higher than the world's population growth and the other developed countries. Figure 2.1 shows the population growth curves of some developed countries. The best guide in selecting a value for per capita use is the previous records of the city under study or data from similar cities in the area.

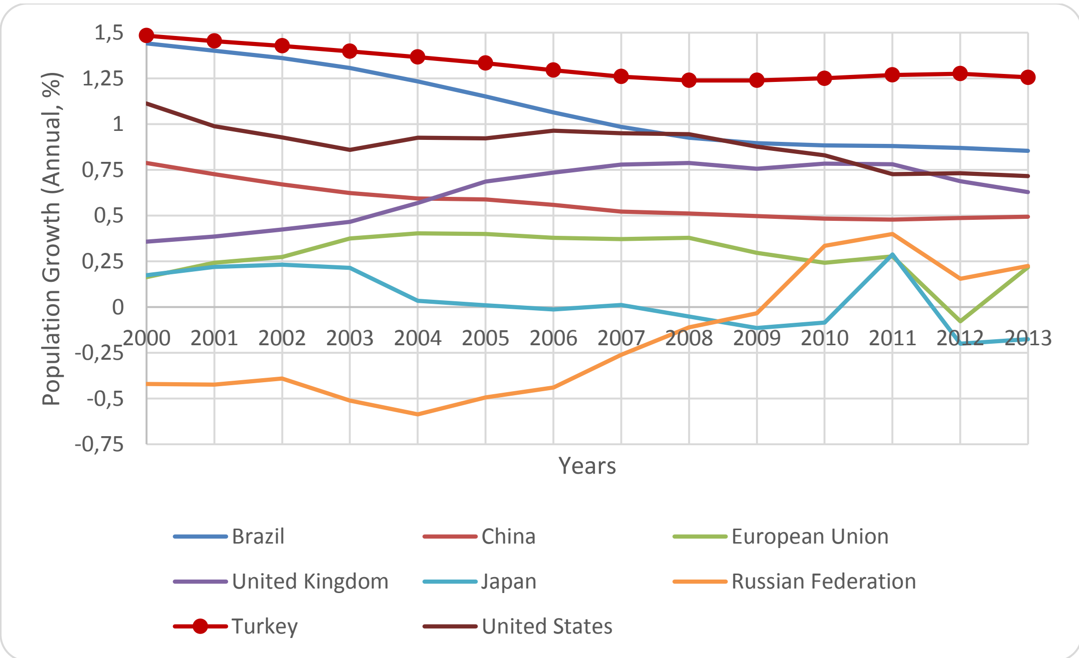


Figure 2.1. Population Growth Rate of Various Countries (World Bank Group, n.d.)

After deciding on an average per capita requirement, the future population of the city must be estimated to determine average total use. The economic aspects of the problem include determining how far into the future the population should be projected. Some portions of the system may be more economically built to the ultimate size immediately while other portions are left for expansion. If wells are to be used for the water source, the design period may be short because other wells can be drilled when needed. On the other hand, if a dam must be built, the design period may be long (Linsley and Franzini, 1979). The water distribution network probably designed and constructed at 1990. The population of the area is 25,000 at 1990 (Eker, 1998). There is not any exact information about the population of the area currently but Şendil (2013) states that N8.3 area has a population of nearly 50,000. In addition, Drinking Water Project Regulations of Bank of Provinces' Specifications (1989) states that if the growth rate value must change between %1 and %3. For demonstrative purposes of the methodology developed in this study, the population growth rate is assumed as an average value, 2%, in this study.

2.2. Storage Tanks

Storage tanks, called as distribution reservoirs, are used to provide storage to meet the fluctuation in use, to meet the fire demands and to stabilize pressures of the water distribution system. Water storage tanks should be placed high enough in order to provide necessary discharges and pressure head to the system when required. When the demand of the water supply system is low, the water is pumped into the storage tank and during the peak hours storage tanks feed the system by gravity flow. The most important physical characteristic of the storage tanks is storage capacity. Storage tanks are generally classified as elevated storage tanks and ground storage reservoirs. Various sizes of storage tanks, 650 m^3, 1300 m^3, 1950 m^3, 2600 m^3, 5200 m^3, 6500 m^3 and 7800 m^3 are used in this study.

2.2.1. Elevated Storage Tanks

Elevated storage tanks are constructed above the ground such that the water level in the storage tank is sufficient to deliver water to the water supply system at the required pressure head. The storage tanks are usually made of steel or reinforced concrete. Storage tanks are connected to the water distribution system with a vertical pipe called a riser. A sample of a storage tank is shown in Figure 2.2. The hydraulic grade line of the storage tank is equal to the water level in the tank.

Figure 2.2. Elevated Water Storage Tank (WSSC, 2014)

2.2.2. Ground Storage Reservoirs

Ground storage reservoirs are constructed below the ground, partially below the ground, or above the ground level in the water distribution system. This type of storage tank feeds the system through the pumps. They are also called as distribution-system reservoirs or ground-level tanks.

2.3. Pumps

Pumps are machines that convert the mechanical energy to the hydraulic energy. To carry water from the lower elevation to the higher elevations, the pressure head of the water must be increased. Impeller, which is a rotating element of the pump, increases the pressure of the water (Figure 2.3).

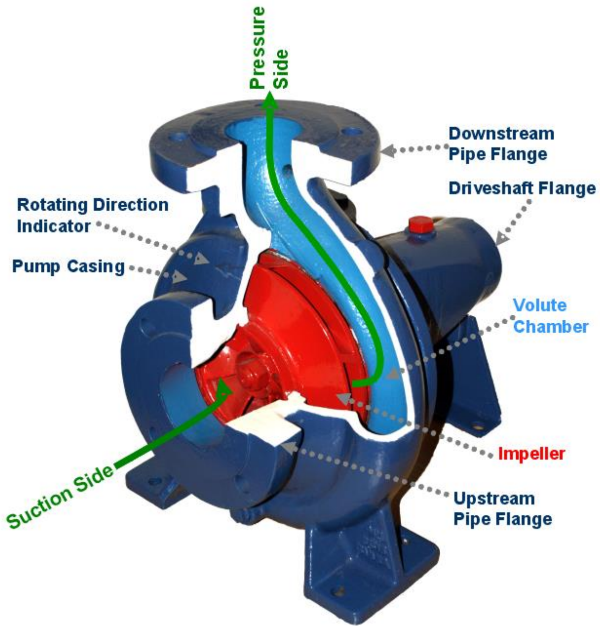


Figure 2.3. Cutaway View of Centrifugal Pump (Fantagu, 2008)

A single pump cannot meet the requirements of the network in most cases, and multiple pump systems are used at these places. Pumps must operate at the intersection point of the pump curve and system curve as indicated in Figure 2.4. There is a substantial variation in pump operating conditions because the system curve is significantly affected by the water demand of the water distribution network. Pumps are directly affecting the energy costs of the water distribution network. The pumps must be optimized for minimizing the costs of water distribution system. Pump scheduling determines the daily working time of the pumps in the pump station. The pump scheduling operation must meet the requirements and minimize the costs of the water distribution system. Three parallel pumps are used in this study and these pumps have 10 years economic life.

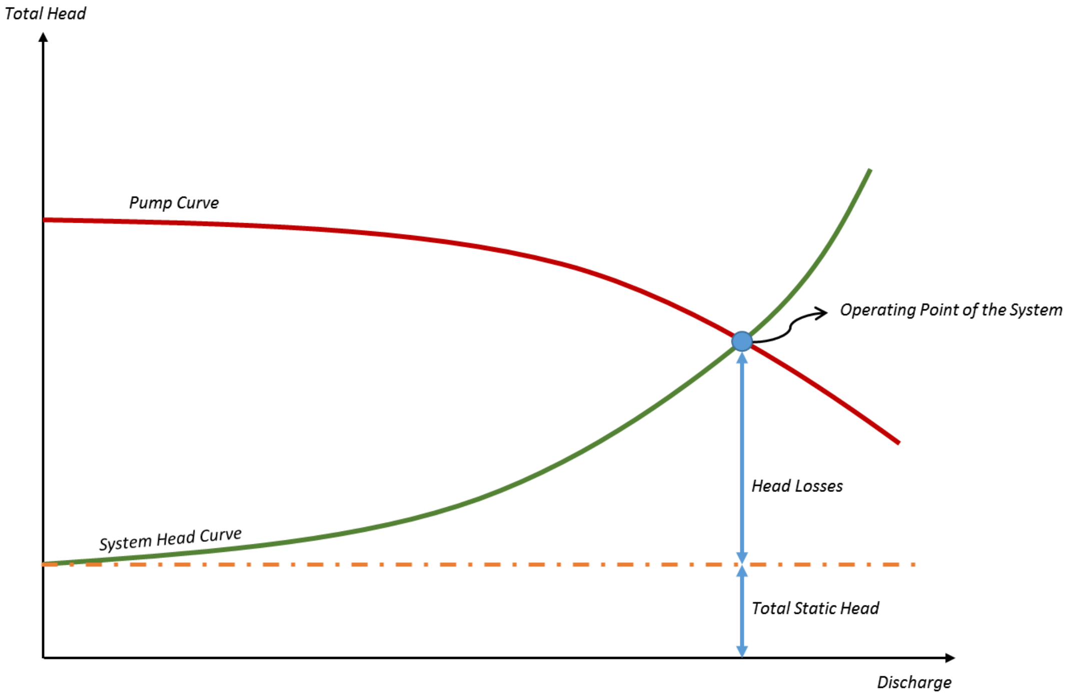


Figure 2.4. System Curve and Pump Curve

2.4. Pipelines

Generally, a pipe is a closed conduit that carries pressurized water. Water distribution networks are composed of pipes that are connected to each other. Three types of pipelines are used in a water distribution network. These are transmission lines, arterial mains and distribution mains. Transmission lines are used to carry the discharge from the reservoir or pump station to a service area and storage tank. Arterial mains are used to withdraw water from the transmission lines, and located in the main streets. Distribution mains set up a grid in the service area and located in alleys mostly.

The pipe materials can be cast iron, ductile iron, steel, plastic (polyvinyl chloride, polyethylene, and polybutylene), asbestos-cement, fiberglass, and concrete. The pipelines of the water supply system must be buried to underground to prevent the frost and to bear against traffic loads.

In any change in the system head curve, the operating point of the system is going to be changed. For example, a decrease and an increase in the diameter of the pipelines effects the system head curve. The aging of pipes causes a decrease in the diameter of pipelines. According to this the carrying capacity of the pipes reduced and roughness coefficient of the pipes increased.

Hazen – Williams coefficient, C, are used for the friction loss calculations. The coefficients of some materials are shown in Table 2.1. In order to demonstrate the power of the methodology developed in this study, all pipes are assumed as a new pipe and the Hazen – Williams coefficient is taken as 140. However, Ar (2011) and Apaydın (2013) states that the Hazen – Williams Coefficient changes in a wide range, between 70 and 140 in N8.3 area.

Table 2.1. Hazen – Williams Coefficients of Some Materials

Material	**Hazen – Williams Coefficient (C)**
Cast-Iron (10 years old)	107 - 113
Cast-Iron (20 years old)	89 - 100
Cast-Iron (30 years old)	75 - 90
Cast-Iron (40 years old)	64 - 83
Concrete	100 - 140
Concrete, old	100 - 110
Ductile Iron Pipe	140
Polyethylene, PE	140
Polyvinyl chloride, PVC	150
Fibre – Reinforced Plastic	150

2.5. Valves

There are various types of valves in pressurized systems. All kinds of valves used automatically to control the parts of the water supply system. The valve can be opened, closed, or throttled according to the condition of the system.

2.5.1. Check Valves

Check valves are used to prevent the backflow in a hydraulic system. Some reverse flows can occur very rapidly so the check valve must respond very quickly. Otherwise, pipeline can fail. It can be considered as fully open when the flow is in the specified direction.

2.5.2. Flow Control Valves

Flow control valves are used to adjust the maximum flow rate from upstream to downstream. It cannot limit the minimum flow rate or the reverse flow.

2.5.3. Pressure Reducing Valves

Pressure reducing valves are usually used isolate pressure zones in water distribution networks. The water hammer effects and pressures can be reduced by the use of these valves. High pressures could damage the pipes, pumps, fixtures, or injure the people.

2.5.4. Pressure Sustaining Valves

Pressure sustaining valves are used to maintain a certain pressure of the specific point of the network.

2.5.5. Pressure Breaker Valves

This type of valve is used to decrease the pressures across the valve. Pressure breaker valves are generally used in the areas that cannot be easily designed by using standard minor loss elements.

2.5.6. Throttle Control Valves

Throttle control valves are used to control the speed or the flow capacity through the system.

2.6. Fire Hydrants

Fire hydrants are connected directly to the water mains and often used for fire protection and flushing. Flushing is the cleaning of the water pipes and getting recovered from the silt, rust, debris, excess chlorine or dirty water. In the areas that finalises the water pipes (dead ends of the system), the water usage becomes smaller so that the old water stays long times in the pipes. After that, amount of the entire impurities increases. The flushing operation is for the cleaning the pipes from these impurities and obtaining the clean and qualified water in these locations. There is flushing operation in Figure 2.5. The location of that fire hydrant must be in the dead end of the water distribution network. The water‘s colour is like brown while the flushing operation comes along. This water goes to the consumers and in a result of this their health situations can become more worsened with time.

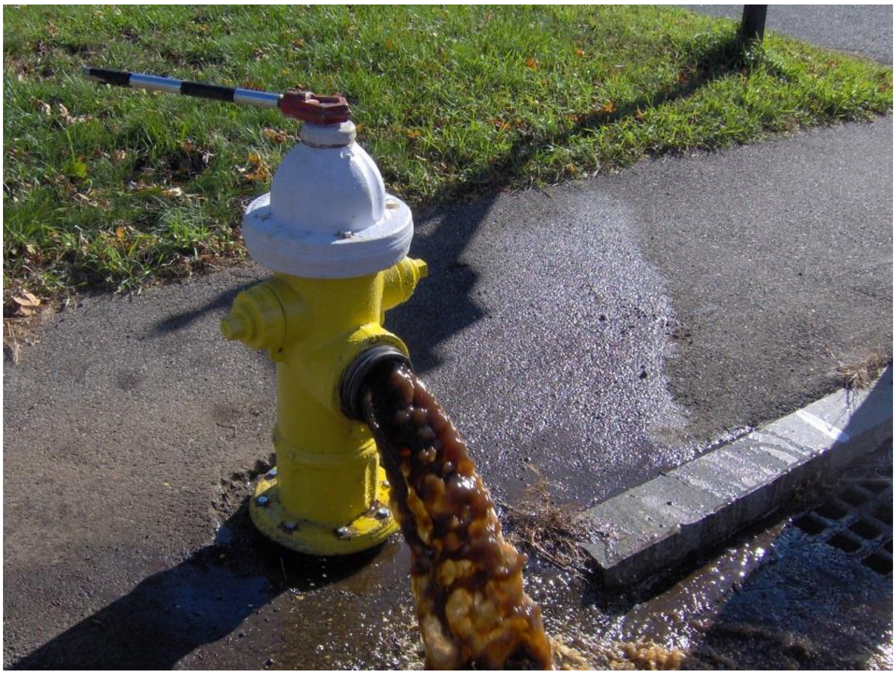


Figure 2.5. Flushing Operation (Needham Water and Sewer Division, n.d.)

2.7. Extended Period Simulation (EPS)

The extended period simulation is performed to see the system behaviour over the time. The energy usage and cost, and water quality of the water distribution systems based upon an extended period simulation. The water level of the storage tanks can be observed by performing extended period simulation. Water usage patterns, detailed storage tank information, and operation rules of pumps and valves are needed to run the extended period simulation.

Depending on the aim of the analysis, an extended period simulation can run for any length of time. The results of the analysis were observed for 24 hours period for this study. The control time intervals, called as hydraulic time step, can be selected in the extended period simulation. In this study, the length of calculation time step was selected as 1 hour. Decreasing calculation time step will increase the size of the solution space and that will cause an increase the time of the optimization process.

CHAPTER 3

ENGINEERING ECONOMY

The need for engineering economy is primarily motivated by the work that engineers do in performing analysis, synthesizing, and coming to a conclusion as they work on projects of all sizes. In other words, engineering economy is at the heart of making decisions. These decisions involve the fundamental elements of cash flows of money, time and interest rates (Blank & Tarquin, 2007). Basic concepts and terminology of the engineering economy are explained in this section of the study.

3.1. Interest Rate

The difference between the ending amount of money and the beginning amount is called as interest. If the ending amount and beginning amount of money are same or negative, interest cannot be mentioned. When a person or an organization borrows money, interest is paid. If an individual or organization saves money or invests, interest is earned. A percentage of the interest per time unit over the original amount of money is called as interest rate. Interest period is the time unit of the interest rate, and commonly used as 1 year. 0.05%, 0.25%, 5.25%, 7.75% and 17.00% interest rates were used in this study.

3.2. Economic Life

Economic life is the expected period of time which an asset is usable with the regular maintenance works. The worth of investments can be determined by estimating the economic life of an asset. Every material and machine, which is used in the water distribution networks, has an economic life. In that study, the lifetime of the water storage tank is taken as 40 years, and pumps are taken as 10 years.

3.3. Annual Cost

An asset cost per year of owning, operating, and maintaining over its lifetime is called as annual cost. The annual cost formulas are shown in the below equations. Figure 3.1 shows the calculation of the annual cost from the present value.

$$A = \frac{PV}{\frac{(1+i)^n - 1}{i * (1+i)^n}} \quad \textbf{(3.1)}$$

$$A = \frac{F * i}{(1+i)^n - 1} \quad \textbf{(3.2)}$$

where,

A: Annual Payment or Cost

PV: Present Value or Worth

F: Future Value

i: Interest Rate

n: Number of Years

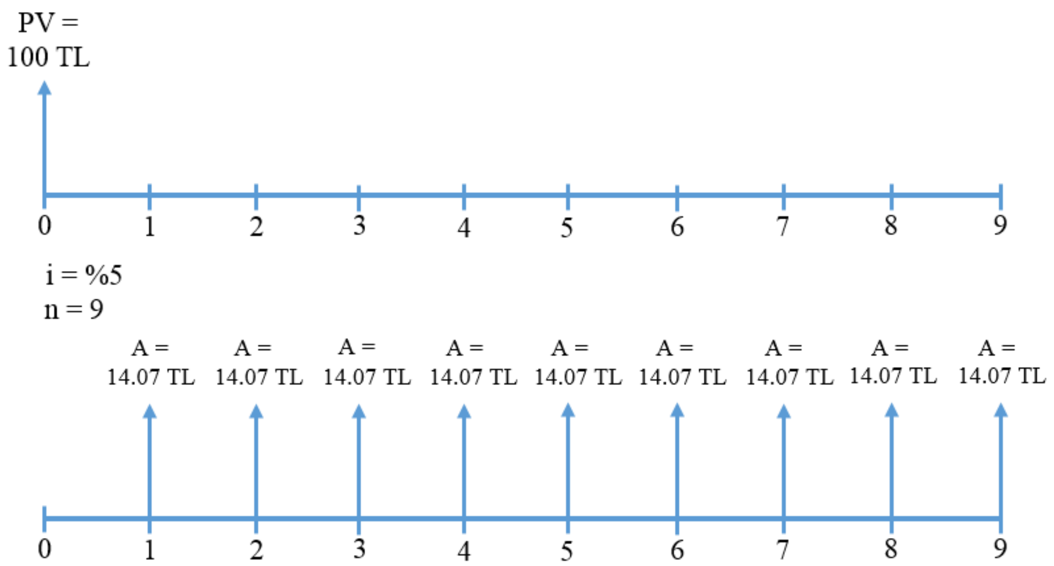


Figure 3.1. Calculation of the Annual Cost from the Present Value

3.4. Present Value

Present worth is the amount of money at a time designated as the present time or time "0". It can be described as a future amount of money that is discounted to represent its current value. Future value is usually bigger than the present value according to the interest rate. If the interest rate is negative the future value will be less than the present value. The equation for the present value of the money is shown below. The calculation of the present value from the future value is shown in Figure 3.2.

$$PV = A * \frac{(1+i)^n - 1}{i * (1+i)^n} \quad \textbf{(3.3)}$$

$$PV = \frac{F}{(1+i)^n} \quad \textbf{(3.4)}$$

where,

PV: Present Value or Worth

F: Future Value

i: Interest Rate

n: Number of Years

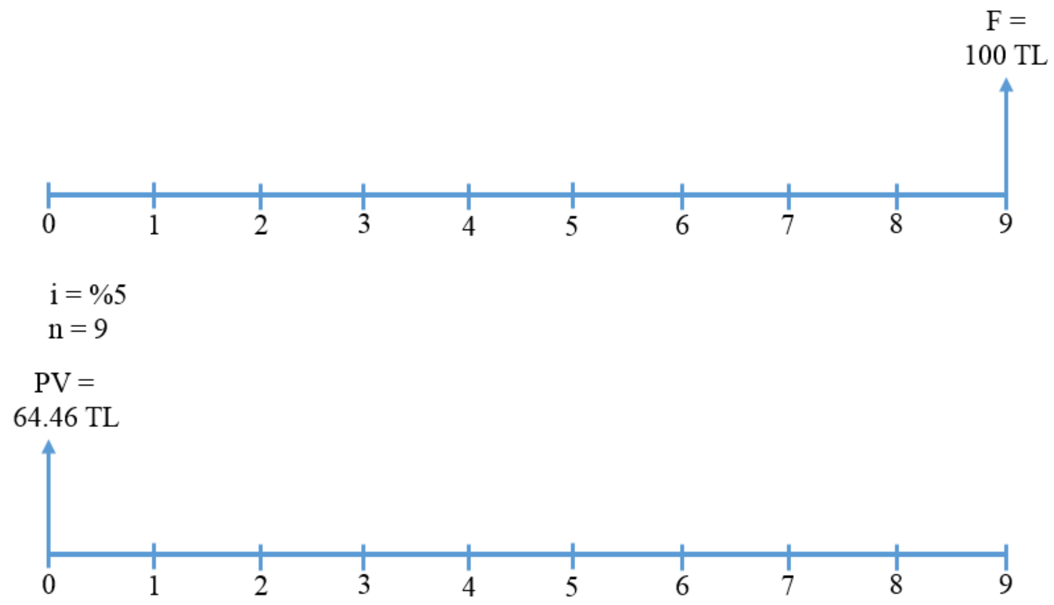


Figure 3.2. Calculation of the Present Value from the Future Value

3.5. Future Value

Future value is the amount of money that will increase the length of time at a given interest rate. It can be described as the equivalent value of a current asset in the future at a specified date. Future value equation is represented in Equation 3.3. Figure 3.3 shows the calculation of the annual cost from the present value.

$$F = \frac{A * (\ (1+i)^n - 1)}{i} \quad \textbf{(3.5)}$$

$$F = PV * \ (1+i)^n \quad \textbf{(3.6)}$$

where,

F: Future Value

A: Annual Cost

i: Interest Rate

n: Number of Years

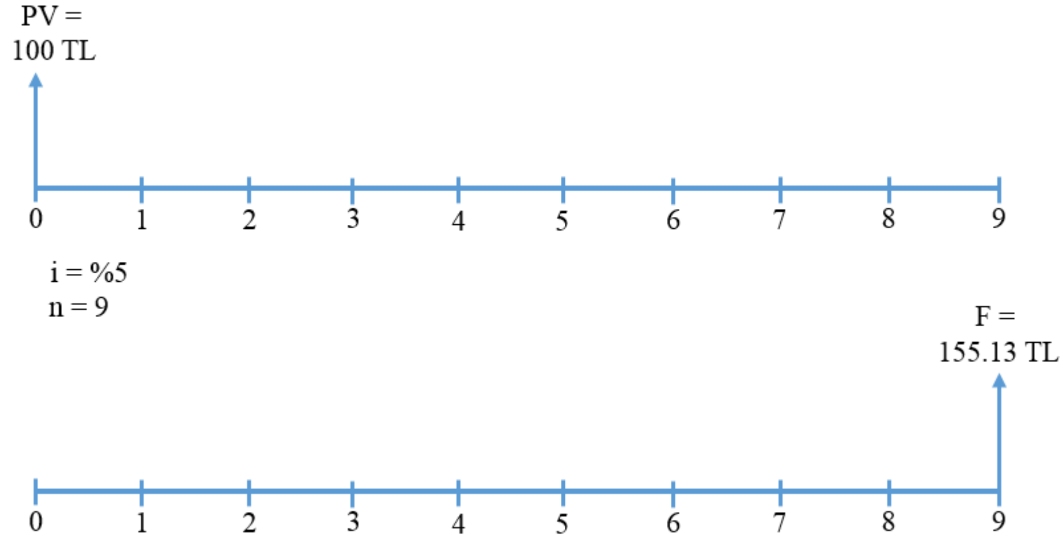


Figure 3.3. Calculation of the Future Value from the Present Value

CHAPTER 4

GENETIC ALGORITHM

4.1. General

A simple genetic algorithm has been applied to the scheduling of multiple pumping units in a water supply system with the objective of minimising the overall cost of pumping operation, taking advantage of storage capacity in the system and the availability of off-peak electricity tariffs (Mackle et al. 1995). The water distribution system in this study contains 3 parallel pumps that are used to move water mechanically. These pumps are located at the P23 pump station and needed to be scheduled in order to minimize the energy costs.

The operation of a pumping station is very important in achieving the tasks of the station. The main task is to maintain a suitable water volume in the reservoir and supply the demands. Another important task is to reduce the operation cost. With the operation scheduling optimized, remarkable reduction of the operation cost could be achieved while no change is needed with the physical elements, such as pumps and civil infrastructures (Zhuan and Xia, 2013).

In this study, genetic algorithm method was used to minimize the costs. However, there are constraints that must be taken into account while applying the genetic algorithm method. Physical and operational constraints such as consumer demands, storage capacities, and nodal pressures must be considered. The working schedule of the pumps changes according to these constraints.

The crucial point about the optimization methods is none of these completely succeed for all types of pump scheduling problems. Because of that, the optimization method cannot be chosen particularly. In this study, WaterCAD Darwin Scheduler (by Bentley) program was used and it is based on genetic algorithm.

In genetic algorithm solving process, user needs to code decision variables of the system, such as pump settings, pipe diameter and tank water levels. Unique binary codes must be given to every variable of the system. In this study, one hour time increment was used for 24 hours (1 day) while performing an extended period simulation of the water supply system.

Boulos et al. (2002) determined the functions of the genetic algorithm as follows.

Fitness Function (Objective Function of the Genetic Algorithm):

$$\text{Minimize} \quad \sum_{n=1}^{N} \left[\sum_{t=0}^{T} E_n(t) C_n(t) + \sum_{bp=1}^{NBPn} Emax_n^{bp} C_n(bp) \right] \qquad \textbf{(4.1)}$$

where,

N: Number of pumps

T: Control time span

$C_n(t)$: Unit energy cost of pump n at schedule time

$E_n(t)$: Energy consumption during the schedule time interval from t to t + 1 with a pump control setting

$Emax_n^{bp}$: Maximum energy consumption of pump n during billing period bp

$C_n(bp)$: Maximum demand charge for pump n during billing period bp

NBPn: Designates the number of billing periods for pump n

The requirements of the network and the hydraulic conditions must be satisfied while minimizing the energy costs of the pumps. The minimization process must satisfy the three different types of constraints. These are implicit system constraints, implicit bound constraints and explicit variable constraints. Hydraulic equilibrium state of the water supply system is defined by implicit system constraints. These are conservation of the mass equilibrium and conservation of energy equilibrium around each loop in the network. Implicit bound constraints have four different equations. These constraints are pressures on nodes, flow velocities in pipes, water level in the storage tank and pump switch operations.

I. Nodal Constraints

Pressures at the nodes must be between the allowable boundaries. $P_{min,j}$ is the minimum pressure limit and $P_{max,j}$ is the maximum pressure limit at node j and at time t. P_j (t) is the pressure at the node j.

$$P_{min,j} \leq P_j(t) \leq P_{max,j} \qquad \forall j, \forall t \qquad \textbf{(4.2)}$$

II. Pipe Constraints

There must be a flow rate limit for all of the pipes in the network. This can be expressed by below equation. V_{max} is the maximum velocity limit and V_j (t) is the velocity of any pipe j during the time interval t.

$$V_j(t) \leq V_{max,j} \qquad \forall j, \forall t \qquad \textbf{(4.3)}$$

III. Storage Tank Constraints

Water level in the storage tank must be between a maximum and minimum values. TL_{min} and TL_{max} are minimum allowable tank level and maximum allowable tank levels respectively a time t. TL_k (t) is the water level in storage k at time interval t.

$$TL_{min,k} \leq TL_k(t) \leq TL_{max,k} \qquad \forall k, \forall t \qquad \textbf{(4.4)}$$

Another constraint can be stated for the storage tanks that do not have constant cross-sections. To maintain hydraulic periodicity and continue repetitive simulation for coming time intervals, final water level in the storage tank should be bigger than or equal to the initial water level in the storage tank at the end of pump scheduling period. This criterion is given in below equation. TL^{final} and $TL^{initial}$ are the final and initial water level in the storage tank k respectively; and ΔTL_k is the allowable tolerance of the final water level for the storage tank k.

$$\left|TL_k^{final} - TL_k^{initial}\right| \leq \Delta TL_{max,k} \qquad \forall k \qquad \textbf{(4.5)}$$

IV. Pump Switch Constraints

Pump maintenance costs are the important factor besides the energy costs. As the number of pump switches increase, the pump maintenance costs also increase.

Because, switches cause high wear effect on the pumps. To prevent this condition, the pump switches should be limited. This limitation was expressed by below constraint.

$$PS_k \leq PS_{max,k}(t) \qquad \forall k \qquad \textbf{(4.6)}$$

PS_k designates number of pump switch for pump k; and $PSmax_k$ is the maximum allowable number of pump switched permitted for pump k. Pump control setting values are the explicit variable constraints. These were defined by on or off at a specific time period. This constraint was expressed by the equation below. S_k (t) represents the control setting of pump k at the time interval t.

$$\forall \text{k}, \forall \text{t}, \forall S_k(t) \in S^0 = \{1, 0\} \qquad \textbf{(4.7)}$$

The constraints of the fitness function are these equations that are given above.

The flow process of the genetic algorithm was formed to understand the working mechanism of the genetic algorithm.

Flow process of the Genetic Algorithm

1. Defining chromosome formation and fitness function
2. Creating initial random population
3. Water supply system model simulation
4. Constraint check
5. Evaluating objective function and penalties
6. Evaluating fitness values
7. Stopping criteria test (If the test is not changing any more according to the stopping criteria then STOP iterations.)
8. Selection of next generations (If the results are changing CONTINUE iterations)
9. Crossing of older generations to form offspring strings which have higher fitness than others
10. Mutation and elitism of older generation
11. Then simulation of water supply system model again and the forward steps respectively.

4.2. Parameters and Definitions

The simple genetic algorithm was used in this study. Default values of the software program (Darwin Scheduler) were used in the optimization process (Bentley WaterCAD V8i User's Guide, 2009).

Genetic Algorithm Parameters

Population Size = 100: Number of genetic algorithm solutions in each step.

Elite Population Size = 10: Size of an elite population of chromosomes that is maintained in parallel to the main generic algorithm population.

Number of Crossover Points = 4: Defines the number of locations along each parent chromosome where the chromosome is cut in order to be crossed over with the other parent.

Probability of Crossover = 95%: The probability that a crossover operation will be performed at the point in the genetic algorithm where crossover operations are performed (during creation of the next generation).

Probability of Mutation = 1.5%: Sets the probability that a genetic algorithm solution is randomly altered. A value closer to 100% causes the solutions to contain more randomization than values closer to 0%.

Probability of Creeping Mutation = 0.1%: The probability that a creeping mutation will occur to a new child chromosome.

Probability of Creeping Down = 65%: The probability that a gene in a child chromosome will mutate to a smaller value (e.g., lower pump speed) versus a higher value (e.g., higher pump speed).

Probability of Elite Mate = 0.5: The probability that a chromosome from the elite population is selected as a parent for the next generation at the point in the genetic algorithm where parent selection is conducted.

Probability of Tournament Winner = 95%: The probability that during parent selection the fit chromosome is selected in a two chromosome tournament.

Stopping Criteria:

Maximum Generations = 1000: The maximum number of generations to run the genetic algorithm optimization.

Maximum Trials = 100000: Set the maximum number of trials you want the optimized run to process before stopping.

Maximum Non Improvement Generations = 200: Set the number of maximum number of non-improvement generations you want the genetic algorithm to process without calculating an improved fitness. If the optimized run makes this number of calculations without finding an improvement in fitness that is better than the defined fitness tolerance, the calibration will stop.

Penalty Factors:

Pressure Penalty: 1000

Velocity Penalty: 1000

Pump Starts Penalty: 10000

Tank Final Level Penalty: 10000

Tank High/Low Level Penalty: 1000

CHAPTER 5

CASE STUDY

Storage tanks play an important role in water supply systems, enabling demand management, regulating pressure head of system, assuring water supply in case of system failure and reserves for emergencies such as firefighting, pipe breakups and allowing for the modulation of pump flow rate. When properly designed and located, storage tanks are a cost-effective means of improving overall network performance. However, an inadequately designed or located tank can increase the pump operation and reduce network performance indices such as reliability and resilience (Batchabani et al. 2014). As shown in Figure 5.1, hydraulic grade line is low at the end of the system when the storage tank is poorly located. If the storage tank is well located, the pressure conditions will be improved.

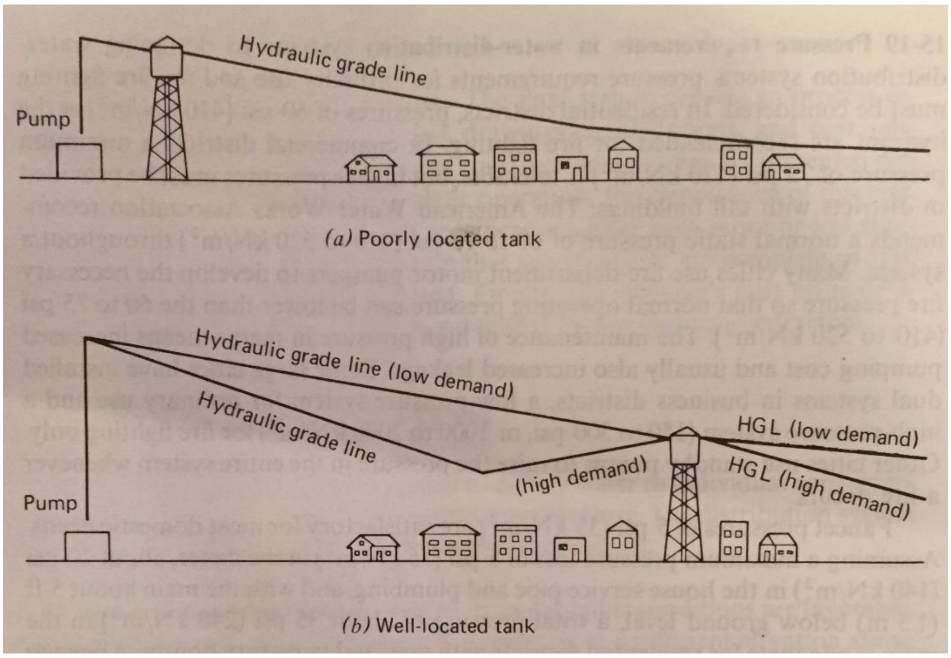


Figure 5.1. Poorly and Well Located Tank (Linsley and Franzini, 1979)

In terms of costs, tanks represent quite a small portion of the whole network costs, as opposed to the network pipes' considerable construction and/or replacement costs, or the pumps' operational costs. Nevertheless, their impact on the overall network performance is significant, disproportionate to their costs: An ill-placed tank may significantly increase pipe design costs for the network as a system, or cause exceedingly high operational costs (Vamvakeridou-Lyroudia et al. 2007).

This study aims to make storage tank rehabilitation of existing municipal water supply system by comparing the annual cost calculations of the daily energy, water tank and pump. Daily pump energy costs of the network are calculated with respect to the different sized water tanks. While doing these calculations, the pumps are assumed to be changed in every 10 years according to the water requirements of the area. Daily energy cost analyses were performed every 5 years between 2015 and 2085. The summation of the daily annual energy costs, water tank costs and pump costs were compared between 2015 and 2085 according to the different tank sizes.

5.1. Study Area

Ankara is the capital of Turkey and has a population of 5,150,072 (TurkStat, 2015b). The city consists of 25 districts that are Akyurt, Altındağ, Ayaş, Bala, Beypazarı, Çamlıdere, Çankaya, Çubuk, Elmadağ, Etimesgut, Evren, Gölbaşı, Güdül, Haymana, Kalecik, Kazan, Keçiören, Kızılcahamam, Mamak, Nallıhan, Polatlı, Pursaklar, Sincan, Şereflikoçhisar and Yenimahalle. A large part of the study area is located within the boundaries of Keçiören and partially in Yenimahalle. Keçiören is the second most crowded district of Turkey. Actually, the district has a population of 872,025 (TurkStat, 2015a). The average water consumption of Ankara is 217 litres per day per capita (TurkStat, 2012). Thus, Keçiören district of Ankara uses 189.23 m^3 water per day.

The study is performed in N8.3 pressure zone of Ankara water distribution network. N8.3 pressure zone is located in the northern supply zone of Ankara (Figure 5.2). The region consists of six District Metered Areas (DMA's). These are North Sancaktepe, South Sancaktepe, Şehit Kubilay, East Çiğdemtepe, West Çiğdemtepe and Yayla (Figure 5.3).

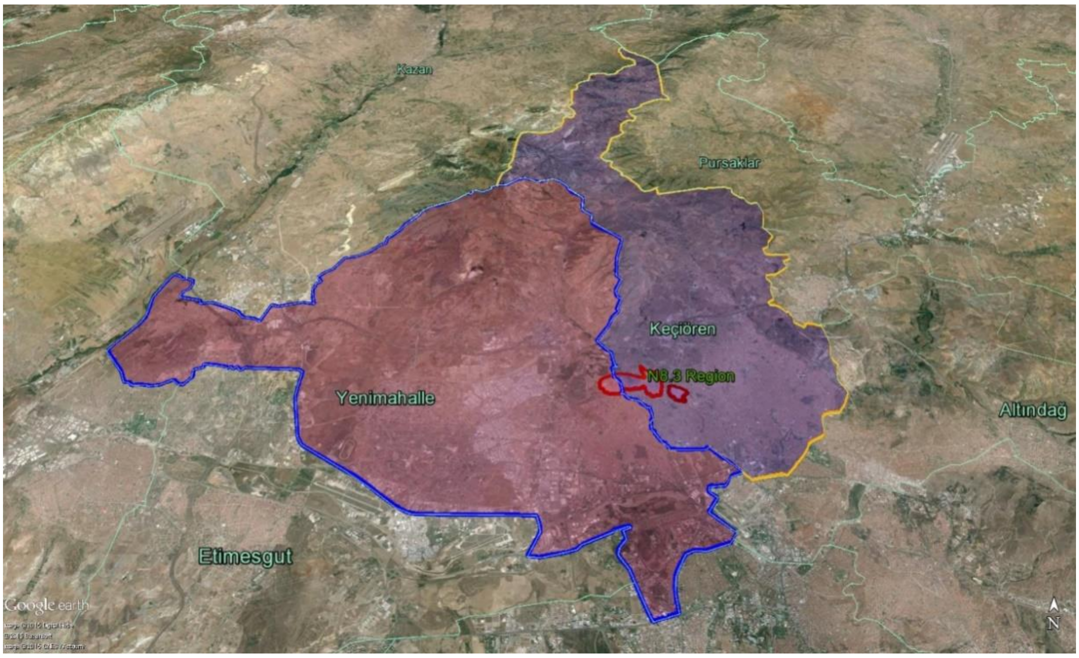


Figure 5.2. Location of N8.3 Pressure Zone in Keçiören and partially in Yenimahalle

Figure 5.3. District Metered Areas of N8.3 Region

Water distribution network of N8.3 area feeds the consumers who are located between 1075 m - 1115 m elevation intervals. P23 pump station feeds whole N8.3 network. T53 is the storage tank of the water distribution network. When the system is in need of water, storage tank and pumps feed the N8.3 area together. The pump station P23 consists of three parallel pumps.

The base elevation of "N8.3 reservoir" (Figure 5.4) is 1106.81 m. The height of the storage tank is 6.5 meters and the base elevation of the storage tank is 1149.82 meters. The base cross-section of the tank is rectangular. Water is transmitted to N8.3 distribution network by the main transmission line. The schematic representation of the network is shown in Figure 5.4 and the configuration of the whole hydraulic model of the N8.3 water distribution network is shown in Figure 5.5. The hydraulic model of the network is adapted based on the study of Şendil (2013).

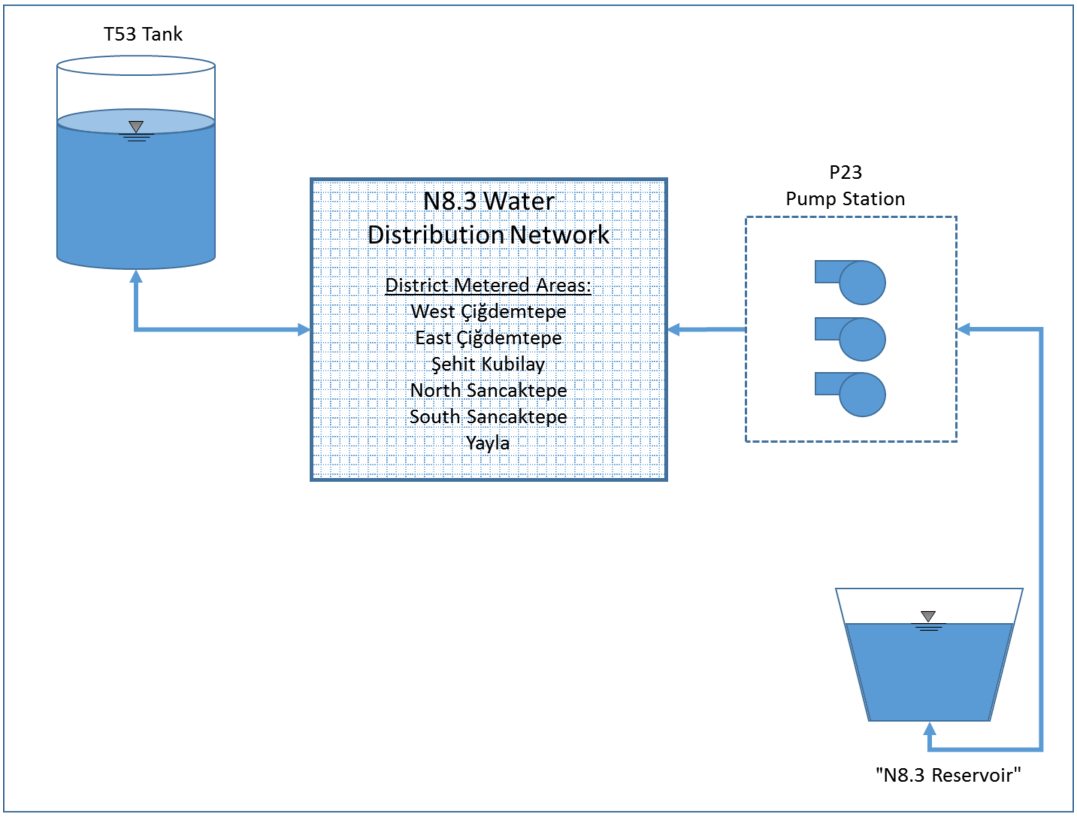


Figure 5.4. Schematic Representation of N8.3 Water Distribution Network

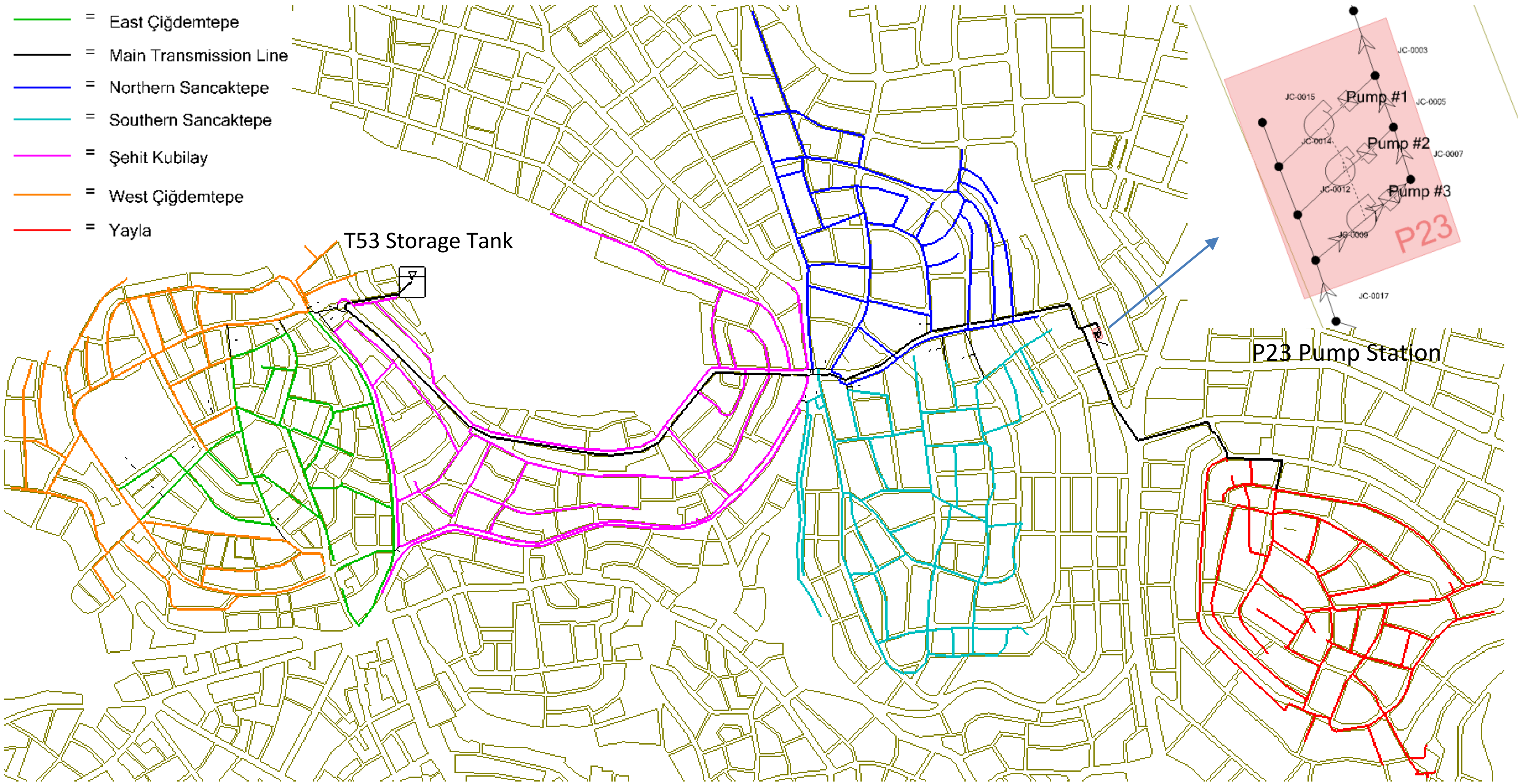
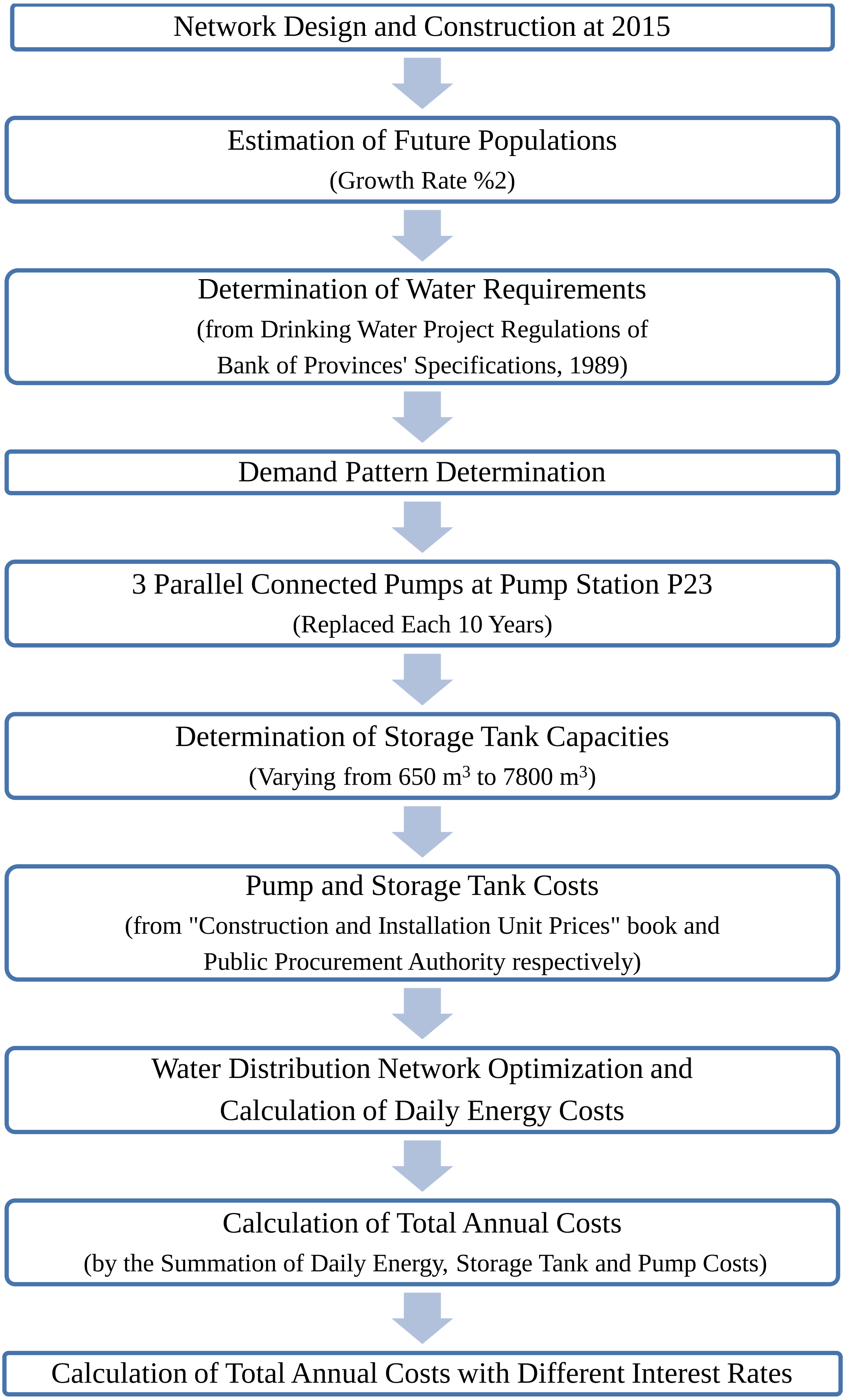


Figure 5.5. Hydraulic Model of N8.3 Water Distribution Network

5.2. Flowchart



5.3. Population Projection

In 2015, the population of the N8.3 area was assumed 25,000. Due to the urban transformation, high residential buildings are constructed in N8.3 area. Also, the area is getting high amount of immigration. Future population of the area must be taken into account in order to estimate future water needs.

Below equation is used for forecasting future populations of the region. The equation was taken from the Drinking Water Project Regulations of Bank of Provinces' Specifications (1989).

$$N_g = N_y * (1 + (c/100)) \wedge (30 + n) \quad \textbf{(5.1)}$$

where,

c: Multiplication Factor (Growth rate is assumed to be 2.00)

N_y: New census (taken as 25000)

n: Time between new census and opening time of the water distribution network

N_g: Future population of the region

“n” value was taken as “0”. Because, the opening time of the network and the new census time are assumed to be equal to each other in this study. Beginning year was taken as 2015. The years were increased to be the multiples of five until the year 2085. The future populations of the N8.3 area are tabulated in Table 5.1.

Table 5.1. Population Projections of N8.3 Region

Estimated Future Populations	
Years	**N_g**
2015	25,000
2020	27,602
2025	30,475
2030	33,647
2035	37,149
2040	41,015
2045	45,284
2050	49,997
2055	55,201
2060	60,946
2065	67,290
2070	74,293
2075	82,026
2080	90,563
2085	99,989

5.4. Water Requirements

In this study, water requirements of the N8.3 region were found according to the Bank of Provinces' (BoP) Specifications, 1989. The water requirements with respect to the populations are shown in Table 5.2.

Table 5.2. Water Requirement Values (Bank of Provinces' Specifications, 1989)

Population	Water Requirements (lt/day/cap)
< 3000	60
3001 - 5000	70
5001 - 10000	80
10001 - 30000	100
30001 - 50000	120
50001 - 100000	170
100001 - 200000	200
200001 - 300000	225

A third order polynomial curve is obtained based on the water requirement values presented on Table 5.2. The water requirements of the N8.3 area was found making use of the equation of the 3rd order polynomial curve (Figure 5.6).

In the previous part, the future populations of the area had been found. According to those populations, annual daily demand values were found. Then, characteristic discharge values were calculated using annual daily demand value. These discharges were computed by following equations.

$$Q_{annual} = \text{Daily Water Need x } N_g \,/\, (24 \text{ x } 60 \text{ x } 60) \quad \textbf{(5.2)}$$

$$Q_{max} = Q_{annual} \text{ x } 1.5 \quad \textbf{(5.3)}$$

where,

Q_{annual}: Annual Daily Demand (lt/s)

Q_{max}: The Average Discharge on the Day of the Highest Amount of the Water Used at the end of the Economic Life (lt/s)

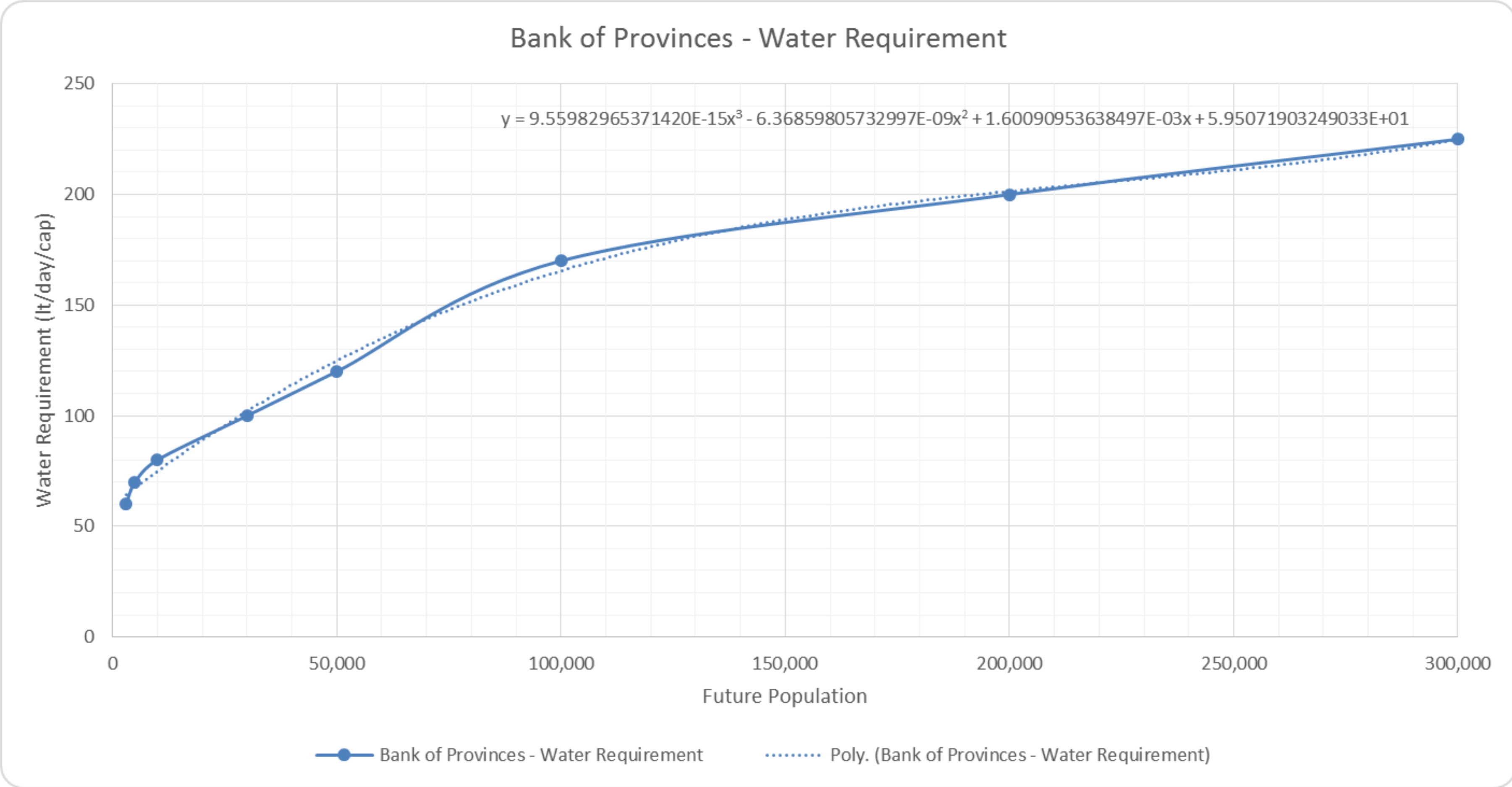


Figure 5.6. Bank of Provinces – Water Requirements Curve and Equation

Table 5.3 shows the water requirements that are used in this study.

Table 5.3. Water Requirements of the N8.3 Pressure Zone

Year	Future Population	Water Requirements (lt/day/cap)	Q_{annual} (lt/s)	Q_{max} (lt/s)	Q_{max} (m^3/h)
2015	25,000	95.699	27.691	41.537	149.533
2020	27,602	99.045	31.642	47.463	170.867
2025	30,475	102.651	36.207	54.311	195.520
2030	33,647	106.527	41.485	62.228	224.021
2035	37,149	110.680	47.588	71.382	256.975
2040	41,015	115.115	54.647	81.971	295.096
2045	45,284	119.831	62.806	94.209	339.152
2050	49,997	124.823	72.232	108.348	390.053
2055	55,201	130.081	83.109	124.664	448.790
2060	60,946	135.585	95.641	143.462	516.463
2065	67,290	141.308	110.053	165.080	594.288
2070	74,293	147.213	126.585	189.878	683.561
2075	82,026	153.250	145.491	218.237	785.653
2080	90,563	159.358	167.036	250.554	901.994
2085	99,989	165.465	191.489	287.234	1,034.042
2095	121,886	177.333	250.167	375.251	1,350.904

5.5. Demand Patterns

The nodal demands change along the day. Demand patterns show that the water requirement multipliers of the junctions for the entire day. In this study, each district metered area has own demand pattern and they were shown in Figure 5.7. The demand patterns were given in the Şendil's (2013) study.

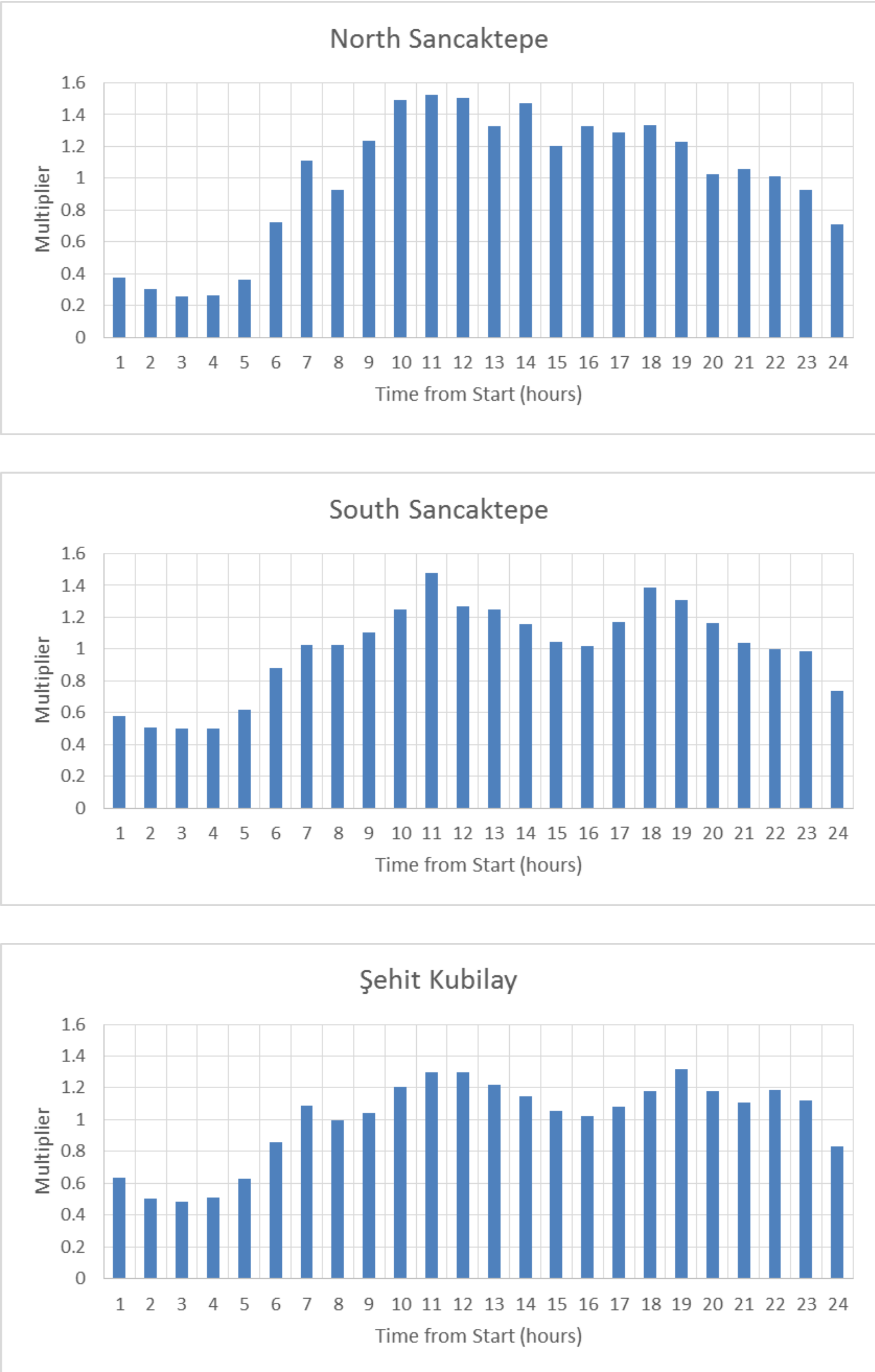


Figure 5.7 (a, b, c). Demand Patterns of N8.3 Zones

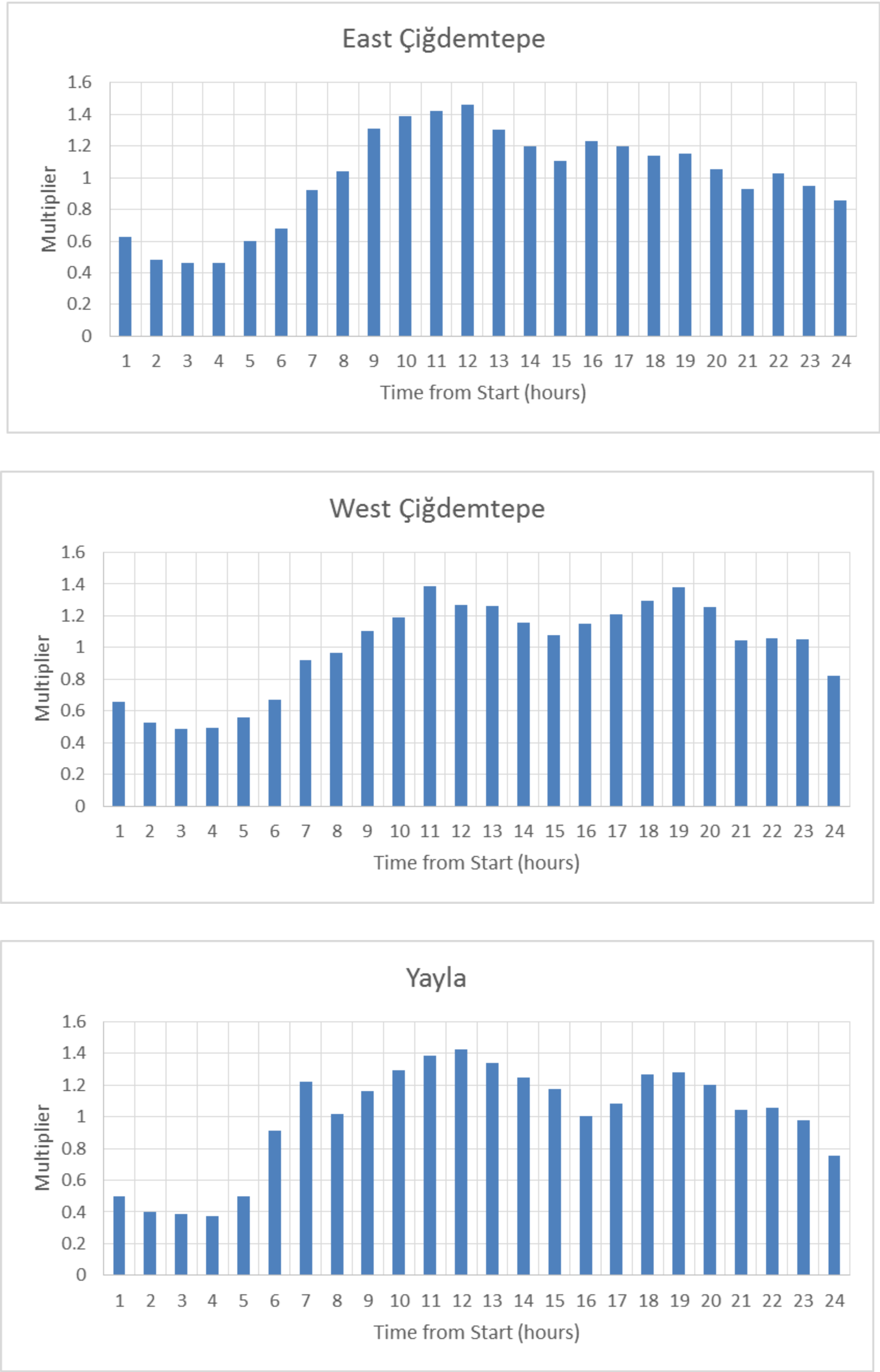


Figure 5.7 (d, e, f). Demand Patterns of N8.3 Zones

5.6. Energy Price

There are two types of energy tariffs. Single tariff has a fixed value during all day. Multi energy tariff changes in different time intervals and has three different values for different times of a day. Multi energy tariffs were used in this study and shown in the Table 5.4.

Table 5.4. Multi Tariff Energy Prices (Şendil, 2013)

Time Interval		**Multi Tariff Energy Price (TL/kWh)**
Day	06:00 - 17:00	0.2336
Peak	17:00 - 22:00	0.3556
Night	22:00 - 06:00	0.1456

5.7. Pumps

In the water distribution networks, the pumps are generally used to deliver water to the higher elevations at required pressure heads. P23 pump station contains three parallel pumps. In this study, these three pumps were selected as identical. In the pump design, the maximum 10 years design discharge was used; according to this discharge, the pump head was calculated. Pump design flows and pump design heads were presented in Table 5.5.

According to the maximum flow value, the pump head was calculated and entered into the hydraulic design software as a “1-point pump”. The pipe diameters of the main transmission line of the hydraulic model (Şendil, 2013) were assumed to be 300 mm. The head loss values are important while selecting pumps of the water distribution network. If the pump head is too low, the pump cannot transmit the water to the requested height.

The pump head was calculated according to Hazen - Williams equation. Calculations are shown below:

$$h_f = \frac{10.68 * L}{D^{4.87} C^{1.85}} * Q^{1.85} \quad \textbf{(5.4)}$$

where,

h_f: Head Loss (m)

C: Pipe Roughness Coefficient, 140

L: Length of Pipe (m), Main Transmission Line Length = 2726.08 m

Q: Discharge (m^3/s), Q_{max} values in Table 5.3.

D: Diameter (m)

Energy Equation

$$H_p = H_s + h_f \quad \textbf{(5.5)}$$

where,

H_p: Pump Head (m)

H_s: Head Difference between T53 Water Storage Tank and “N8.3 Reservoir” (m)

“N8.3 Reservoir” Elevation = 1106.81 m

Water Storage Tank Elevation = 1149.82 m, Tank Height = 6.50 m

Table 5.5. Properties of the Pumps in P23 Pump Station

Pump of the Year	Design Flow (m^3/h)	Design Head (m)
2015 and 2020	195.520	54.519
2025 and 2030	256.975	57.815
2035 and 2040	339.152	63.386
2045 and 2050	448.790	72.808
2055 and 2060	594.288	88.678
2065 and 2070	785.653	115.156
2075 and 2080	1034.042	158.636
2085	1350.904	228.442

Pumps curves are shown in Figure 5.8a, 5.8b, 5.8c, 5.8d, 5.8e, 5.8f, 5.8g, 5.8h.

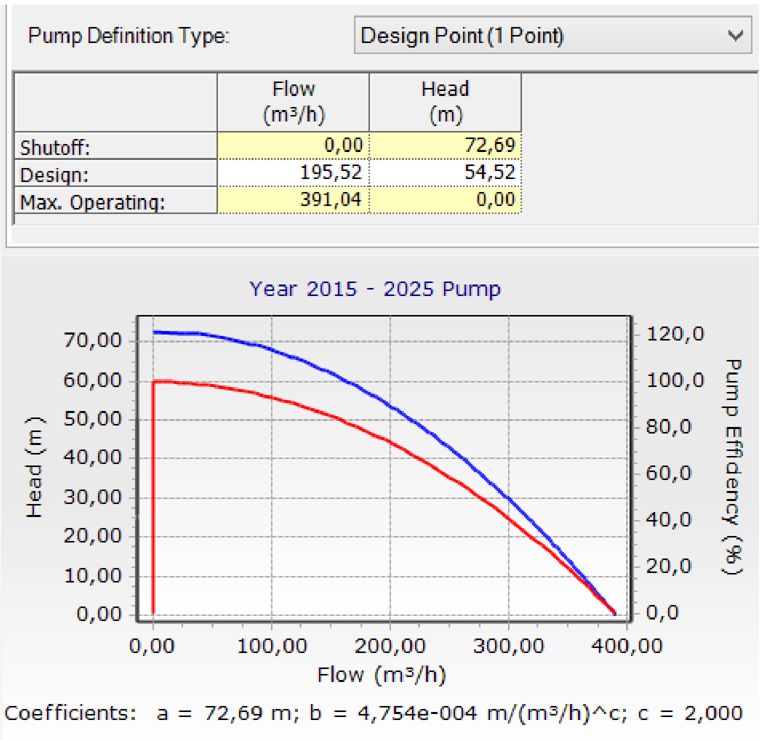


Figure 5.8a. Pump Curve between Years 2015 – 2025

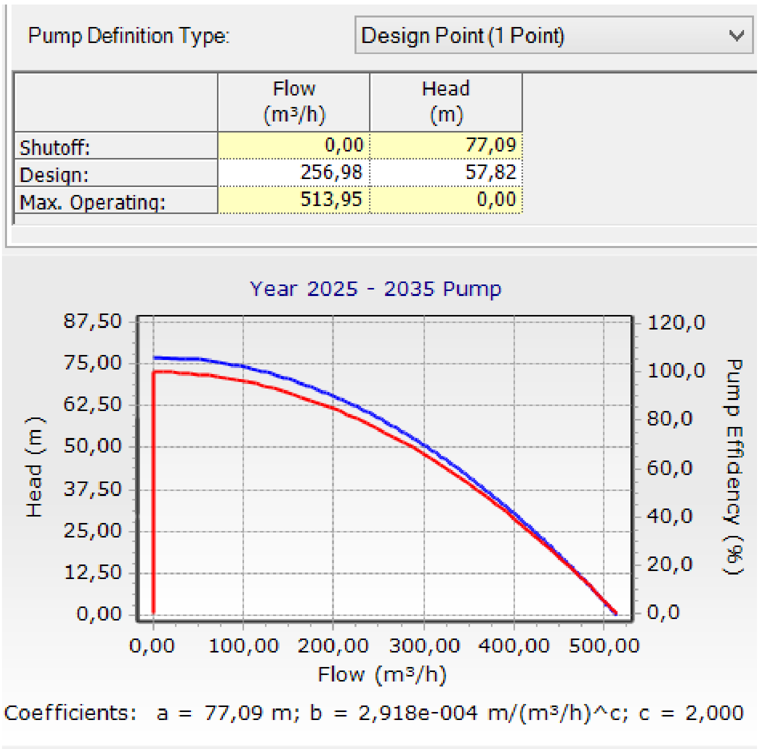


Figure 5.8b. Pump Curve between Years 2025 - 2035

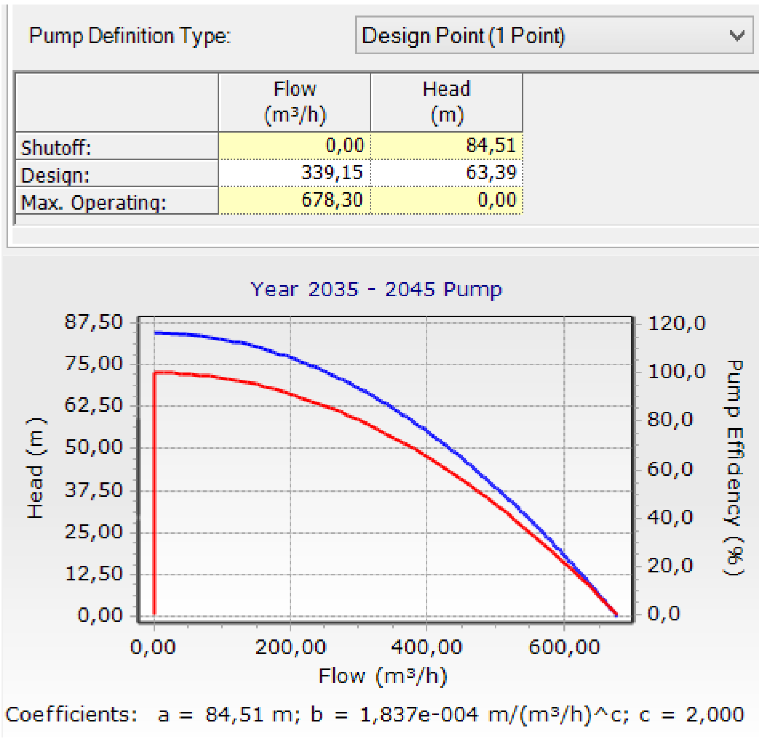


Figure 5.8c. Pump Curve between Years 2035 – 2045

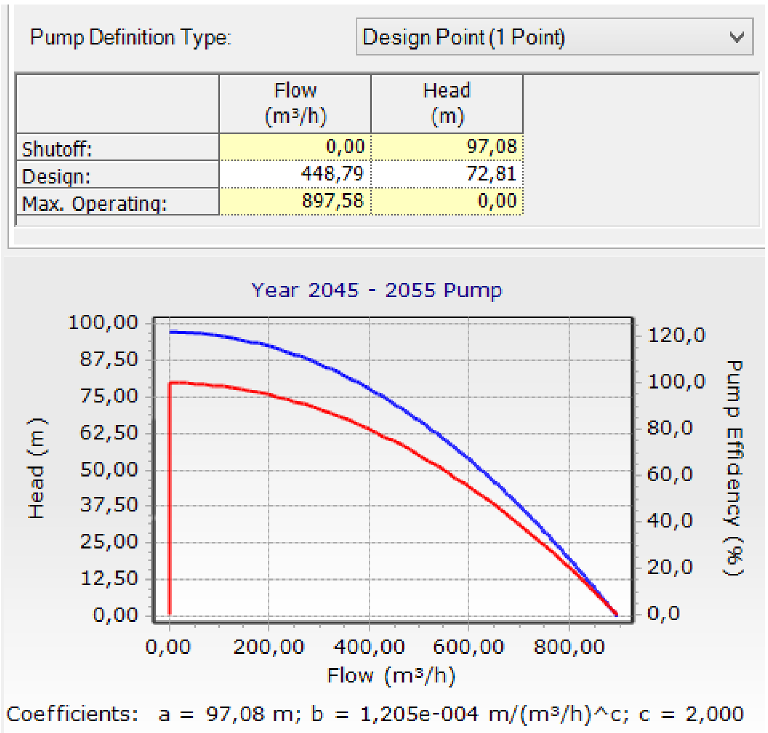


Figure 5.8d. Pump Curve between Years 2045 - 2055

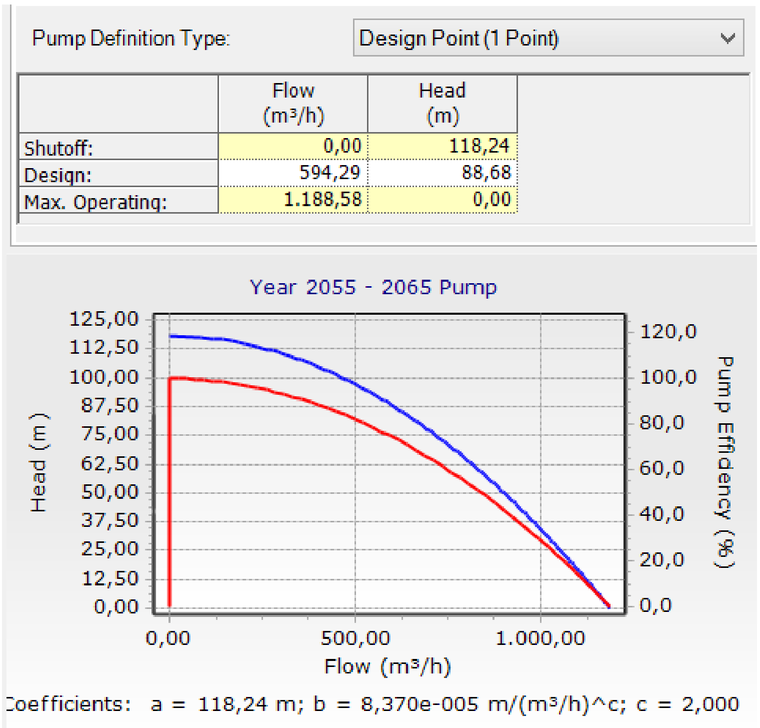


Figure 5.8e. Pump Curve between Years 2055 – 2065

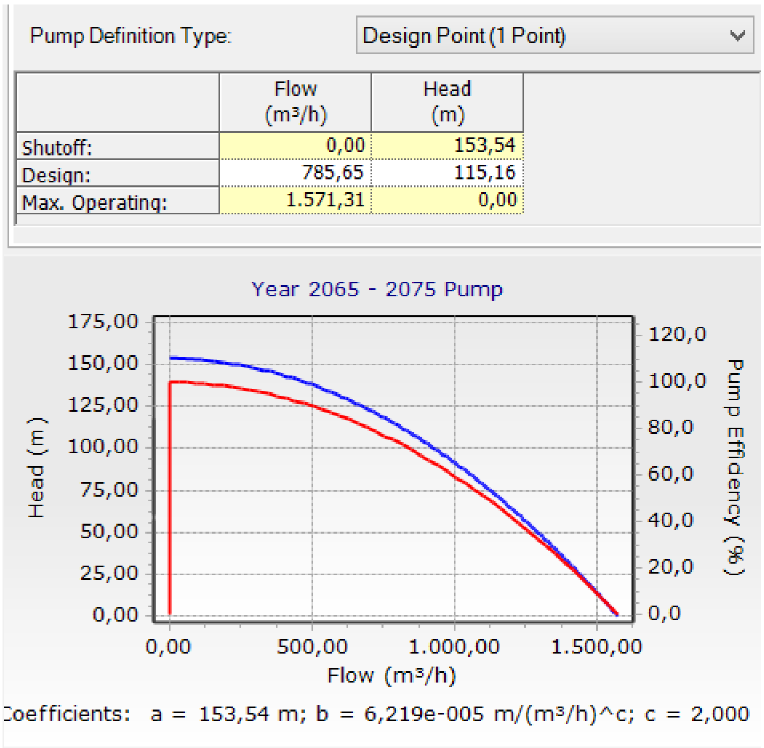


Figure 5.8f. Pump Curve between Years 2065 - 2075

Pump Definition Type: Design Point (1 Point)

	Flow (m³/h)	Head (m)
Shutoff:	0,00	211,51
Design:	1.034,04	158,64
Max. Operating:	2.068,08	0,00

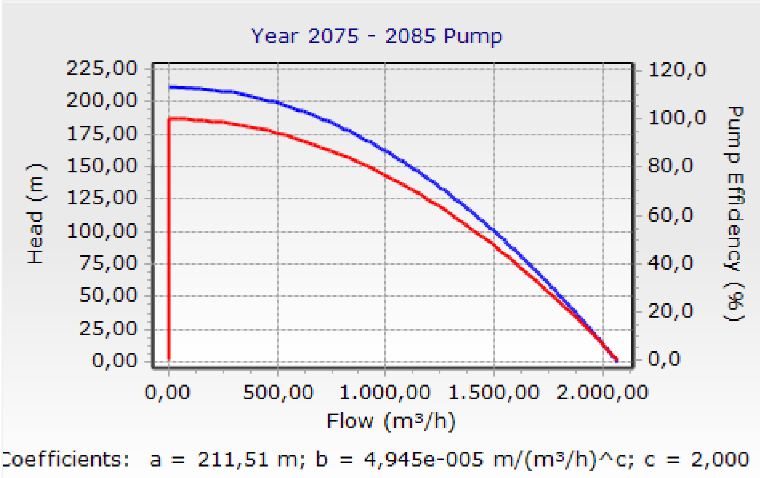


Figure 5.8g. Pump Curve between Years 2075 - 2085

Pump Definition Type: Design Point (1 Point)

	Flow (m³/h)	Head (m)
Shutoff:	0,00	304,59
Design:	1.350,90	228,44
Max. Operating:	2.701,81	0,00

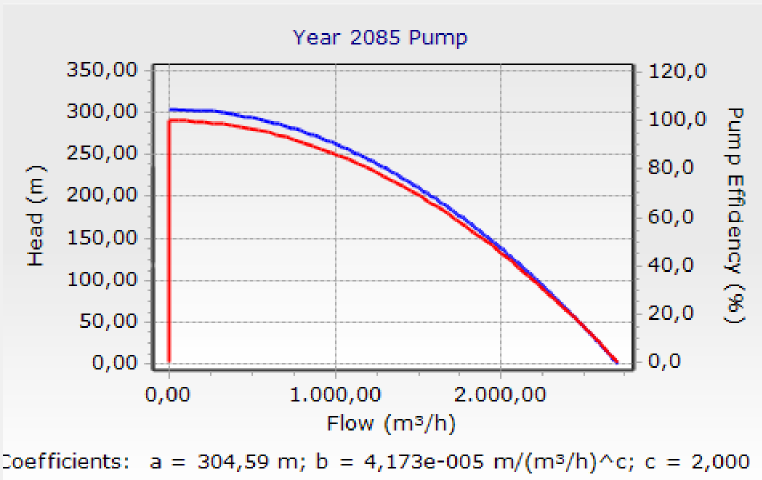


Figure 5.8h. Pump Curve in the year 2085

5.8. Tank Sizes

In the water distribution systems, the water storage tanks are used to store water and to distribute the water to the system when additional water is needed. In N8.3 area, P23 pump station takes water from the "N8.3 reservoir" and distributes to the system and T53 storage tank. T53 storage tank stores water to supply to the system between the required time intervals.

5.8.1. Optimum Tank Size

The optimum size of the water storage tank was selected according to the Bank of Provinces' (BoP) Specifications. The population of the area was estimated as 25,000 in year 2015. Then, the water demand in the year 2015 was calculated from the water requirement equation that was shown in Figure 5.6. Maximum discharge value was found from Equation 5.3. The water requirement calculations are shown in Table 5.6.

Table 5.6. Water Requirement Calculations in Year 2015

(Year 2015 – Population) N_g =	25000

Determination of Water Requirement	
From the Section 5 - 2/A, Q_{annual} = *(lt/day/cap)*	95.699
(making use of general considerations of BoP Specifications)	
People Water Need (lt/s) =	27.691

Determination of Q_{max}	
Q_{max} (lt/s) =	41.537
Q_{max} (m^3/day) =	3588.710

According to the Bank of Provinces' Specifications (Section 6 - 7/A), the tank volume must be ¼ times of maximum daily demand value and the fire volume must be added to the storage tank. The fire volume was taken as 360 m^3 in the calculations. The tank volume was found by the following equation.

$$V_{daily} = \left(\frac{Q_{max}}{4}\right) + \text{Fire Volume} \quad \textbf{(5.6)}$$

where,

V_{daily} = Daily Required Water Volume (m^3/day)

Q_{max} = Maximum Daily Discharge (m^3/day) (Maximum Daily Demand)

The daily-required water volume can be found from Equation 5.6. The volume of the storage tank must be equal to the daily-required water volume. Therefore, the storage tank volume and surface area were calculated as 1300 m^3 and 200 m^2 respectively. The representation of the storage tank was shown in Figure 5.9.

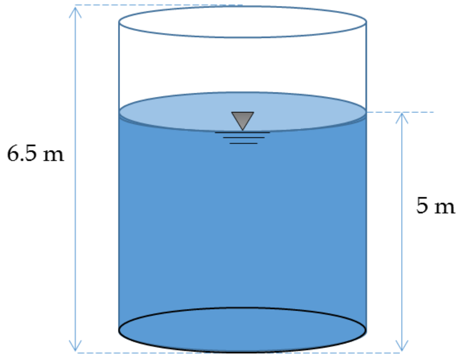


Figure 5.9. Storage Tank Representation

5.8.2. Determined Tank Sizes for Calculations

The major part of this study is the rehabilitation of storage tanks of water distribution networks. T53 storage tank stores water to feed the water distribution network when required. Water storage means that less work of pumps. Because of this, the daily energy cost can be decreased in a larger water storage tank. The tank sizes that used in this study are shown in Table 5.7.

Table 5.7. Determined Tank Sizes

Surface Area (m^2)	Volume (m^3)
100	**650**
200	**1300**
300	**1950**
400	**2600**
600	**3900**
800	**5200**
1000	**6500**
1200	**7800**

5.9. Tank Costs

Water tanks are used for storing clean water and feed the water distribution system when necessary. The material of a water tank can be plastics, fiberglass, concrete, stone or steel. In Turkey, most of the water storage tanks are made of concrete.

In all countries, public administrations need construction works and purchase of goods and services in order to fulfil their missions. Administrations take these services from the outside and public procurement need arises. Planning is the first phase of the public acquisition. Planning phase consists of the determination of needs and finding solution for these needs. After that, the method of procurement is determined and the tender takes place. The final phase of the public procurement covers the contract management.

Public Procurement Authority publishes tender notices in Turkey, in Electronic Public Procurement Platform (EPPP). EPPP is a platform that user can follow public procurements, tenders (government bids), view tender details and download tender documents.

In this study, the tank costs of the water distribution network were determined from the results of tenders about water storage tanks that were made in the year 2014. Contract prices of the tenders for 100 m^3 and 5000 m^3 reinforced concrete water storage tanks are 94,824 TL and 1,438,200 TL respectively. Results of the tenders are shown in the Table 5.8 and Table 5.9 (Electronic Public Procurement Platform, 2014).

Prices of the water storage tanks were found by interpolation between 100 m^3 and 5000 m^3. Also, these costs were added to the annual costs of the water distribution network system. The costs of the water tanks are shown in Table 5.10.

SONUÇ İLANI
NİĞDE-ÇAMARDI / KAVLAKTEPE KÖYÜ 100M3'LÜK BETONARME İÇMESUYU DEPOSU YAPIMI
NİĞDE ÖZEL İDARESİ DESTEK HİZMETLERİ

İhale kayıt numarası	**: 2014/75192**
1- İhalenin	
a) Tarihi	: 21.07.2014
b) Türü	: Yapım işi
c) Usulü	: Açık
d) Yaklaşık Maliyeti	: 106.876,11 TRY
2- İhale konusu yapım işinin	
a) Adı	: NİĞDE-ÇAMARDI / KAVLAKTEPE KÖYÜ 100M3'LÜK BETONARME İÇMESUYU DEPOSU YAPIMI
b) Yapılacağı yer	: Niğde-Çamardı/Kavlaktepe Köyü
c) Süresi	: 120
3- Teklifler	
a) Doküman Satın Alan Sayısı	: 6
b) Dokümanı EKAP üzerinden e-imza kullanarak indiren sayısı	: 4
c) Toplam Teklif Sayısı	: 3
d) Toplam Geçerli Teklif Sayısı	: 3
e) Yerli istekli lehine fiyat avantajı uygulaması	: Uygulanmamıştır
4- Sözleşmenin	
a) Tarihi	: 18.08.2014
b) Bedeli	: 94.824,00 TRY
c) Süresi	: 22.08.2014 - 16.12.2014
d) Yüklenicisi	: KIRLANGIÇ YAPI İNŞAAT İZOLASYON TAŞIMACILIK TİCARET LİMİTED ŞİRKETİ
e) Yüklenicinin uyruğu	: Türkiye

Kamuoyuna saygıyla duyurulur.

Table 5.8. Contract Price of 100 m^3 Reinforced Concrete Water Storage Tank Construction (Electronic Public Procurement Platform, 2014)

SONUÇ İLANI
DEPO YAPTIRILACAKTIR
ALANYA BELEDİYESİ FEN İŞLERİ MÜDÜRLÜĞÜ

İhale kayıt numarası	**: 2014/5473**
1- İhalenin	
a) Tarihi	: 05.02.2014
b) Türü	: Yapım işi
c) Usulü	: Açık
d) Yaklaşık Maliyeti	: 1.428.965,90 TRY
2- İhale konusu yapım işinin	
a) Adı	: 5000 M³ KAPASİTELİ İÇME SUYU DEPOSU YAPILMASI
b) Yapılacağı yer	: T.C.ALANYA BELEDİYESİ
c) Süresi	: 365
3- Teklifler	
a) Doküman Satın Alan Sayısı	: 13
b) Dokümanı EKAP üzerinden e-imza kullanarak indiren sayısı	: 10
c) Toplam Teklif Sayısı	: 8
d) Toplam Geçerli Teklif Sayısı	: 8
e) Yerli istekli lehine fiyat avantajı uygulaması	: Uygulanmamıştır
4- Sözleşmenin	
a) Tarihi	: 12.03.2014
b) Bedeli	: 1.438.200,00 TRY
c) Süresi	: 18.03.2014 - 17.03.2015
d) Yüklenicisi	: SALMAN BETON YAPI MALZ.İNŞ.TAŞ.TAAH.TİC.VE SAN.LTD.Ş
e) Yüklenicinin uyruğu	: Türkiye

Kamuoyuna saygıyla duyurulur.

Table 5.9. Contract Price of 5000 m^3 Reinforced Concrete Water Storage Tank Construction (Electronic Public Procurement Platform, 2014)

Table 5.10. Costs of Water Storage Tanks

Volume (m^3)	Price (TL)
650	245,611
1300	423,814
1950	602,017
2600	780,220
3900	1,136,626
5200	1,493,032
6500	1,849,438
7800	2,205,843

5.10. Pump Costs

Centrifugal pumps are used to convert mechanical energy into hydraulic energy. Pressure head of the water must be increased to carry water from the lower elevations to the higher elevations. A centrifugal pump increases the pressure of the water by its rotating elements that are called as impeller. Prices of the centrifugal pumps vary according to the discharge pressure and pump head.

Unit price is the cost of one unit of measure of a product. In Turkey, Ministry of Environment and Urban Planning publishes “Construction and Installation Unit Prices” book every year. Every construction work has its own analyses and item number in that book. Analyses consist of the required works and prices to make the manufacturing or the construction works. Item number is numbering of these construction works.

In this study, various types of centrifugal pumps are used in the water distribution system. Three pumps were used in the P23 pump station. The costs of these centrifugal pumps were added to the annual costs of the system. While adding the costs of the pumps, the lifetime of the pumps was assumed as 10 years. The cost of the pumps that are used in the year 2015 is found from item number 217.913 in the “Construction and Installation Unit Prices” book (Ministry of Environment and Urbanization, 2014). Costs of other pumps were calculated from the ratio of discharge of the year 2015. The costs of the pumps are shown in Table 5.11.

Table 5.11. Costs of the Centrifugal Pumps (Sum of Three Pumps)

Years	Pumps	Flow (m^3/h)	Head (m)	Price (TL)
2015	Year 2015	195.52	54.519	34,440.00
2020	Year 2015	195.52	54.519	34,440.00
2025	Year 2025	256.975	57.815	45,265.03
2030	Year 2025	256.975	57.815	45,265.03
2035	Year 2035	339.152	63.386	59,740.15
2040	Year 2035	339.152	63.386	59,740.15
2045	Year 2045	448.79	72.808	79,052.41
2050	Year 2045	448.79	72.808	79,052.41
2055	Year 2055	594.288	88.678	104,681.25
2060	Year 2055	594.288	88.678	104,681.25
2065	Year 2065	785.653	115.156	138,389.37
2070	Year 2065	785.653	115.156	138,389.37
2075	Year 2075	1034.042	158.636	182,142.01
2080	Year 2075	1034.042	158.636	182,142.01
2085	Year 2085	1350.904	228.442	237,955.88

5.11. Scenarios

"Scenarios" and "Alternatives" concept were taken from the hydraulic network software WaterCAD (Bentley WaterCAD V8i User's Guide, 2009). Scenarios and alternatives were used in the major part of this study. Scenarios are important for modelling the water distribution networks. Alternatives are building blocks of the scenarios. They are categorized data files that create scenarios when placed together. Alternatives hold the input data for the elements in the water supply system.

Scenarios are composed of alternatives and calculation options, allowing the user to compute and compare the results of various changes to the system. Alternatives can be changed independently within scenarios or can be shared between scenarios. Scenarios allow user to specify alternatives and analyse these alternatives. Calculations can be performed to see the effect of each alternative. For instance, user can change the tank sizes by creating two scenarios (tank size #1 and tank size #2), which consists of alternatives with different tank sizes. Therefore, user can run the system with these tank sizes and compare the results of the scenarios within a single model.

Scenario management gives the user to configure, run, evaluate, visualize and compare various "what if" scenarios within one model. User can easily make decisions by comparing several scenarios, analysing rehabilitation alternatives, or evaluating pump operation strategies.

The model of the water distribution network of this study consists of different tank sizes and different demands. 8 different tank sizes and 15 different demands were used in the model. Water storage tank sizes that were used in this model 650 m^3, 1300 m^3, 1950 m^3, 2600 m^3, 3900 m^3, 5200 m^3, 6500 m^3 and 7800 m^3 respectively. Different nodal demands were assigned to the model every five years between 2015 and 2085. Totally 120 different scenarios were created for this study. The amount of the scenarios can be found from the Equation 5.7.

$$\text{Number of Scenarios} = \text{Number of Years} * \text{Number of Storage Tank Sizes} \qquad \textbf{(5.7)}$$

5.12. Constraints

Constraints are defined to the optimization process in order to meet required hydraulic constraint.

1. Service Elevations = between 1075 – 1115 meters: Water distribution network model designed to service the elevation between 1075 and 1115 meters in the N8.3 pressure zone.
2. Minimum Pressure Constraint = 2.5 bars: The minimum pressure head has to be maintained throughout the water distribution network.
3. Minimum Tank Level = 1.75 meters: The storage tank level cannot be lower than 1.75 meters to supply water to the system in case of fire and emergency situations.
4. Tank Initial and Final Level = 2.5 meters (or higher than 2.5 meters): To maintain the continuity of the software model, initial and final level of the storage tank must be equal or higher than 2.5 meters.
5. Number of Pump Starts (On - Off) Allowed = 3: This constraint is the global maximum number of pump starts allowed and it was selected as 3 in this study.

5.13. Energy Costs

Optimum pump scheduling study was performed in the N8.3 pressure zone. Daily energy costs of the selected scenarios were calculated. Water levels in storage tank T53 and pump flow graphs were obtained by 24 hours period simulation analyses. The results of the optimum pump scheduling runs of the N8.3 area will be presented.

5.13.1. Daily Energy Costs

Year 2015, Tank Volume: 650 m^3

The water demand of the water distribution network for the year 2015 is 149.533 m^3/h. For the minimization of the total energy cost of the water supply system, optimum pump scheduling analysis was performed. The best solution of the optimization was calculated as 166.18 TL, which is the daily energy cost of this scenario. The water demand of the system is low during the night period. For this reason, pumps worked for a short time and filled the tank nearly to the maximum water level limit. As shown in Figure 5.10, the water level at time 03:00 is 4.51 meters. Because of that, pumps are in the off position between time intervals 03:00 and 05:00. Water level in T53 storage tank fluctuates during the 24 hours simulation. The final level of the water decreases to 4.07 meters at the end of the day. Totally, 3746.28 m^3 of water is pumped to the water distribution network in EPS analysis for 24 hours. T53 storage tank stored 157.45 m^3 of water. There is not any violation occurred in that scenario so that 650 m^3 tank size can be used in the year 2015.

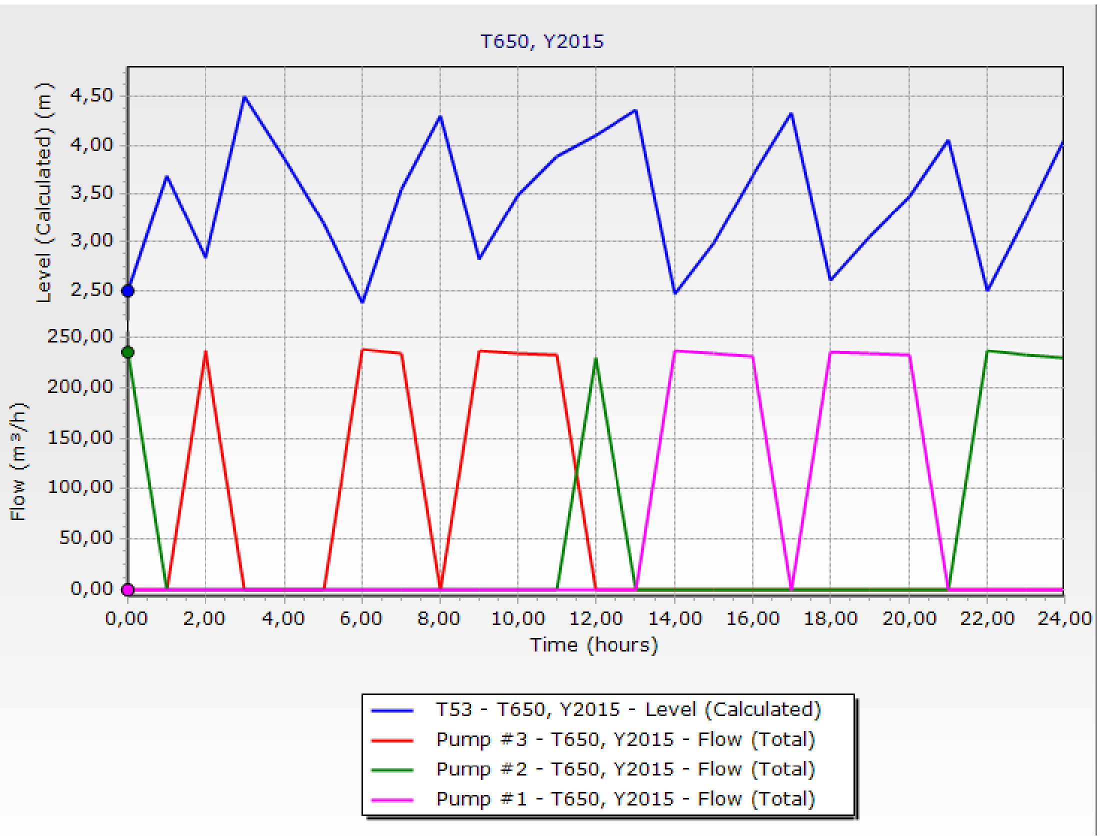


Figure 5.10. T53 Storage Tank Water Level and Pump Flow versus Time Graph – T650, Y2015

Year 2020, Tank Volume: 650 m^3

Water demand in the year 2020 is 170.867 m^3/h. Optimum pump scheduling operation was performed and the daily energy cost was calculated as 191.27 TL. The optimization process tends to fill the storage tank at the night time period so that the water level in storage tank increases at night period. As shown in Figure 5.11, the water level at the T53 storage tank is 4.95 meters at 05:00 and closes to the maximum limit. The water level at the storage tank decreases during the day and peak hours. At the end of the day, the water level is 3.67 meters. In this scenario, 4218.35 m^3 volume of water was pumped through the network and 117.41 m^3 of water was stored in the T53 storage tank. The violation did not exist in this scenario. Therefore, 650 m^3 tank size can be used in the year 2025.

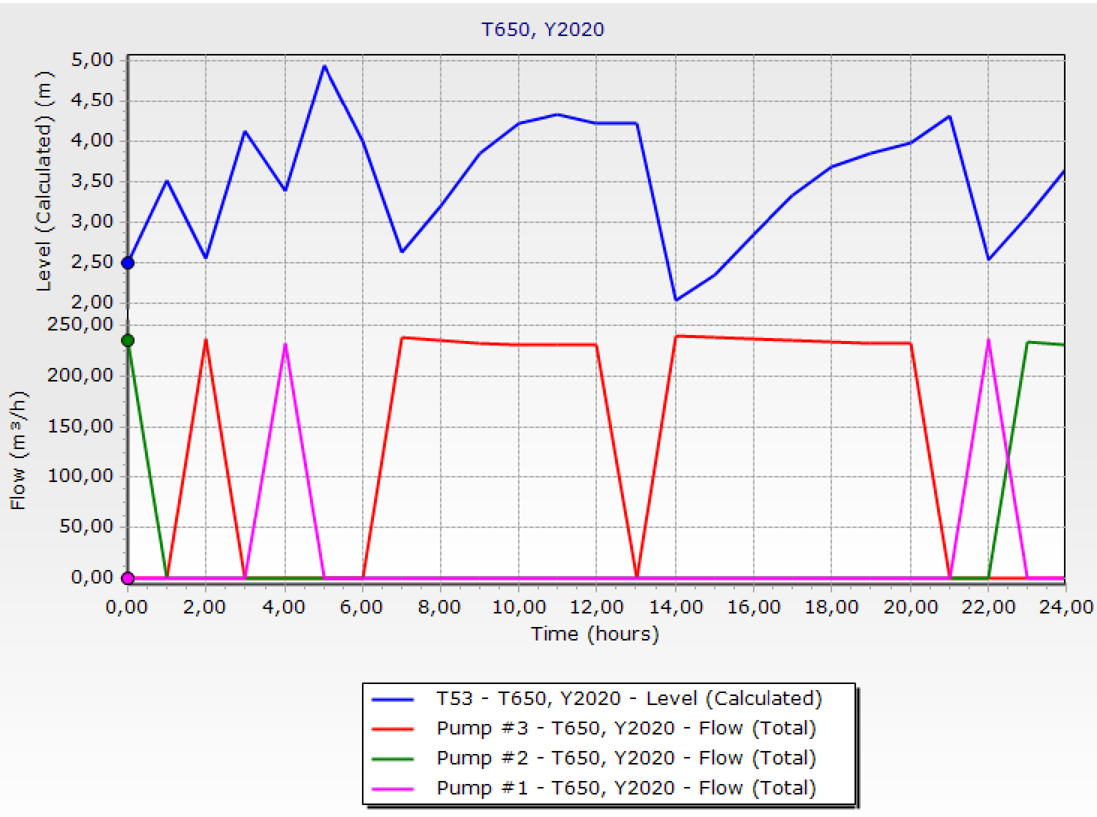


Figure 5.11. T53 Storage Tank Water Level and Pump Flow versus Time Graph – T650, Y2020

Year 2025, Tank Volume: 650 m^3

In year 2025, the water demand of the water distribution network is 195.52 m^3/h. In a result of the optimization process, the daily energy cost was calculated as 240.80 TL. T53 storage tank is filled by the pumps when the water level in the storage tank decreases during day and peak periods. As shown in Figure 5.12, the storage tank reaches to the maximum 5.00 meters water limit three times, so that violation is occurred in this scenario hence the penalty is applied. This means that this scenario failed to meet the requirements of the water distribution network. 4828.84 m^3 of water is pumped to the network and 136.26 m^3 of water stored in the T53 storage tank. The storage tank must be changed with a larger one so that the storage tank can store more water and pumps can work more efficiently. If the N8.3 area continues to use 650 m^3 volume tank, there will be technical problems such as pump corruption or tank overflow.

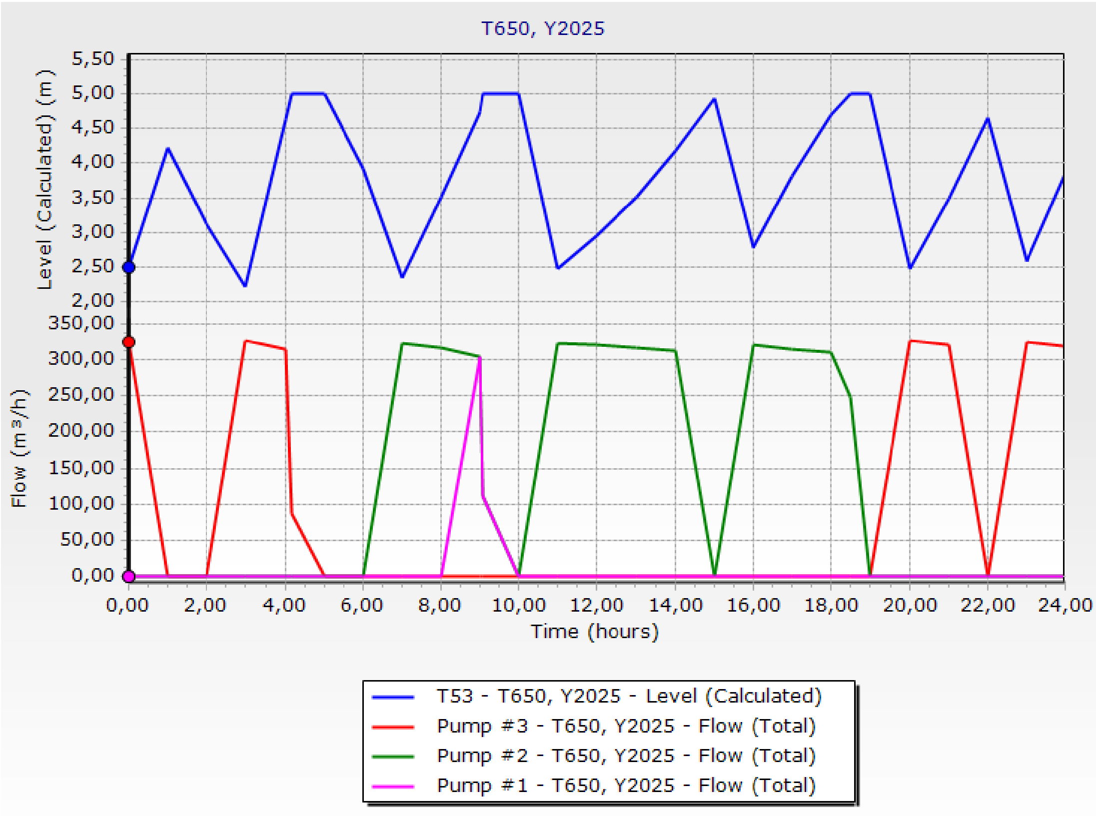


Figure 5.12. T53 Storage Tank Water Level and Pump Flow versus Time Graph – T650, Y2025

Year 2025, Tank Volume: 1300 m^3

Water demand is the same as the value in the previous scenario. Optimum pump scheduling analysis was performed and daily energy cost of the system was determined as 219.42 TL. Between the lowest cost intervals, the pumps are working to fill the T53 storage tank. Water level in T53 storage tank fluctuates during the 24 hours simulation and the final level of the water is 4.70 meters that is higher than the minimum water limit. Total amount of pumped water is 5133.49 m^3 and the stored water amount in T53 storage tank is 440.95 m^3 for 24 hours period. Violation did not occur in the optimization process. As shown in the Figure 5.13, there is not any tank overflow situation. Because of these, in 2025, 1300 m^3 water storage tank can be used.

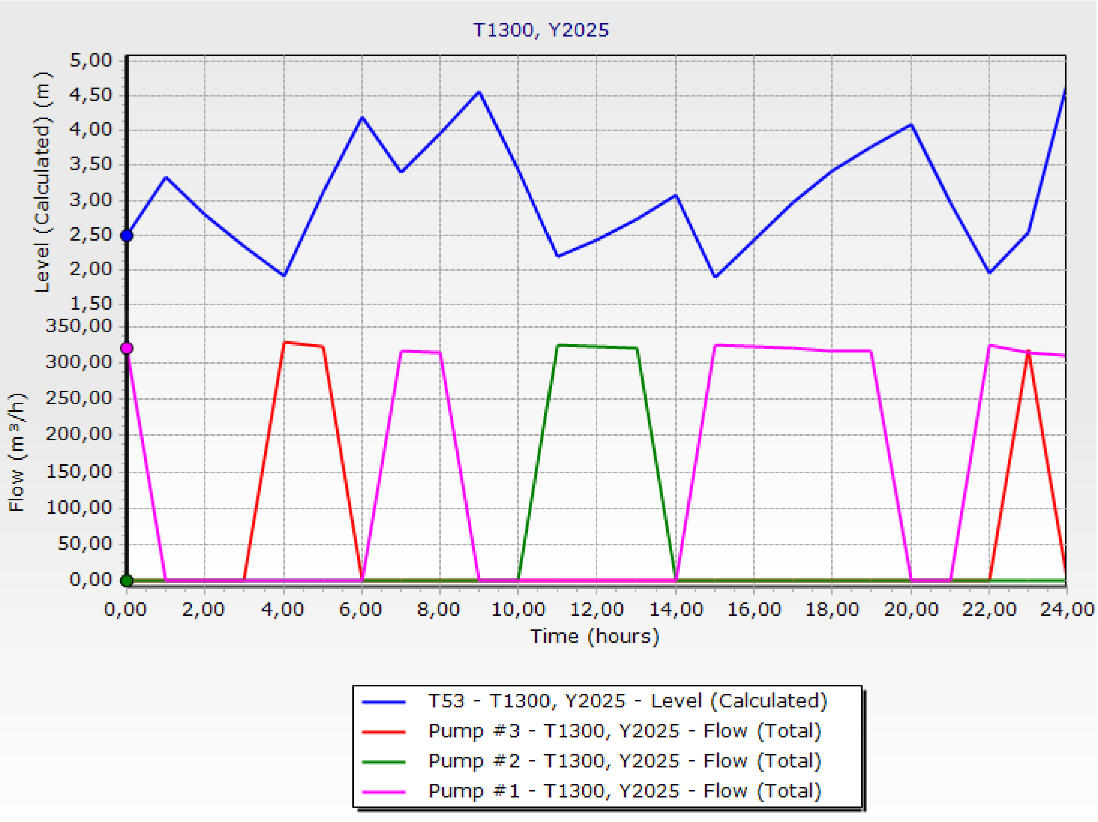


Figure 5.13. T53 Storage Tank Water Level and Pump Flow versus Time Graph – T1300, Y2025

Year 2030, Tank Volume: 1300 m^3

224.021 m^3/h of water must be distributed in the year 2030 in order to fulfil the requirements of the water supply system. Optimum pump schedule in P23 pump station was determined and the best solution between three alternatives was calculated as 252.55 TL. As indicated in the Figure 5.14, pumps provide water until the storage tank reaches nearly 5 meters maximum limit. At the beginning, the tank level is 2.5 meters as an initial constraint and after the optimization process and 24 hours period simulation the final water level at the T53 storage tank is 4.29 meters. For 24 hours simulation analysis, pumps are provided 5735.12 m^3 water to the water supply system and 358.62 m^3 of water stored in T53 storage tank. The storage tank works efficiently in this scenario and no penalty is applied to the storage tank. Therefore, 1300 m^3 water storage tank can still be used in the year 2030.

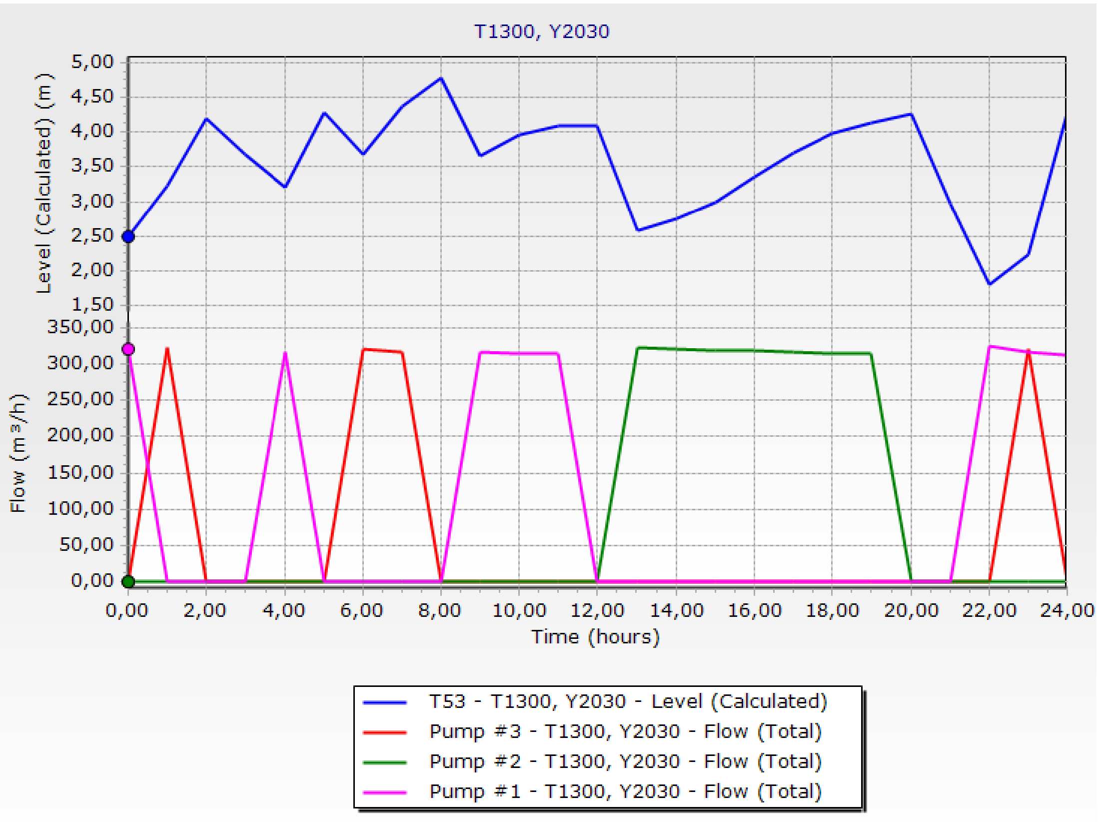


Figure 5.14. T53 Storage Tank Water Level and Pump Flow versus Time Graph – T1300, Y2030

Year 2035, Tank Volume: 1300 m^3

Water demand in the year 2035 is 256.975 m^3/h. Optimum pump scheduling analysis was performed and the best solution generated as 322.45 TL. Totally, 6567.59 m^3 of water is pumped and 481.52 m^3 of water stored in the storage tank. The water level in the storage tank begins with 2.5 meters and ends with 4.91 meters. Pumps cannot be able to work continuously at the lowest price intervals that are between 22:00 and 06:00. Therefore, pumps are forced to work in peak time intervals and this will be an extra cost for the water distribution network. The most important point of this scenario occurs at the time 04:53. The water level of the storage tank reaches the maximum limit 5 meters until 05:00 as shown in Figure 5.15. Violation is occurred in the optimization process of this scenario so that the storage tank must be changed with a larger one.

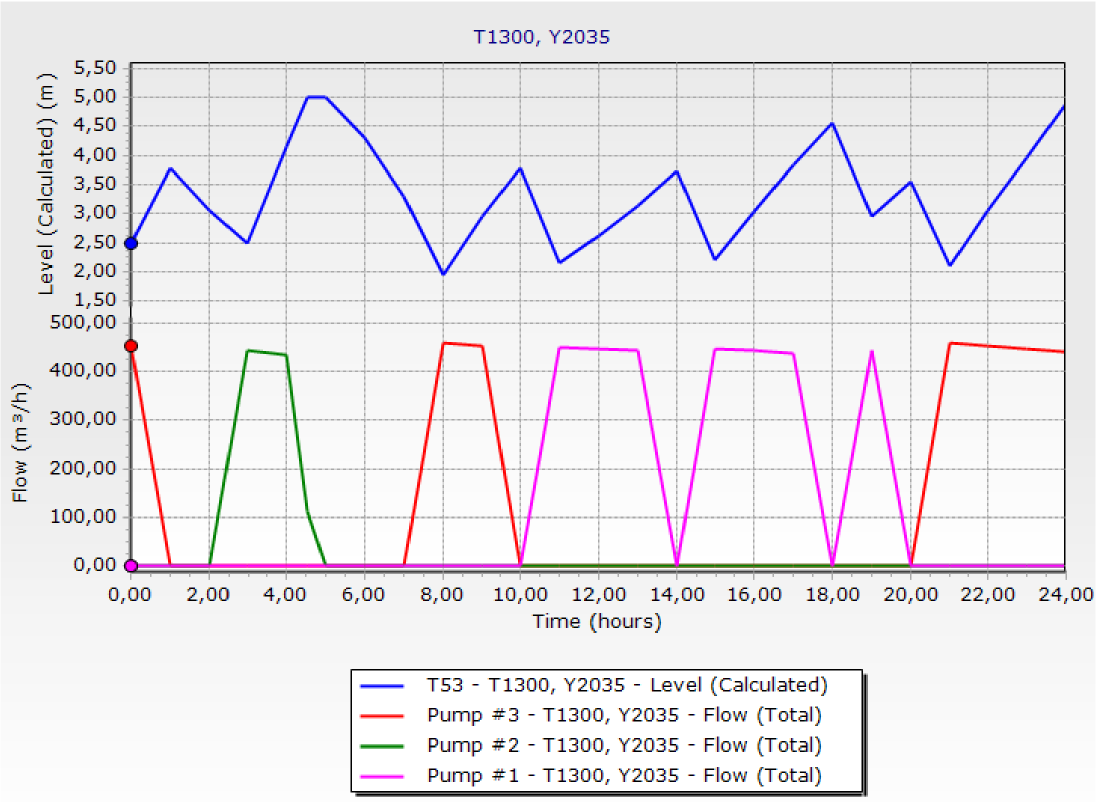


Figure 5.15. T53 Storage Tank Water Level and Pump Flow versus Time Graph – T1300, Y2035

Year 2035, Tank Volume: 1950 m^3

Storage tank size was not sufficient in the previous scenario. The tank size is selected as 1950 m^3 for this scenario in the year 2035. The daily energy cost of the network was calculated as 320.29 TL for 24 hours period by the optimization process. Storage tank was filled by the pumps when the water level in the storage tank decreases during day and peak periods of the day. During the night period, the water demand of the system is low. For this reason, pumps worked for a short time and filled the tank nearly to the maximum water level limit. As shown in Figure 5.16, the water level at time 01:00 is 4.70 meters. Total amount of pumped water is 6643.14 m^3 and the stored water amount in T53 storage tank is 557.08 m^3 for 24 hours period. This storage tank can be used in the year 2035.

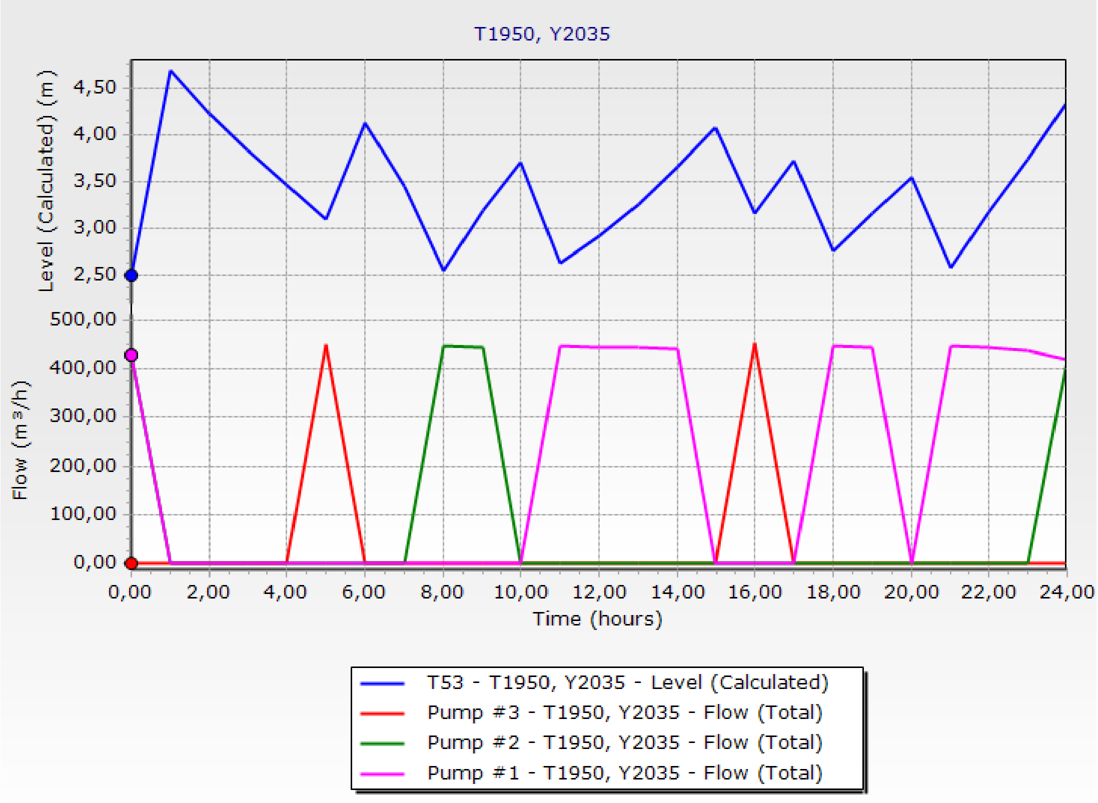


Figure 5.16. T53 Storage Tank Water Level and Pump Flow versus Time Graph – T1950, Y2035

Year 2040, Tank Volume: 1950 m^3

The water demand of the network is 295.096 m^3/h in the year 2040. The best solution of the optimization was calculated as 372.91 TL that is the daily energy cost of this scenario. The water level of the storage tank starts the day with 2.5 meters as previously defined and ends the day with 4.02 meters as shown in Figure 5.17. The level in the tank reaches 4.77 and 4.97 meters at the time 18:00 and 19:00 respectively. 7538.60 m^3 of water is pumped to the water distribution network and 456.26 m^3 of water stored in the T53 storage tank. In this scenario, the violation does not occur but T53 storage tank can be insufficient in the coming years.

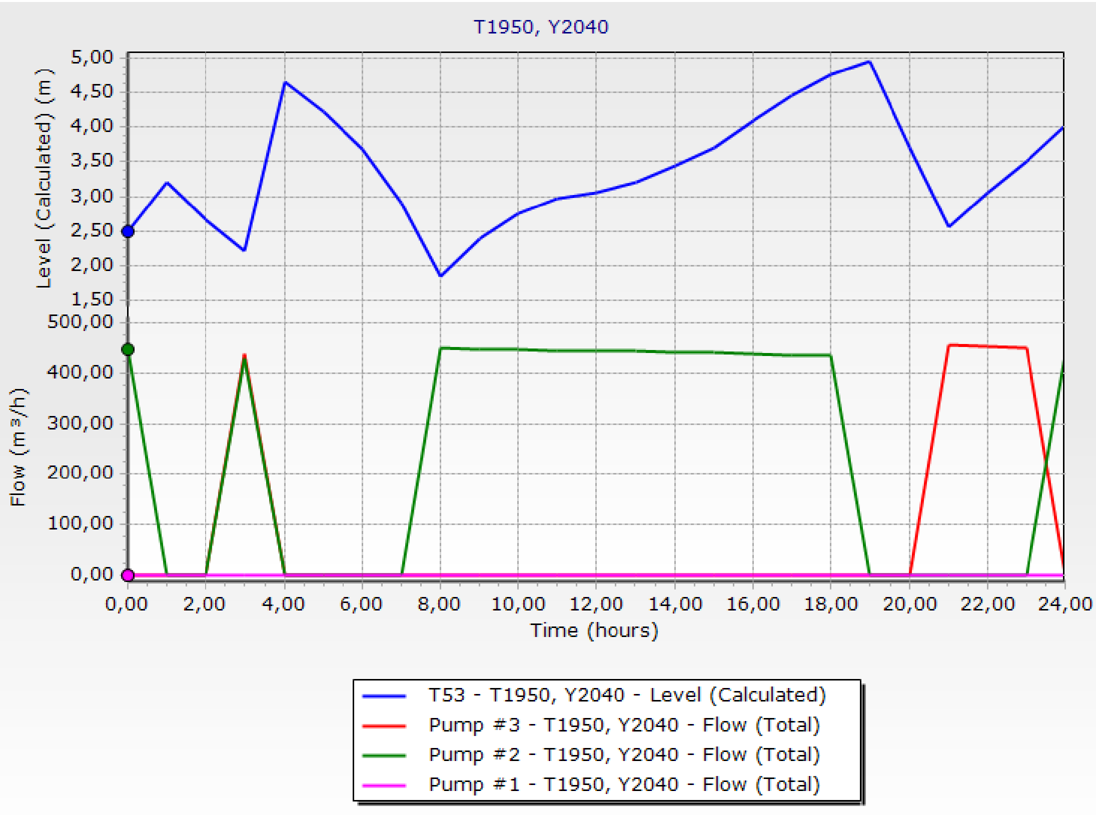


Figure 5.17. T53 Storage Tank Water Level and Pump Flow versus Time Graph – T1950, Y2040

Year 2045, Tank Volume: 1950 m^3

Water demand in the year 2045 is 339.152 m^3/h. Optimum pump scheduling operation was performed and the daily energy cost was calculated as 498.52 TL. Figure 5.18 shows that, the water level of the T53 storage tank is 2.5 meters at the beginning and 4.73 meters at the end of the 24 hours period. At the time 01:92, the T53 storage tank reaches the maximum limit until the time 02:00 as shown in Figure 5.18. The pumps are stopped working when the storage tank reaches the highest water level and cannot store water in low price period of the day. Total amount of pumped water is 8702.58 m^3 and the stored water amount in T53 storage tank is 670.20 m^3 for 24 hours period. Penalty cost is applied to this scenario because of the storage tank final level constraint violation. The storage tank must be changed with a larger one so that the storage tank can store more water.

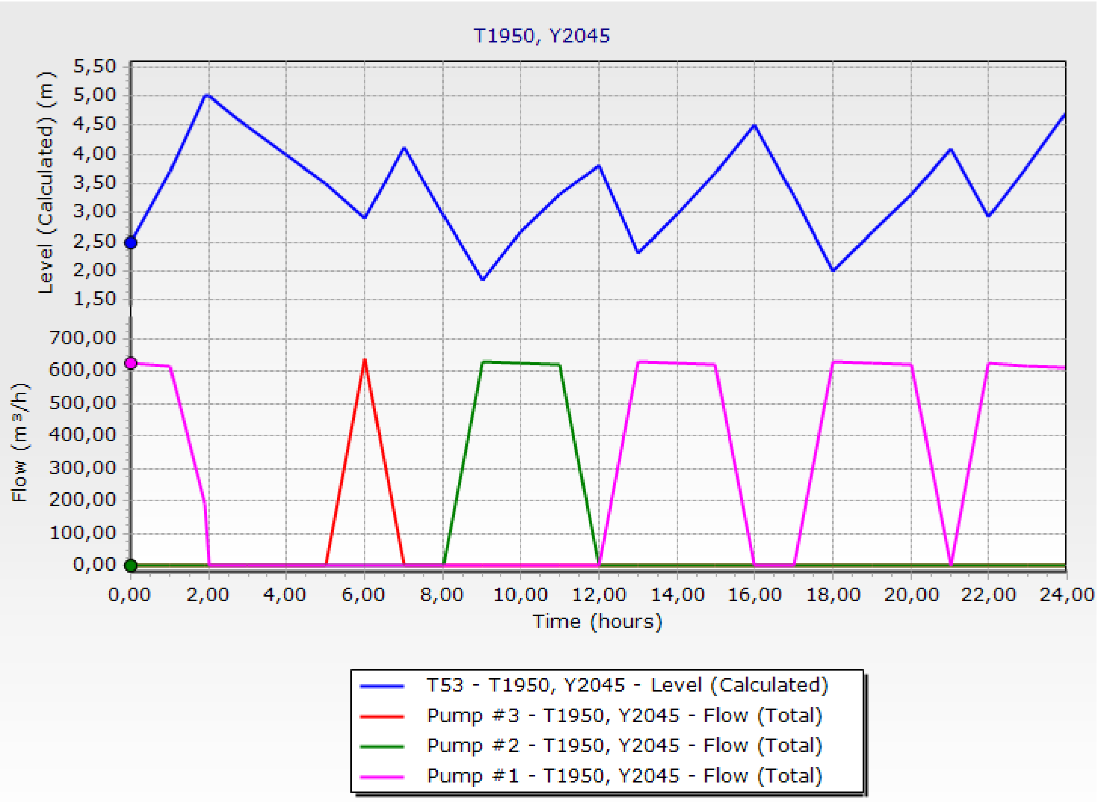


Figure 5.18. T53 Storage Tank Water Level and Pump Flow versus Time Graph – T1950, Y2045

Year 2045, Tank Volume: 2600 m^3

The storage tank was replaced with the larger one that has 2600 m^3 volume to store more water in lowest price periods of the day. Optimum pump scheduling operation was performed and the daily energy cost is calculated as 479.78 TL. The water level in the storage tank begins with 2.5 meters and ends with 4.27 meters. At the time 15:00, the water level in the storage tank is 4.91 meters, nearly the maximum limit. Totally, 8739.77 m^3 of water is pumped and 707.41 m^3 of water stored in the storage tank. There is not any violence occurred for this scenario. However, the storage tank will be insufficient in the following years as shown in Figure 5.19.

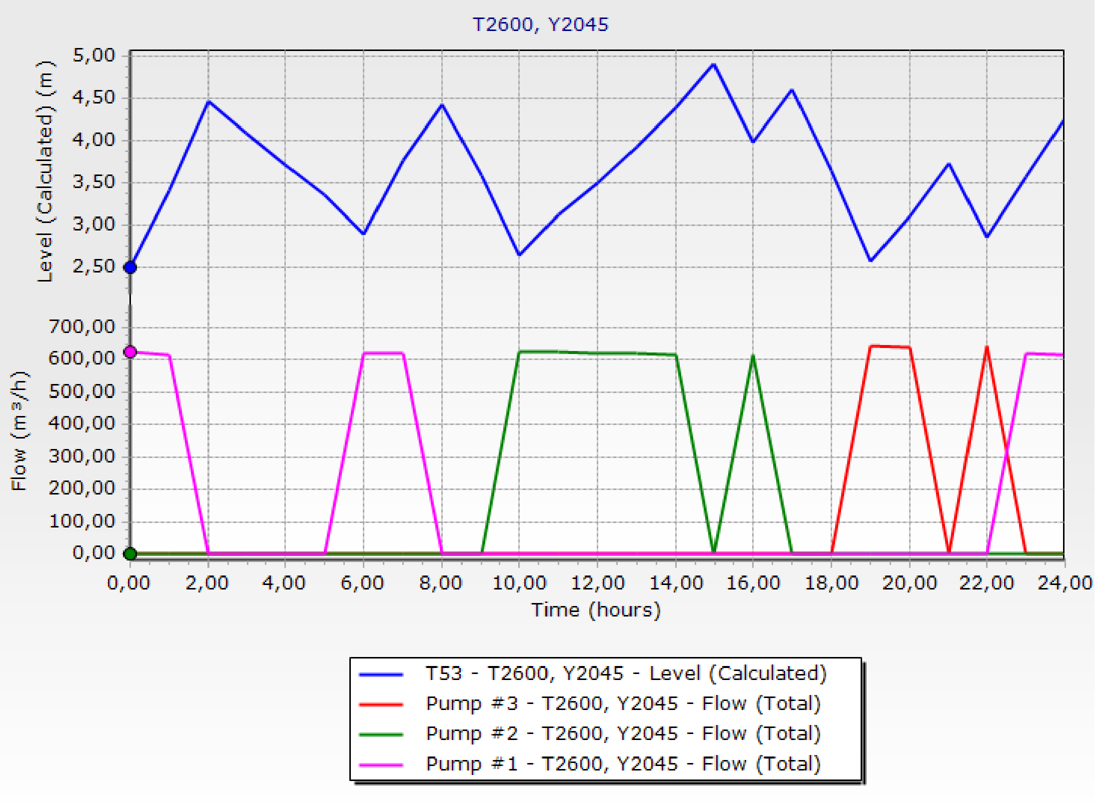


Figure 5.19. T53 Storage Tank Water Level and Pump Flow versus Time Graph – T2600, Y2045

Year 2050, Tank Volume: 2600 m^3

In year 2050, the water demand of the water distribution network is 390.053 m^3/h. Optimum pump scheduling analysis was performed and the best solution generated as 567.54 TL. T53 storage tank takes water from the pump #1 between the time intervals 21:00 and 02:00 as indicated in Figure 5.20. At the time 02:00, the water level of the storage tank reaches 4.29 meters. Because of this, pump #1 stops working until 04:00. The water level of the storage tank ends the day with 4.13 meters. Total amount of pumped water is 10014.85 m^3 and the stored water amount in T53 storage tank is 653.30 m^3 for 24 hours period. Violence was not occurred for this scenario so that T53 storage tank can be used in the year 2050.

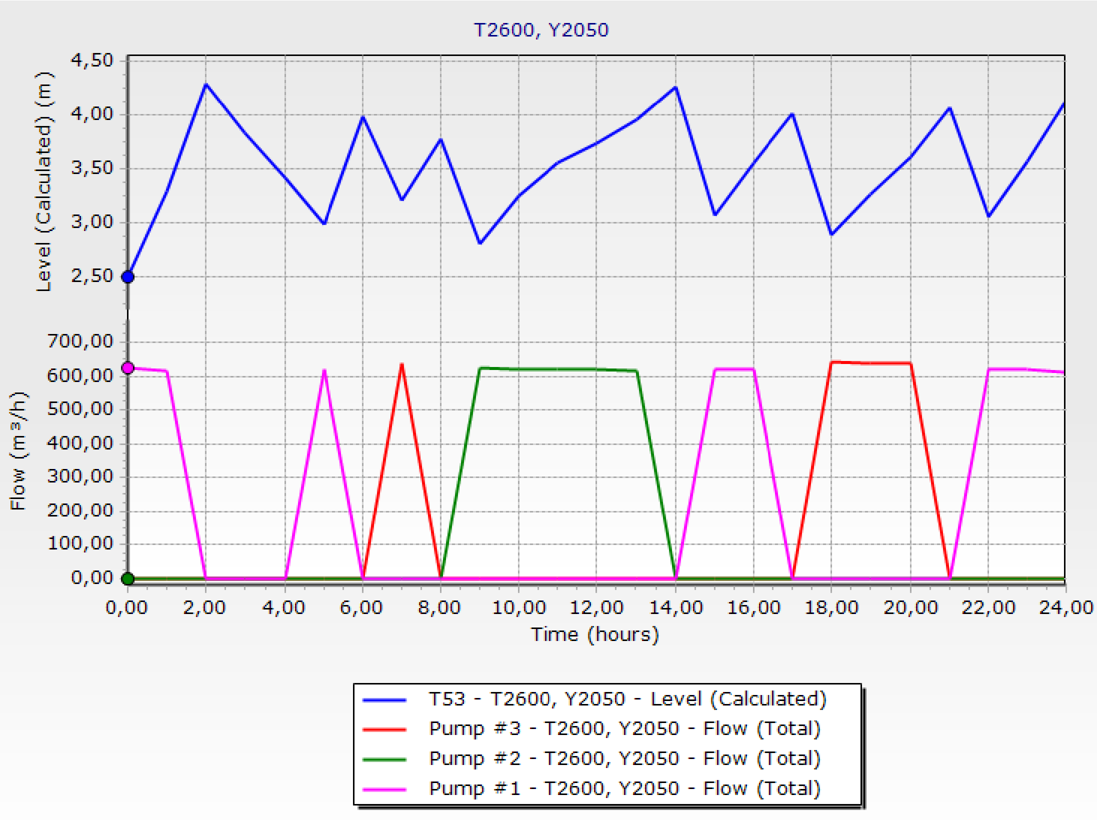


Figure 5.20. T53 Storage Tank Water Level and Pump Flow versus Time Graph – T2600, Y2050

Year 2055, Tank Volume: 2600 m^3

The water demand of the network is 448.79 m^3/h in the year 2055. The best solution of the optimization was calculated as 773.29 TL that is the daily energy cost of this scenario. As shown in Figure 5.21, the water level of the storage tank reaches to a maximum limit between the time intervals 12:00 and 13:00. Thus, pumps stop between these time intervals. The water cannot be pumped efficiently in the night time period because water level of the storage tank reaches to maximum 5 meters again at the time 02:00. Hence, the violation occurred and the optimization process applied penalty to this scenario. The 2600 m^3 storage tank becomes inadequate in the year 2055. Total amount of pumped water is 11314.01 m^3 and the stored water amount in T53 storage tank is 685.41 m^3 for 24 hours period.

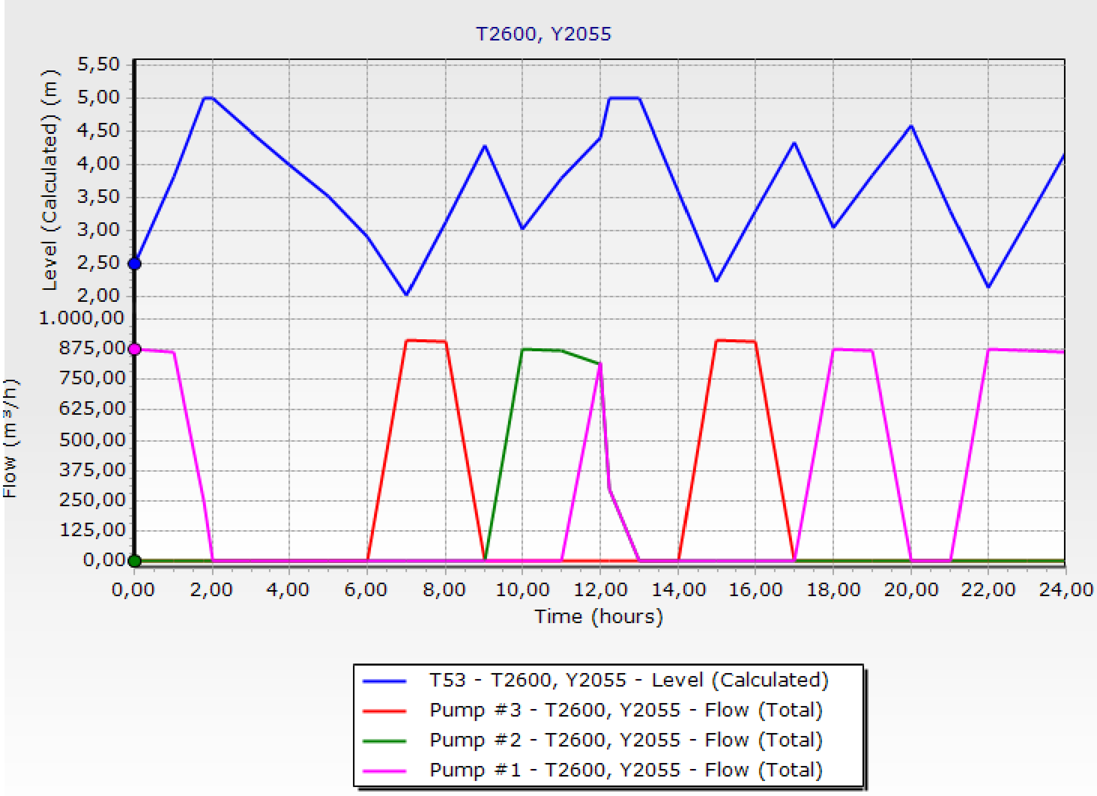


Figure 5.21. T53 Storage Tank Water Level and Pump Flow versus Time Graph – T2600, Y2055

Year 2055, Tank Volume: 3900 m^3

In the previous scenario, the T53 storage tank was insufficient so that a larger one was used in this scenario. Optimum pump schedule in P23 pump station was determined and the best solution between three alternatives was calculated as 746.64 TL. As indicated in Figure 5.22. The water level of the storage tank reaches maximum 4.5 meters in this scenario. In the lowest cost period of the day, the pumps provide water to the storage tanks until the 4.5 meters. 11427.85 m^3 of water is pumped to the water distribution network and 799.16 m^3 of water stored in the T53 storage tank. The violation does not occur in this scenario so that 3900 m^3 storage tank can be used in this year.

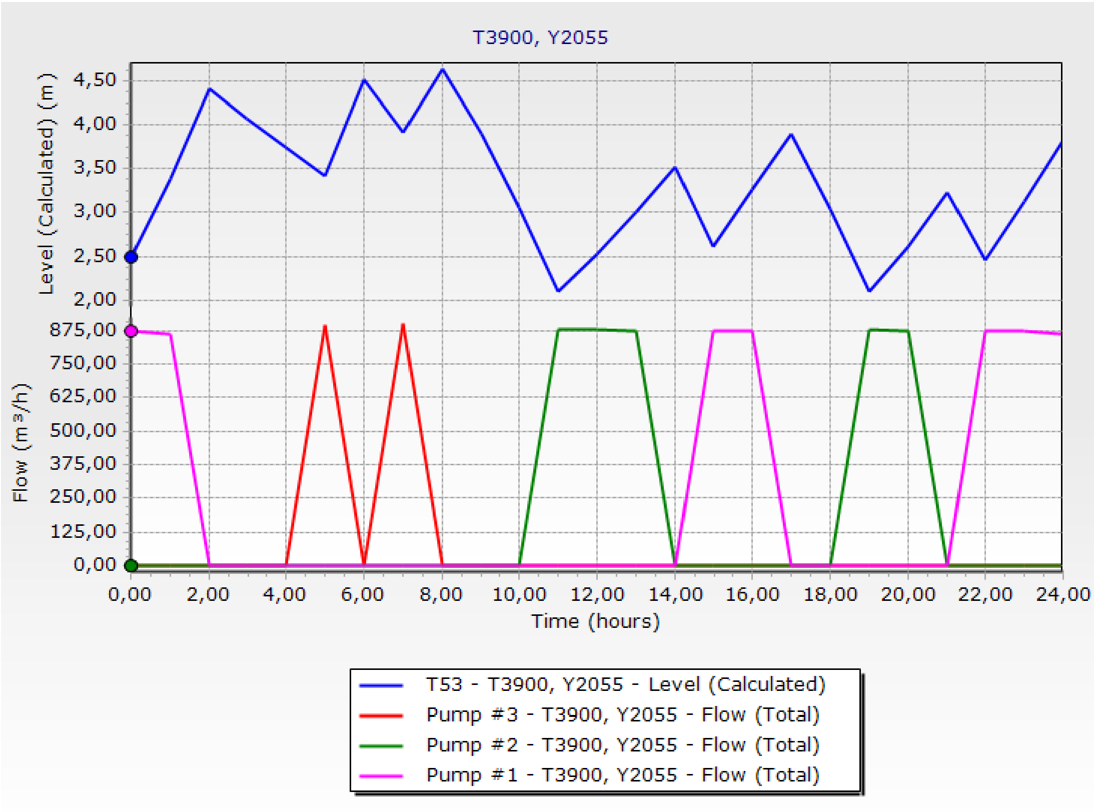


Figure 5.22. T53 Storage Tank Water Level and Pump Flow versus Time Graph – T3900, Y2055

Year 2060, Tank Volume: 3900 m^3

The water demand of the network is 516.463 m^3/h in the year 2060. The Optimum pump scheduling operation was performed and the daily energy cost is calculated as 877.89 TL. The pump #2 works between the time intervals 21:00 and 01:00; and the pump #3 works between the time intervals 02:00 and 05:00 during the night time period. The water level of the storage tank reaches 4.64 meters at the time 05:00. The water level decreases to 1.79 meters at the time 13:00. Because of this, pumps begin to work once again until the time 17:00. At that time, the water level reaches 4.99 meters that is too close to the maximum water level limit 5.00 meters as shown in Figure 5.23. At the end of the day, the water level is 3.94 meters. There is not any violence occurred for this scenario but easy to estimate that the storage tank will be insufficient in the following years. Totally, 13258.25 m^3 of water is pumped and 862.70 m^3 of water stored in the storage tank.

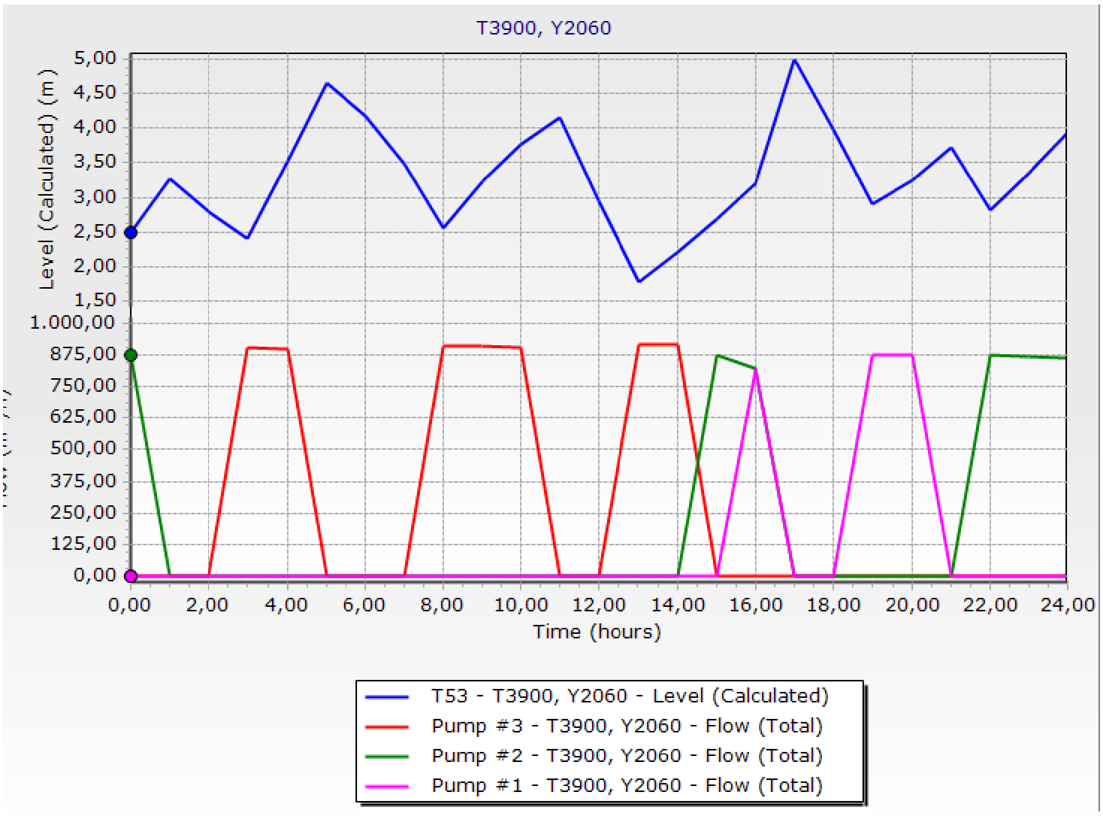


Figure 5.23. T53 Storage Tank Water Level and Pump Flow versus Time Graph – T3900, Y2060

Year 2065, Tank Volume: 3900 m^3

The pumps are changed to provide necessary amount water to the system in this year. In year 2065, the total water demand of the water distribution network is 594.288 m^3/h. Pump scheduling optimization was performed and the daily energy cost is calculated as 1422.99 TL. Water level in T53 storage tank fluctuates during the 24 hours simulation and the final level of the water is 3.76 meters that is higher than the minimum water limit 2.5 meters. At the time 09:00, the water level of the storage tank reaches 4.91 meters and because of that pump #2 stops to feed the water distribution network as shown in Figure 5.24. 14829.15 m^3 of water is pumped to the water distribution network and 754.38 m^3 of water stored in the T53 storage tank.

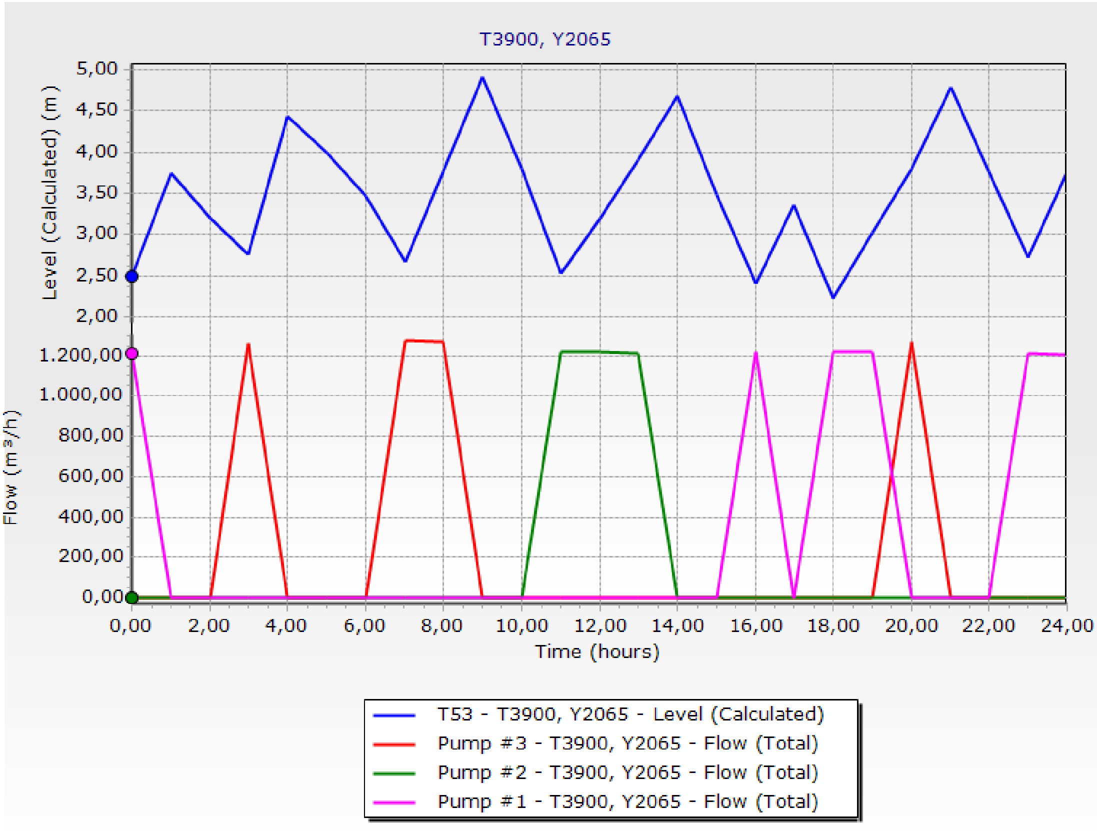


Figure 5.24. T53 Storage Tank Water Level and Pump Flow versus Time Graph – T3900, Y2065

Year 2070, Tank Volume: 3900 m^3

683.561 m^3/h of water must be distributed in the year 2070 in order to fulfil the requirements of the water supply system. The daily energy cost of the network was calculated as 1520.93 TL for 24 hours period by optimization process. The pump #2 provides water to the network between the time intervals 21:00 and 02:00 as shown in Figure 5.25. At the time 02:00 and 05:00, the water levels of the storage tank are 4.99 and 5.00 meters respectively. The storage tank reaches the maximum 5.00 meters water limit so that violation is occurred in this scenario. 17123.01 m^3 of water is pumped to the water distribution network and 717.32 m^3 of water stored in the T53 storage tank. The storage tank must be changed with a larger one so that the storage tank can store more water and pumps can work more efficiently.

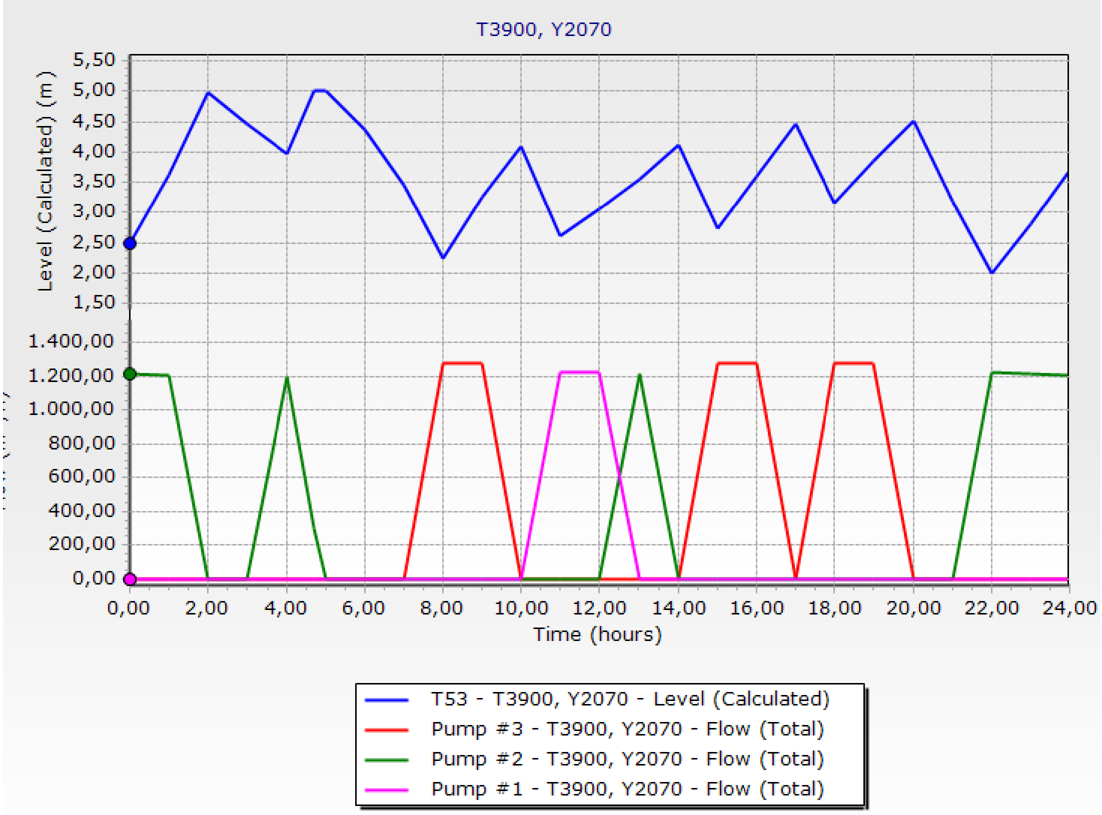


Figure 5.25. T53 Storage Tank Water Level and Pump Flow versus Time Graph – T3900, Y2070

Year 2070, Tank Volume: 5200 m^3

The tank volume is changed at the year 2070. The pumps and the water demand of the network are same as in the previous scenario. Optimum pump schedule in P23 pump station was determined and the best solution was calculated as 1517.24 TL. Water level in T53 storage tank fluctuates during the 24 hours simulation and the final level of the water is 4.50 meters that is higher than the minimum water limit 2.5 meters as indicated in Figure 5.26. There is not any violence occurred at this scenario. Total amount of pumped water is 18002.56 m^3 and the stored water amount in T53 storage tank is 1596.87 m^3 for 24 hours period.

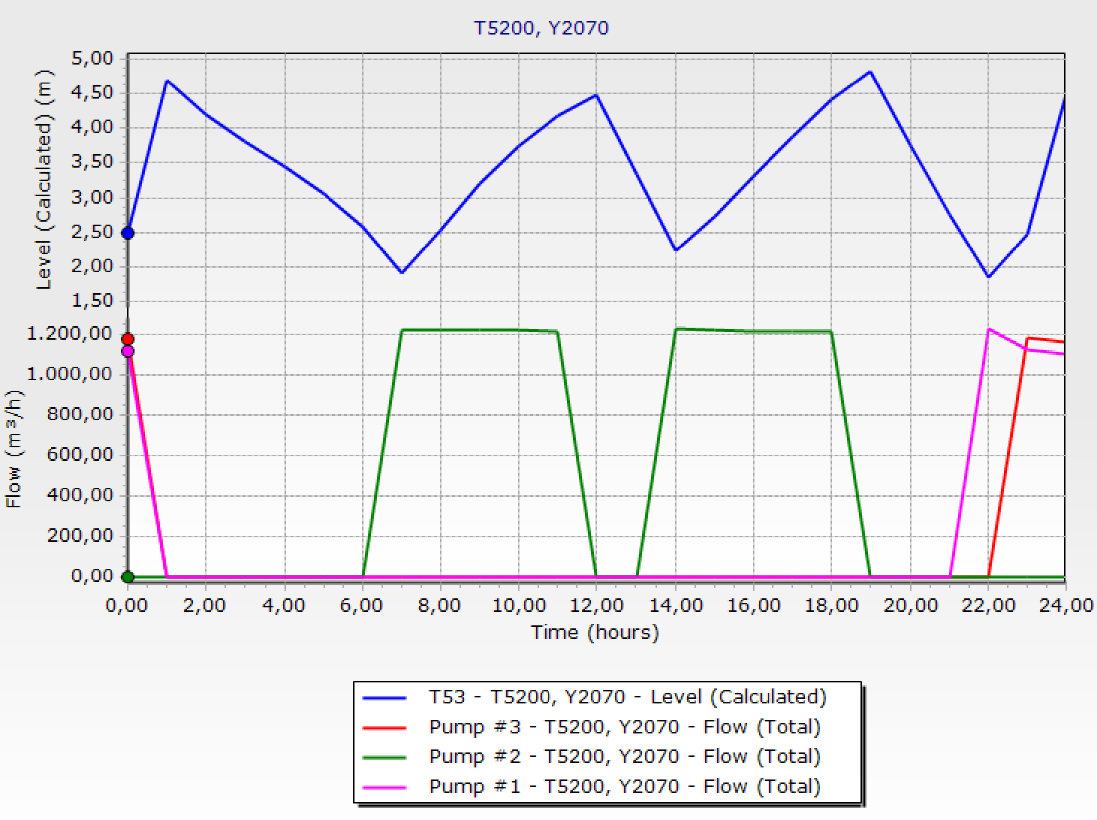


Figure 5.26. T53 Storage Tank Water Level and Pump Flow versus Time Graph – T5200, Y2070

Year 2075, Tank Volume: 5200 m^3

The water demand of the network is 785.653 m^3/h in the year 2075. Optimum pump schedule in P23 pump station was determined and the best solution was calculated as 2616.88 TL. As indicated in Figure 5.27, the water level of the storage tank reaches to maximum 5 meters at the time 12:00. Hence, the violation occurred and the optimization process applied penalty to this scenario. The 5200 m^3 storage tank becomes inadequate in the year 2075. Total amount of pumped water is 20006.85 m^3 and the stored water amount in T53 storage tank is 1150.74 m^3 for 24 hours period.

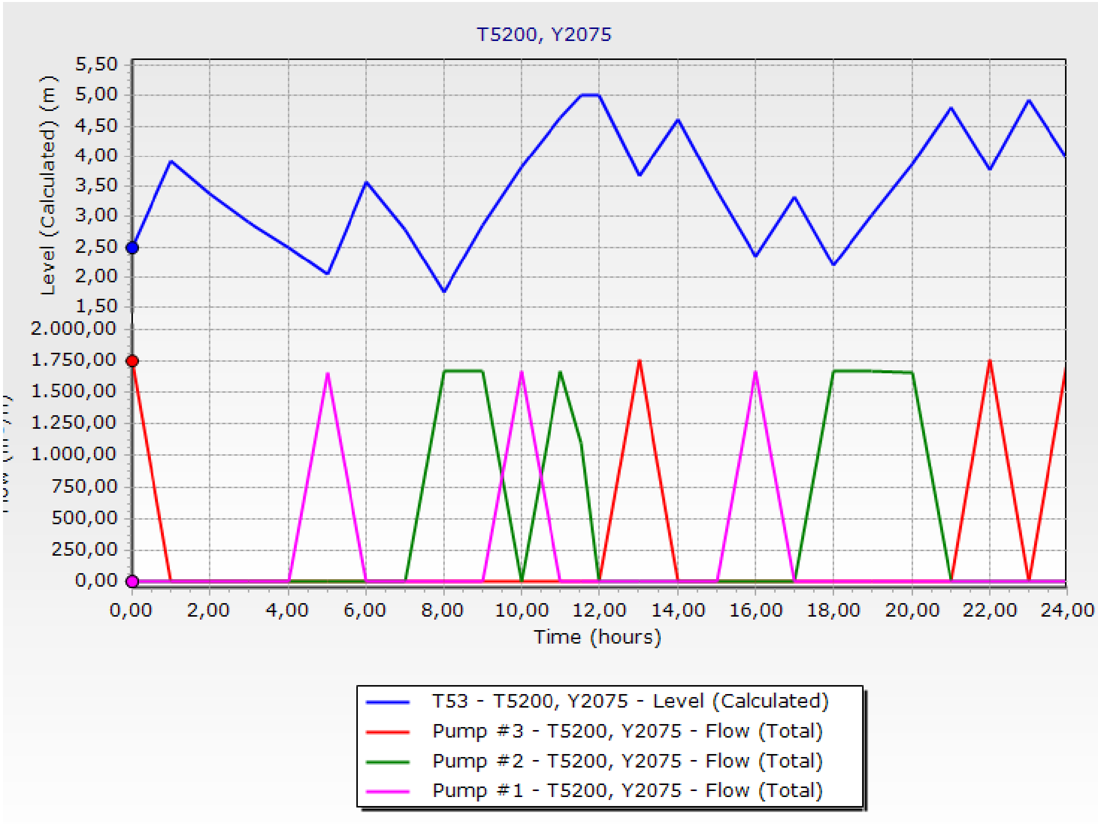


Figure 5.27. T53 Storage Tank Water Level and Pump Flow versus Time Graph – T5200, Y2075

Year 2075, Tank Volume: 6500 m^3

Optimum pump scheduling analysis was performed and the best solution generated as 2428.11 TL. Water level in T53 storage tank fluctuates during the 24 hours simulation and the final level of the water is 3.94 meters that is higher than the minimum water limit as shown in the Figure 5.28. Total amount of pumped water is 20293.98 m^3 and the stored water amount in T53 storage tank is 1437.90 m^3 for 24 hours period. The water distribution system works properly and meets the requirements of the network in this scenario. Violation did not occur in the optimization process so that 6500 m^3 storage tank can be used in the year 2080.

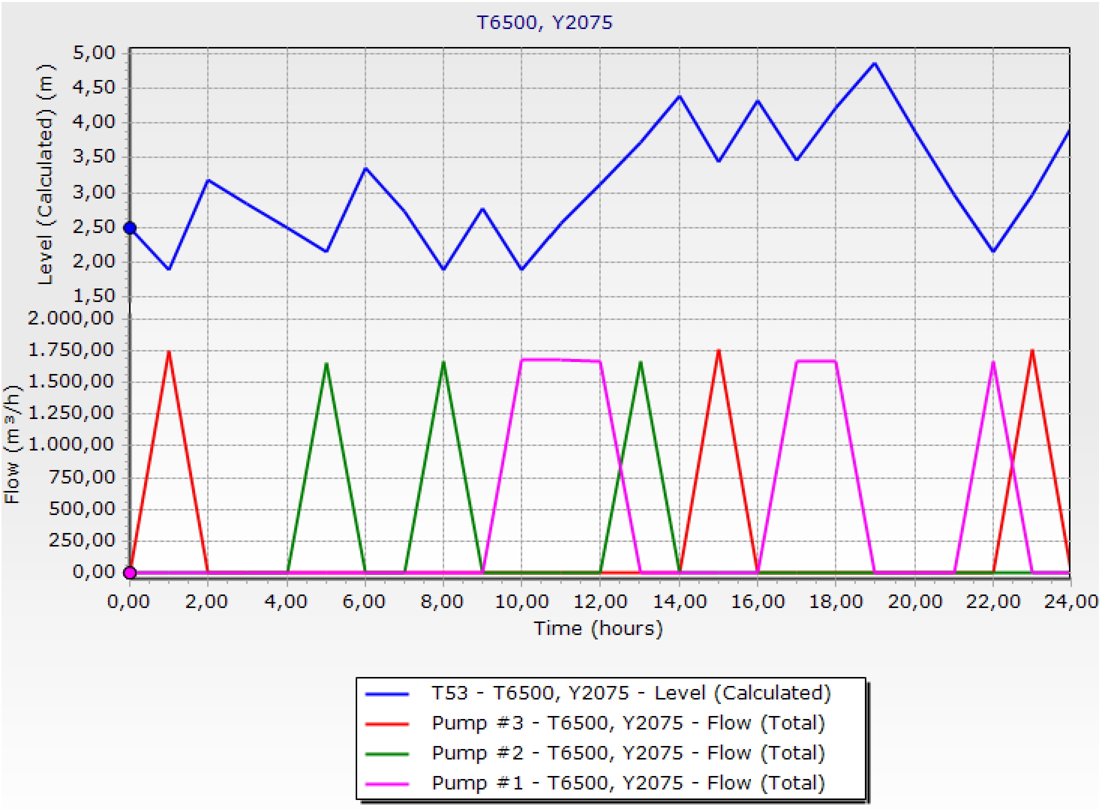


Figure 5.28. T53 Storage Tank Water Level and Pump Flow versus Time Graph – T6500, Y2075

Year 2080, Tank Volume: 6500 m^3

The water demand of the network is 901.994 m^3/h in the year 2080. The daily energy cost of the network was calculated as 2846.94 TL for 24 hours period by the optimization process. The water level in the storage tank begins with 2.5 meters and ends with 4.47 meters. At the time 01:00, the water level at the storage tank is 1.79 meters so that the pumps #1 and #3 begin to work together. The water level in the storage tank decreases to the critical level again, 1.93 meters, at the time 07:00. Because of this, pumps begin to work once again at this time. The most important point of this scenario occurs between time intervals 11:34 - 15:00 and 17:54 - 20:00. The water level of the storage tank reaches the maximum limit 5.00 meters as shown in Figure 5.29. Violation is occurred in the optimization process of this scenario so that the storage tank must be changed with a larger one. Total amount of pumped water is 23620.25 m^3 and the stored water amount in T53 storage tank is 1971.82 m^3 for 24 hours period.

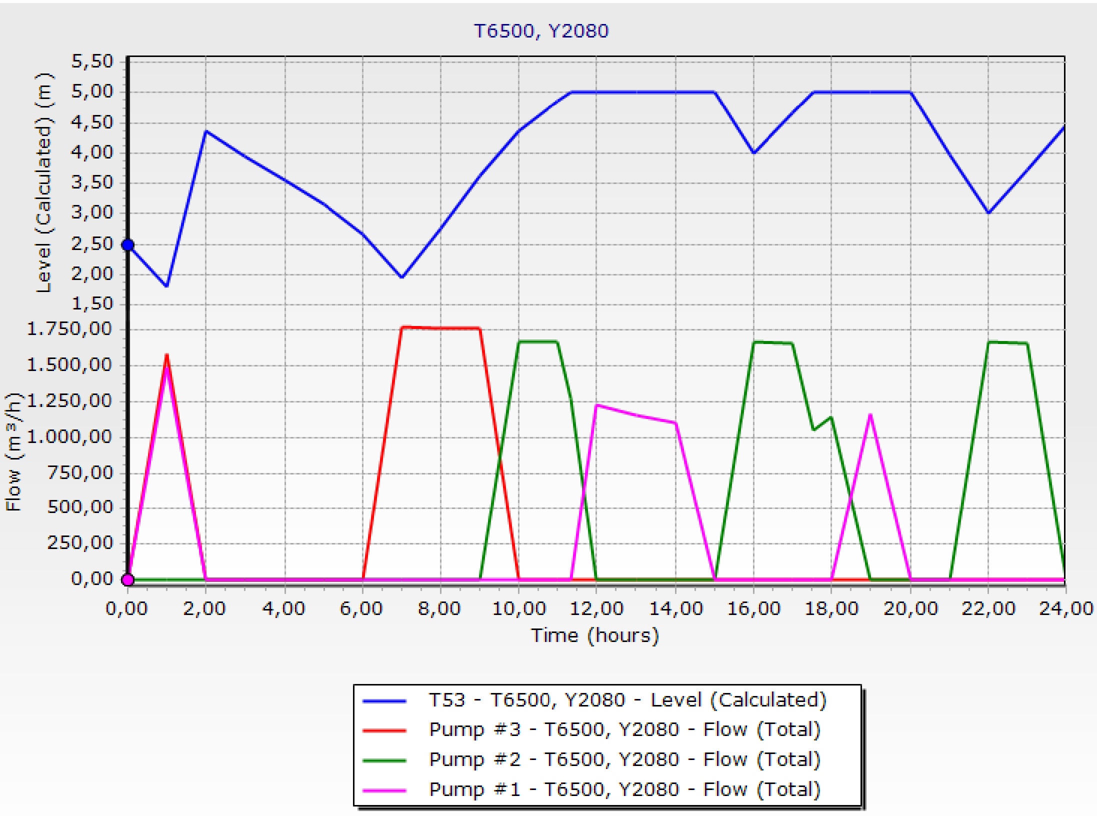


Figure 5.29. T53 Storage Tank Water Level and Pump Flow versus Time Graph – T6500, Y2080

Year 2080, Tank Volume: 7800 m^3

The tank volume is changed at the year 2080. The pumps and the water demand of the network are same as in the previous scenario. Optimum pump schedule in P23 pump station was determined and the best solution between three alternatives was calculated as 2750.79 TL. Water level in T53 storage tank fluctuates during the 24 hours simulation and the final level of the water is 4.72 meters that is higher than the minimum water limit. Between the time intervals 12:05 - 15:00 and 17:54 - 20:00, the water level of the storage tank reaches the maximum limit 5.00 meters as shown in Figure 5.30. Total amount of pumped water is 24313.72 m^3 and the stored water amount in T53 storage tank is 2665.33 m^3 for 24 hours period. Violation is occurred in the optimization process so that the storage tank must be changed with a larger one.

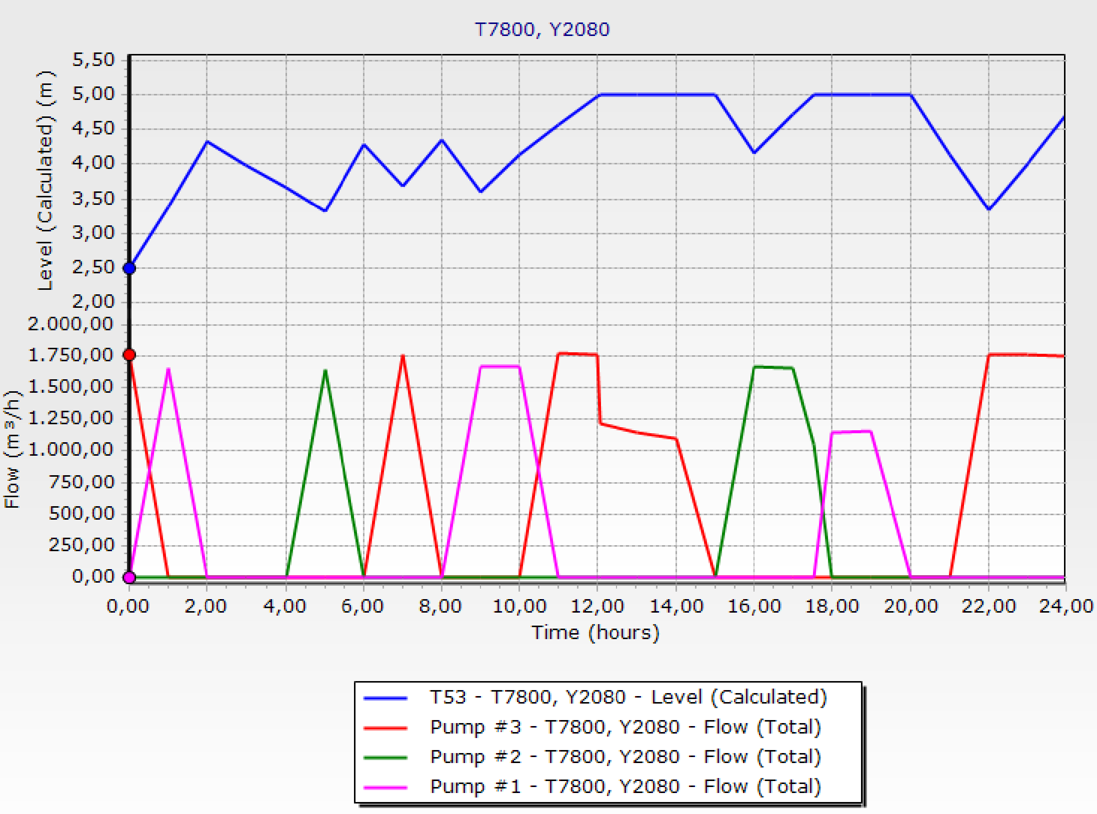


Figure 5.30. T53 Storage Tank Water Level and Pump Flow versus Time Graph – T7800, Y2080

5.13.2. Results of the Daily Energy Costs

The water level of the T53 storage tank and pump flow versus time graphs of the critical scenarios were explained and the daily energy costs of the water distribution network were mentioned in the previous pages. The population increased with respect to the growth rate (%2). The daily energy costs of all 120 scenarios are indicated in Table 5.12.

Daily energy costs are decreased when the tank volumes are increased. In addition, increase in the water that stored in the T53 storage tank and the total amount of water pumped to the water supply system are observed when the storage tank volumes are increased as expected. The hydraulic constraints were not satisfied in the red marked cells in Table 5.12.

The most important point is the decrease in the daily energy costs. Storage tank volumes have a significant effect on the daily energy cost. The larger sized storage tank can store more water in the lowest cost periods and feeds the water distribution system in the highest cost intervals. Consequently, the energy costs decreased when the storage tank size was increased.

Table 5.12. Daily Energy Costs

Year	Population	c	Scenario Costs (TL) - Daily Energy Costs							
			Tank Volumes							
			650 m^3	1300 m^3	1950 m^3	2600 m^3	3900 m^3	5200 m^3	6500 m^3	7800 m^3
2015	25,000		166.18	152.84	141.33	132.28	119.69	106.70	103.25	103.25
2020	27,602	2.0	191.27	177.13	166.71	153.31	138.28	132.17	121.52	117.98
2025	30,475	2.0	240.80	219.42	204.55	186.82	178.64	162.95	153.92	143.16
2030	33,647	2.0	278.33	252.55	245.21	223.33	202.62	196.85	184.15	174.50
2035	37,149	2.0	325.02	322.45	320.29	301.61	262.32	249.89	236.51	218.81
2040	41,015	2.0	383.73	393.63	372.91	366.87	313.23	295.72	280.75	267.96
2045	45,284	2.0	515.43	518.34	498.52	479.78	438.82	383.93	376.32	367.65
2050	49,997	2.0	601.74	613.71	561.27	567.54	495.90	474.68	445.41	437.76
2055	55,201	2.0	826.42	835.28	833.25	773.29	746.64	681.43	676.41	622.92
2060	60,946	2.0	965.02	977.51	938.03	913.07	877.89	855.17	809.44	766.83
2065	67,290	2.0	1424.34	1435.29	1434.92	1433.28	1422.99	1255.10	1189.16	1079.86
2070	74,293	2.0	1661.80	1651.97	1652.89	1718.07	1520.93	1517.24	1439.16	1356.56
2075	82,026	2.0	2633.26	2619.62	2682.26	2581.71	2618.41	2616.88	2428.11	2327.05
2080	90,563	2.0	3025.25	3011.56	3008.87	2958.18	3033.65	2821.16	2846.94	2750.79
2085	99,989	2.0	4997.09	5018.08	4998.30	5014.94	4954.55	4760.19	5001.82	5009.08

Tank Final Level Violation Only

Pump Starts, Pressure and Tank Final Level Violation

5.13.3. Total Annual Costs

In the previous section, daily energy costs, which vary according to the storage tank sizes, are calculated. The decrease in the daily energy prices is observed when the storage tank capacity is increased. To understand better the results of the daily energy costs, the construction costs of the storage tank and the pump costs must be included. Daily energy costs, storage tank costs and pumps costs must be calculated as a whole. To do this, all costs are converted into the annual costs in this study.

From the results of tenders about water storage tanks that were made in the year 2014. Tank costs of the water distribution network were determined. Contract prices of the tenders for 100 m^3 and 5000 m^3 reinforced concrete water storage tank are 94,824 TL and 1,438,200 TL respectively. The lifetime of the water storage tanks was assumed as 40 years.

The interest rate was taken as 7.75% in the calculation of the annual cost (latest interest rate before 20/01/2015). 7.75% was used to convert the present worth of the storage tank and pumps to the annual cost. To convert the daily energy cost to the annual energy cost, the daily and monthly interest rates were used. The daily and monthly interest rates were calculated from the annual interest rate. 40 years lifetime period was determined for the water storage tank. In addition, 10 years lifetime period was determined for the pumps in the P23 pumps station. The annual costs of the daily energy costs, tank costs and pump costs are shown in Table 5.13. The present worth of the storage tanks and pumps were converted into the annual costs; and the daily energy costs were converted into the yearly costs. In other words, future worth of the annual pump costs were calculated in the areas labelled with orange in Table 5.13.

Total annual costs for Turkey are shown in Table 5.14. At the red marked cells in the Table 5.14, the hydraulic constraints were not satisfied so that the larger size storage tank was required in these years. The results of the calculations show that the annual costs of the smaller volume tanks are higher than the larger one after the year 2065. Therefore, 3900 m^3 storage tank is changed with 7800 m^3 at the year 2065. When the population is increased, the water requirements of the water distribution network increase. Because of the increase in the water requirements, larger tank requirement occurred.

Table 5.13a. Annual Costs of Storage Tanks, Pumps and Daily Energy Costs for Turkey

Year 2015	**650 m^3**	**1300 m^3**	**1950 m^3**	**2600 m^3**	**3900 m^3**	**5200 m^3**	**6500 m^3**	**7800 m^3**
Tank Cost (TL) =	245,611.10	423,814.04	602,016.98	780,219.92	1,136,625.80	1,493,031.67	1,849,437.55	2,205,843.43
Annual Tank Cost (TL) =	20,047.29	34,592.58	49,137.88	63,683.17	92,773.76	121,864.35	150,954.94	180,045.53
Pump Cost (TL) =	34,440.00	34,440.00	34,440.00	34,440.00	34,440.00	34,440.00	34,440.00	34,440.00
Annual Pump Cost (TL) =	5,074.85	5,074.85	5,074.85	5,074.85	5,074.85	5,074.85	5,074.85	5,074.85
Daily Energy Cost (TL) =	166.178	152.842	141.330	132.277	119.688	106.701	103.247	103.247
Monthly Energy Cost (TL) =	5,000.93	4,599.60	4,253.16	3,980.72	3,601.87	3,211.04	3,107.10	3,107.10
Annual Energy Cost (TL) =	62,189.41	57,198.63	52,890.45	49,502.51	44,791.28	39,931.11	38,638.51	38,638.51
Total Annual Costs (TL) =	**87,311.55**	**96,866.06**	**107,103.18**	**118,260.53**	**142,639.90**	**166,870.31**	**194,668.30**	**223,758.89**

Year 2020	**650 m^3**	**1300 m^3**	**1950 m^3**	**2600 m^3**	**3900 m^3**	**5200 m^3**	**6500 m^3**	**7800 m^3**
Tank Cost (TL) =	245,611.10	423,814.04	602,016.98	780,219.92	1,136,625.80	1,493,031.67	1,849,437.55	2,205,843.43
Annual Tank Cost (TL) =	20,047.29	34,592.58	49,137.88	63,683.17	92,773.76	121,864.35	150,954.94	180,045.53
Pump Cost (TL) =	34,440.00	34,440.00	34,440.00	34,440.00	34,440.00	34,440.00	34,440.00	34,440.00
Annual Pump Cost (TL) =	5,074.85	5,074.85	5,074.85	5,074.85	5,074.85	5,074.85	5,074.85	5,074.85
Daily Energy Cost (TL) =	191.271	177.133	166.712	153.305	138.275	132.165	121.519	117.980
Monthly Energy Cost (TL) =	5,756.08	5,330.61	5,017.00	4,613.54	4,161.22	3,977.35	3,656.97	3,550.47
Annual Energy Cost (TL) =	71,580.06	66,289.14	62,389.25	57,371.90	51,747.17	49,460.60	45,476.51	44,152.09
Total Annual Costs (TL) =	**96,702.19**	**105,956.57**	**116,601.98**	**126,129.92**	**149,595.78**	**176,399.80**	**201,506.30**	**229,272.47**

Year 2025	**650 m^3**	**1300 m^3**	**1950 m^3**	**2600 m^3**	**3900 m^3**	**5200 m^3**	**6500 m^3**	**7800 m^3**
Tank Cost (TL) =	245,611.10	423,814.04	602,016.98	780,219.92	1,136,625.80	1,493,031.67	1,849,437.55	2,205,843.43
Annual Tank Cost (TL) =	20,047.29	34,592.58	49,137.88	63,683.17	92,773.76	121,864.35	150,954.94	180,045.53
Pump Cost (TL) =	45,265.03	45,265.03	45,265.03	45,265.03	45,265.03	45,265.03	45,265.03	45,265.03
Annual Pump Cost (TL) =	6,669.95	6,669.95	6,669.95	6,669.95	6,669.95	6,669.95	6,669.95	6,669.95
Daily Energy Cost (TL) =	240.798	219.423	204.552	186.815	178.637	162.948	153.916	143.161
Monthly Energy Cost (TL) =	7,246.54	6,603.28	6,155.75	5,621.98	5,375.87	4,903.73	4,631.92	4,308.26
Annual Energy Cost (TL) =	90,114.73	82,115.48	76,550.25	69,912.47	66,851.99	60,980.63	57,600.56	53,575.67
Total Annual Costs (TL) =	**116,831.97**	**123,378.02**	**132,358.09**	**140,265.60**	**166,295.70**	**189,514.94**	**215,225.45**	**240,291.16**

Table 5.13b. Annual Costs of Storage Tanks, Pumps and Daily Energy Costs for Turkey

Year 2030	**650 m^3**	**1300 m^3**	**1950 m^3**	**2600 m^3**	**3900 m^3**	**5200 m^3**	**6500 m^3**	**7800 m^3**
Tank Cost (TL) =	245,611.10	423,814.04	602,016.98	780,219.92	1,136,625.80	1,493,031.67	1,849,437.55	2,205,843.43
Annual Tank Cost (TL) =	20,047.29	34,592.58	49,137.88	63,683.17	92,773.76	121,864.35	150,954.94	180,045.53
Pump Cost (TL) =	45,265.03	45,265.03	45,265.03	45,265.03	45,265.03	45,265.03	45,265.03	45,265.03
Annual Pump Cost (TL) =	6,669.95	6,669.95	6,669.95	6,669.95	6,669.95	6,669.95	6,669.95	6,669.95
Daily Energy Cost (TL) =	278.332	252.553	245.210	223.334	202.617	196.854	184.153	174.500
Monthly Energy Cost (TL) =	8,376.08	7,600.29	7,379.31	6,720.98	6,097.52	5,924.09	5,541.87	5,251.37
Annual Energy Cost (TL) =	104,161.22	94,513.85	91,765.85	83,579.11	75,826.11	73,669.40	68,916.26	65,303.78
Total Annual Costs (TL) =	**130,878.46**	**135,776.38**	**147,573.68**	**153,932.24**	**175,269.83**	**202,203.71**	**226,541.16**	**252,019.27**

Year 2035	**650 m^3**	**1300 m^3**	**1950 m^3**	**2600 m^3**	**3900 m^3**	**5200 m^3**	**6500 m^3**	**7800 m^3**
Tank Cost (TL) =	245,611.10	423,814.04	602,016.98	780,219.92	1,136,625.80	1,493,031.67	1,849,437.55	2,205,843.43
Annual Tank Cost (TL) =	20,047.29	34,592.58	49,137.88	63,683.17	92,773.76	121,864.35	150,954.94	180,045.53
Pump Cost (TL) =	59,740.15	59,740.15	59,740.15	59,740.15	59,740.15	59,740.15	59,740.15	59,740.15
Annual Pump Cost (TL) =	8,802.91	8,802.91	8,802.91	8,802.91	8,802.91	8,802.91	8,802.91	8,802.91
Daily Energy Cost (TL) =	325.020	322.454	320.293	301.612	262.324	249.892	236.505	218.808
Monthly Energy Cost (TL) =	9,781.10	9,703.88	9,638.84	9,076.66	7,894.33	7,520.21	7,117.34	6,584.77
Annual Energy Cost (TL) =	121,633.44	120,673.16	119,864.44	112,873.38	98,170.48	93,518.01	88,508.14	81,885.33
Total Annual Costs (TL) =	**150,483.64**	**164,068.65**	**177,805.23**	**185,359.46**	**199,747.16**	**224,185.27**	**248,266.00**	**270,733.77**

Year 2040	**650 m^3**	**1300 m^3**	**1950 m^3**	**2600 m^3**	**3900 m^3**	**5200 m^3**	**6500 m^3**	**7800 m^3**
Tank Cost (TL) =	245,611.10	423,814.04	602,016.98	780,219.92	1,136,625.80	1,493,031.67	1,849,437.55	2,205,843.43
Annual Tank Cost (TL) =	20,047.29	34,592.58	49,137.88	63,683.17	92,773.76	121,864.35	150,954.94	180,045.53
Pump Cost (TL) =	59,740.15	59,740.15	59,740.15	59,740.15	59,740.15	59,740.15	59,740.15	59,740.15
Annual Pump Cost (TL) =	8,802.91	8,802.91	8,802.91	8,802.91	8,802.91	8,802.91	8,802.91	8,802.91
Daily Energy Cost (TL) =	383.734	393.625	372.910	366.870	313.225	295.722	280.752	267.960
Monthly Energy Cost (TL) =	11,548.03	11,845.69	11,222.29	11,040.52	9,426.14	8,899.41	8,448.90	8,063.94
Annual Energy Cost (TL) =	143,606.20	147,307.74	139,555.49	137,295.12	117,219.35	110,669.14	105,066.86	100,279.66
Total Annual Costs (TL) =	**172,456.40**	**190,703.24**	**197,496.28**	**209,781.21**	**218,796.03**	**241,336.40**	**264,824.72**	**289,128.11**

Table 5.13c. Annual Costs of Storage Tanks, Pumps and Daily Energy Costs for Turkey

Year 2045	**650 m^3**	**1300 m^3**	**1950 m^3**	**2600 m^3**	**3900 m^3**	**5200 m^3**	**6500 m^3**	**7800 m^3**
Tank Cost (TL) =	245,611.10	423,814.04	602,016.98	780,219.92	1,136,625.80	1,493,031.67	1,849,437.55	2,205,843.43
Annual Tank Cost (TL) =	20,047.29	34,592.58	49,137.88	63,683.17	92,773.76	121,864.35	150,954.94	180,045.53
Pump Cost (TL) =	79,052.41	79,052.41	79,052.41	79,052.41	79,052.41	79,052.41	79,052.41	79,052.41
Annual Pump Cost (TL) =	11,648.64	11,648.64	11,648.64	11,648.64	11,648.64	11,648.64	11,648.64	11,648.64
Daily Energy Cost (TL) =	515.433	518.338	498.521	479.784	438.818	383.927	376.322	367.648
Monthly Energy Cost (TL) =	15,511.36	15,598.78	15,002.41	14,438.54	13,205.72	11,553.84	11,324.97	11,063.94
Annual Energy Cost (TL) =	192,892.40	193,979.55	186,563.36	179,551.35	164,220.49	143,678.43	140,832.38	137,586.28
Total Annual Costs (TL) =	**224,588.33**	**240,220.77**	**247,349.88**	**254,883.16**	**268,642.89**	**277,191.42**	**303,435.96**	**329,280.44**

Year 2050	**650 m^3**	**1300 m^3**	**1950 m^3**	**2600 m^3**	**3900 m^3**	**5200 m^3**	**6500 m^3**	**7800 m^3**
Tank Cost (TL) =	245,611.10	423,814.04	602,016.98	780,219.92	1,136,625.80	1,493,031.67	1,849,437.55	2,205,843.43
Annual Tank Cost (TL) =	20,047.29	34,592.58	49,137.88	63,683.17	92,773.76	121,864.35	150,954.94	180,045.53
Pump Cost (TL) =	79,052.41	79,052.41	79,052.41	79,052.41	79,052.41	79,052.41	79,052.41	79,052.41
Annual Pump Cost (TL) =	11,648.64	11,648.64	11,648.64	11,648.64	11,648.64	11,648.64	11,648.64	11,648.64
Daily Energy Cost (TL) =	601.739	613.705	561.269	567.542	495.899	474.682	445.410	437.760
Monthly Energy Cost (TL) =	18,108.63	18,468.74	16,890.74	17,079.51	14,923.50	14,285.00	13,404.09	13,173.88
Annual Energy Cost (TL) =	225,191.02	229,669.10	210,045.78	212,393.35	185,582.12	177,642.01	166,687.44	163,824.55
Total Annual Costs (TL) =	**256,886.95**	**275,910.32**	**270,832.30**	**287,725.16**	**290,004.52**	**311,155.00**	**329,291.02**	**355,518.72**

Year 2055	**650 m^3**	**1300 m^3**	**1950 m^3**	**2600 m^3**	**3900 m^3**	**5200 m^3**	**6500 m^3**	**7800 m^3**
Tank Cost (TL) =	245,611.10	423,814.04	602,016.98	780,219.92	1,136,625.80	1,493,031.67	1,849,437.55	2,205,843.43
Annual Tank Cost (TL) =	20,047.29	34,592.58	49,137.88	63,683.17	92,773.76	121,864.35	150,954.94	180,045.53
Pump Cost (TL) =	104,681.25	104,681.25	104,681.25	104,681.25	104,681.25	104,681.25	104,681.25	104,681.25
Annual Pump Cost (TL) =	15,425.13	15,425.13	15,425.13	15,425.13	15,425.13	15,425.13	15,425.13	15,425.13
Daily Energy Cost (TL) =	826.418	835.279	833.254	773.294	746.642	681.431	676.414	622.922
Monthly Energy Cost (TL) =	24,870.09	25,136.75	25,075.81	23,271.38	22,469.32	20,506.87	20,355.89	18,746.11
Annual Energy Cost (TL) =	309,273.47	312,589.56	311,831.74	289,392.68	279,418.61	255,014.45	253,136.92	233,118.41
Total Annual Costs (TL) =	**344,745.90**	**362,607.28**	**376,394.75**	**368,500.99**	**387,617.50**	**392,303.94**	**419,517.00**	**428,589.07**

Table 5.13d. Annual Costs of Storage Tanks, Pumps and Daily Energy Costs for Turkey

Year 2060	650 m^3	1300 m^3	1950 m^3	2600 m^3	3900 m^3	5200 m^3	6500 m^3	7800 m^3
Tank Cost (TL) =	245,611.10	423,814.04	602,016.98	780,219.92	1,136,625.80	1,493,031.67	1,849,437.55	2,205,843.43
Annual Tank Cost (TL) =	20,047.29	34,592.58	49,137.88	63,683.17	92,773.76	121,864.35	150,954.94	180,045.53
Pump Cost (TL) =	104,681.25	104,681.25	104,681.25	104,681.25	104,681.25	104,681.25	104,681.25	104,681.25
Annual Pump Cost (TL) =	15,425.13	15,425.13	15,425.13	15,425.13	15,425.13	15,425.13	15,425.13	15,425.13
Daily Energy Cost (TL) =	965.018	977.512	938.034	913.074	877.887	855.165	809.437	766.830
Monthly Energy Cost (TL) =	29,041.09	29,417.08	28,229.04	27,477.90	26,418.99	25,735.19	24,359.06	23,076.85
Annual Energy Cost (TL) =	361,142.27	365,817.94	351,043.94	341,703.07	328,534.91	320,031.57	302,918.61	286,973.64
Total Annual Costs (TL) =	**396,614.69**	**415,835.66**	**415,606.96**	**420,811.38**	**436,733.80**	**457,321.06**	**469,298.69**	**482,444.30**

Year 2065	650 m^3	1300 m^3	1950 m^3	2600 m^3	3900 m^3	5200 m^3	6500 m^3	7800 m^3
Tank Cost (TL) =	245,611.10	423,814.04	602,016.98	780,219.92	1,136,625.80	1,493,031.67	1,849,437.55	2,205,843.43
Annual Tank Cost (TL) =	20,047.29	34,592.58	49,137.88	63,683.17	92,773.76	121,864.35	150,954.94	180,045.53
Pump Cost (TL) =	138,389.37	138,389.37	138,389.37	138,389.37	138,389.37	138,389.37	138,389.37	138,389.37
Annual Pump Cost (TL) =	20,392.14	20,392.14	20,392.14	20,392.14	20,392.14	20,392.14	20,392.14	20,392.14
Daily Energy Cost (TL) =	1,424.340	1,435.294	1,434.923	1,433.276	1,422.986	1,255.104	1,189.156	1,079.860
Monthly Energy Cost (TL) =	42,863.85	43,193.50	43,182.33	43,132.77	42,823.10	37,770.89	35,786.26	32,497.13
Annual Energy Cost (TL) =	533,036.04	537,135.40	536,996.56	536,380.20	532,529.33	469,702.23	445,022.26	404,120.01
Total Annual Costs (TL) =	**573,475.47**	**592,120.12**	**606,526.57**	**620,455.50**	**645,695.23**	**611,958.71**	**616,369.34**	**604,557.68**

Year 2070	650 m^3	1300 m^3	1950 m^3	2600 m^3	3900 m^3	5200 m^3	6500 m^3	7800 m^3
Tank Cost (TL) =	245,611.10	423,814.04	602,016.98	780,219.92	1,136,625.80	1,493,031.67	1,849,437.55	2,205,843.43
Annual Tank Cost (TL) =	20,047.29	34,592.58	49,137.88	63,683.17	92,773.76	121,864.35	150,954.94	180,045.53
Pump Cost (TL) =	138,389.37	138,389.37	138,389.37	138,389.37	138,389.37	138,389.37	138,389.37	138,389.37
Annual Pump Cost (TL) =	20,392.14	20,392.14	20,392.14	20,392.14	20,392.14	20,392.14	20,392.14	20,392.14
Daily Energy Cost (TL) =	1,661.797	1,651.967	1,652.886	1,718.069	1,520.927	1,517.239	1,439.155	1,356.564
Monthly Energy Cost (TL) =	50,009.84	49,714.02	49,741.68	51,703.28	45,770.53	45,659.54	43,309.69	40,824.21
Annual Energy Cost (TL) =	621,900.46	618,221.74	618,565.66	642,959.34	569,182.15	567,801.98	538,580.32	507,671.98
Total Annual Costs (TL) =	**662,339.88**	**673,206.46**	**688,095.68**	**727,034.65**	**682,348.05**	**710,058.47**	**709,927.39**	**708,109.65**

Table 5.13e. Annual Costs of Storage Tanks, Pumps and Daily Energy Costs for Turkey

Year 2075	**650 m^3**	**1300 m^3**	**1950 m^3**	**2600 m^3**	**3900 m^3**	**5200 m^3**	**6500 m^3**	**7800 m^3**
Tank Cost (TL) =	245,611.10	423,814.04	602,016.98	780,219.92	1,136,625.80	1,493,031.67	1,849,437.55	2,205,843.43
Annual Tank Cost (TL) =	20,047.29	34,592.58	49,137.88	63,683.17	92,773.76	121,864.35	150,954.94	180,045.53
Pump Cost (TL) =	182,142.01	182,142.01	182,142.01	182,142.01	182,142.01	182,142.01	182,142.01	182,142.01
Annual Pump Cost (TL) =	26,839.24	26,839.24	26,839.24	26,839.24	26,839.24	26,839.24	26,839.24	26,839.24
Daily Energy Cost (TL) =	2,633.258	2,619.622	2,682.262	2,581.705	2,618.412	2,616.876	2,428.111	2,327.046
Monthly Energy Cost (TL) =	79,244.83	78,834.47	80,719.55	77,693.40	78,798.06	78,751.83	73,071.17	70,029.74
Annual Energy Cost (TL) =	985,453.91	980,350.86	1,003,792.86	966,161.04	979,898.04	979,323.21	908,680.99	870,859.06
Total Annual Costs (TL) =	**1,032,340.44**	**1,041,782.68**	**1,079,769.97**	**1,056,683.45**	**1,099,511.04**	**1,128,026.80**	**1,086,475.16**	**1,077,743.82**
Year 2080	**650 m^3**	**1300 m^3**	**1950 m^3**	**2600 m^3**	**3900 m^3**	**5200 m^3**	**6500 m^3**	**7800 m^3**
Tank Cost (TL) =	245,611.10	423,814.04	602,016.98	780,219.92	1,136,625.80	1,493,031.67	1,849,437.55	2,205,843.43
Annual Tank Cost (TL) =	20,047.29	34,592.58	49,137.88	63,683.17	92,773.76	121,864.35	150,954.94	180,045.53
Pump Cost (TL) =	182,142.01	182,142.01	182,142.01	182,142.01	182,142.01	182,142.01	182,142.01	182,142.01
Annual Pump Cost (TL) =	26,839.24	26,839.24	26,839.24	26,839.24	26,839.24	26,839.24	26,839.24	26,839.24
Daily Energy Cost (TL) =	3,025.252	3,011.564	3,008.873	2,958.181	3,033.651	2,821.164	2,846.935	2,750.789
Monthly Energy Cost (TL) =	91,041.43	90,629.51	90,548.53	89,023.01	91,294.19	84,899.64	85,675.19	82,781.79
Annual Energy Cost (TL) =	1,132,151.28	1,127,028.77	1,126,021.71	1,107,051.05	1,135,294.47	1,055,774.67	1,065,419.05	1,029,437.97
Total Annual Costs (TL) =	**1,179,037.80**	**1,188,460.59**	**1,201,998.82**	**1,197,573.46**	**1,254,907.47**	**1,204,478.26**	**1,243,213.22**	**1,236,322.74**
Year 2085	**650 m^3**	**1300 m^3**	**1950 m^3**	**2600 m^3**	**3900 m^3**	**5200 m^3**	**6500 m^3**	**7800 m^3**
Tank Cost (TL) =	245,611.10	423,814.04	602,016.98	780,219.92	1,136,625.80	1,493,031.67	1,849,437.55	2,205,843.43
Annual Tank Cost (TL) =	20,047.29	34,592.58	49,137.88	63,683.17	92,773.76	121,864.35	150,954.94	180,045.53
Pump Cost (TL) =	237,955.88	237,955.88	237,955.88	237,955.88	237,955.88	237,955.88	237,955.88	237,955.88
Annual Pump Cost (TL) =	35,063.60	35,063.60	35,063.60	35,063.60	35,063.60	35,063.60	35,063.60	35,063.60
Daily Energy Cost (TL) =	4,997.093	5,018.079	4,998.297	5,014.941	4,954.546	4,760.185	5,001.818	5,009.080
Monthly Energy Cost (TL) =	150,381.69	151,013.24	150,417.92	150,918.80	149,101.29	143,252.22	150,523.88	150,742.42
Annual Energy Cost (TL) =	1,870,080.65	1,877,934.32	1,870,531.23	1,876,759.98	1,854,158.13	1,781,421.69	1,871,848.91	1,874,566.59
Total Annual Costs (TL) =	**1,925,191.54**	**1,947,590.50**	**1,954,732.70**	**1,975,506.74**	**1,981,995.49**	**1,938,349.64**	**2,057,867.44**	**2,089,675.72**

Table 5.14. Total Annual Costs for Turkey

Year	Population	c	Total Annual Costs (TL) (Daily Energy + Tank + Pump Yearly Costs), (Turkey, 7.75%)							
			650 m^3	1300 m^3	1950 m^3	2600 m^3	3900 m^3	5200 m^3	6500 m^3	7800 m^3
2015	25,000		**87,311.55**	**96,866.06**	107,103.18	118,260.53	142,639.90	166,870.31	194,668.30	223,758.89
2020	27,602	2.0	96,702.19	**105,956.57**	116,601.98	126,129.92	149,595.78	176,399.80	201,506.30	229,272.47
2025	30,475	2.0	116,831.97	**123,378.02**	132,358.09	140,265.60	166,295.70	189,514.94	215,225.45	240,291.16
2030	33,647	2.0	130,878.46	**135,776.38**	147,573.68	153,932.24	175,269.83	202,203.71	226,541.16	252,019.27
2035	37,149	2.0	150,483.64	**164,068.65**	**177,805.23**	185,359.46	199,747.16	224,185.27	248,266.00	270,733.77
2040	41,015	2.0	172,456.40	190,703.24	**197,496.28**	209,781.21	218,796.03	241,336.40	264,824.72	289,128.11
2045	45,284	2.0	224,588.33	240,220.77	**247,349.88**	**254,883.16**	268,642.89	277,191.42	303,435.96	329,280.44
2050	49,997	2.0	256,886.95	275,910.32	270,832.30	**287,725.16**	290,004.52	311,155.00	329,291.02	355,518.72
2055	55,201	2.0	344,745.90	362,607.28	376,394.75	**368,500.99**	**387,617.50**	392,303.94	419,517.00	428,589.07
2060	60,946	2.0	396,614.69	415,835.66	415,606.96	420,811.38	**436,733.80**	457,321.06	469,298.69	482,444.30
2065	67,290	2.0	573,475.47	592,120.12	606,526.57	620,455.50	**645,695.23**	**611,958.71**	**616,369.34**	**604,557.68**
2070	74,293	2.0	662,339.88	673,206.46	688,095.68	727,034.65	682,348.05	710,058.47	709,927.39	708,109.65
2075	82,026	2.0	1,032,340.44	1,041,782.68	1,079,769.97	1,056,683.45	1,099,511.04	1,128,026.80	1,086,475.16	1,077,743.82
2080	90,563	2.0	1,179,037.80	1,188,460.59	1,201,998.82	1,197,573.46	1,254,907.47	1,204,478.26	1,243,213.22	1,236,322.74
2085	99,989	2.0	1,925,191.54	1,947,590.50	1,954,732.70	1,975,506.74	1,981,995.49	1,938,349.64	2,057,867.44	2,089,675.72

Transition Because of the Annual Cost
Tank Final Level Violation Only
Pump Starts, Pressure and Tank Final Level Violation

5.13.4. Total Annual Costs with Different Interest Rates

The interest rates are different for every country. While calculating the total annual cost, the interest rate is a significant factor. The sum of the storage tank, pump and daily energy costs will be changed according to the interest rates. The interest rates that are used in this study are listed in Table 5.15.

Table 5.15. Interest Rates

Interest Rates (%)
0.05
0.25
5.75
7.75
17.00

Total annual costs with respect to the interest rates are shown in related tables (Table 5.16, Table 5.17, Table 5.18, Table 5.19). The earliest shifts between the annual cost tables occurred when the interest rate is 0.05%. In the year 2025, 2600 m^3 storage tank's total annual cost is lower than 1300 m^3 storage tank. After this year, the shifts occurred in the years 2035, 2045, 2050 and 2055. Table 5.16 shows that, 7800 m^3 storage is needed for the year 2055. Table 5.17 shows the total annual costs for the interest rate 0.25%. The shifts are not changed according to the interest rate 0.05%. When the interest rate is increased from 0.05% to 0.25%, nothing changed in terms of the shifts in the tables.

Total annual costs of the interest rate 5.25% are shown in Table 5.18. Tank final water level violation occurs for 1300 m^3 storage tank in the years 2025, 2035, 2045 and 2055. The tank level reaches to the 5 meters, which is the maximum limit of the storage tank water level. The storage tank must be replaced with a larger one in these years. The annual cost calculation shows that the least cost scenario occurred when 5200 m^3 storage tank is used in the year 2055. Finally, annual cost of the 7800 m^3 storage tank is lower than 5200 m^3 and 6500 m^3 storage tanks at the year 2065.

The biggest interest rate that was selected within this study 17.00%. According to that interest rate, the annual costs were calculated and shown in Table 5.19. The storage tank is inadequate in the years 2025, 2035, 2045, 2055 and 2075. The annual cost transition occurs only in the year 2065.

The annual cost calculations showed that when the interest rates are low, investments returns to profit earlier. In other words, the rate of return of the investment (capital cost) is high when the interest rates are low. The smallest interest rate is 0.05%. According to this interest rate, the annual costs of the storage tank are smaller than the others. Low interest rates decreases the total annual costs of the water distribution system and constructing bigger size of the storage tank becomes meaningful.

Table 5.16. Total Annual Costs for i = 0.05%

Year	Population	c	Total Annual Costs (TL) (Daily Energy + Tank + Pump Yearly Costs), (i = 0.05%)							
			650 m^3	**1300 m^3**	**1950 m^3**	**2600 m^3**	**3900 m^3**	**5200 m^3**	**6500 m^3**	**7800 m^3**
2015	25,000		**69,495.89**	**69,194.62**	69,550.16	70,791.15	75,259.75	79,585.04	87,343.06	96,344.84
2020	27,602	2.0	78,531.63	**77,941.56**	78,689.96	78,363.12	81,952.74	88,754.37	93,922.62	101,650.04
2025	30,475	2.0	97,451.28	**94,255.24**	**93,401.23**	**91,515.21**	97,572.17	100,924.49	106,673.93	111,802.94
2030	33,647	2.0	110,966.88	106,185.02	108,041.76	**104,665.33**	106,207.12	113,133.69	117,561.97	123,087.79
2035	37,149	2.0	129,230.25	132,807.15	136,529.88	**134,303.93**	**129,158.49**	133,683.63	137,864.88	140,494.15
2040	41,015	2.0	150,372.56	158,435.10	155,476.72	157,802.67	**147,487.42**	150,186.55	153,797.77	158,193.28
2045	45,284	2.0	199,732.56	205,279.51	202,644.50	200,398.38	**194,648.72**	**183,884.80**	190,148.09	196,026.45
2050	49,997	2.0	230,810.47	239,620.19	225,239.41	231,999.14	215,203.00	**216,564.75**	**215,025.98**	221,273.06
2055	55,201	2.0	314,285.02	321,976.66	325,748.36	308,658.27	308,062.93	293,582.89	**300,778.09**	**290,517.94**
2060	60,946	2.0	364,193.46	373,193.31	363,478.57	358,991.61	355,322.91	356,142.72	348,678.31	342,337.74
2065	67,290	2.0	532,970.70	541,416.01	545,783.30	549,691.12	554,987.57	503,536.75	488,791.32	458,436.72
2070	74,293	2.0	618,476.53	619,437.73	624,269.54	652,242.16	590,255.12	597,928.88	578,813.40	558,075.00
2075	82,026	2.0	972,677.00	972,267.70	999,324.61	967,615.95	989,835.54	998,284.21	939,313.64	911,922.94
2080	90,563	2.0	1,113,830.02	1,113,402.00	1,116,933.89	1,103,181.10	1,139,358.85	1,071,846.23	1,090,127.87	1,064,508.46
2085	99,989	2.0	1,829,466.53	1,841,524.26	1,838,901.85	1,849,396.07	1,836,650.22	1,775,664.59	1,871,675.93	1,883,292.68

Transition Because of the Annual Cost
Tank Final Level Violation Only
Pump Starts, Pressure and Tank Final Level Violation

Table 5.17. Total Annual Costs for i = 0.25%

Year	Population	c	Total Annual Costs (TL) (Daily Energy + Tank + Pump Yearly Costs), (i = 0.25%)							
			650 m^3	**1300 m^3**	**1950 m^3**	**2600 m^3**	**3900 m^3**	**5200 m^3**	**6500 m^3**	**7800 m^3**
2015	25,000		**69,850.31**	**69,730.46**	70,268.08	71,692.03	76,528.54	81,221.59	89,350.80	98,725.00
2020	27,602	2.0	78,895.06	**78,486.13**	79,416.99	79,271.55	83,228.21	90,400.07	95,936.93	104,035.50
2025	30,475	2.0	97,844.47	**94,826.97**	**94,153.83**	**92,447.65**	98,874.10	102,593.21	108,711.84	114,209.41
2030	33,647	2.0	111,373.56	106,768.65	108,808.97	**105,610.89**	107,517.67	114,814.60	119,610.74	125,505.52
2035	37,149	2.0	129,669.70	133,431.89	137,340.06	**135,293.61**	**130,506.49**	135,399.59	139,948.46	142,943.79
2040	41,015	2.0	150,833.11	159,085.41	156,305.81	158,815.80	**148,853.71**	151,918.97	155,897.25	160,660.59
2045	45,284	2.0	200,261.77	205,995.98	203,540.06	201,473.42	**196,081.47**	**185,670.26**	192,303.25	198,550.91
2050	49,997	2.0	231,370.69	240,370.92	226,157.52	233,105.71	216,656.26	**218,382.82**	**217,205.95**	223,822.72
2055	55,201	2.0	314,954.28	322,835.32	326,792.51	309,867.09	309,634.60	295,503.56	**303,069.39**	**293,162.45**
2060	60,946	2.0	364,912.53	374,103.08	364,560.37	360,250.66	356,941.74	358,125.82	351,017.41	345,033.95
2065	67,290	2.0	533,892.05	542,527.51	547,080.89	551,174.33	556,839.51	505,700.80	491,304.10	461,282.66
2070	74,293	2.0	619,483.21	620,627.10	625,645.45	653,827.70	592,142.25	600,187.12	581,416.01	561,020.37
2075	82,026	2.0	974,081.08	973,853.10	1,001,118.73	969,560.15	992,165.36	1,000,985.91	942,319.94	915,265.36
2080	90,563	2.0	1,115,374.96	1,115,128.23	1,118,845.37	1,105,260.58	1,141,837.88	1,074,621.33	1,093,284.67	1,068,003.13
2085	99,989	2.0	1,831,781.65	1,844,033.14	1,841,589.84	1,852,276.25	1,839,881.13	1,779,198.09	1,875,668.68	1,887,660.47

Transition Because of the Annual Cost
Tank Final Level Violation Only
Pump Starts, Pressure and Tank Final Level Violation

Table 5.18. Total Annual Costs for i = 5.25%

Year	Population	c	Total Annual Costs (TL) (Daily Energy + Tank + Pump Yearly Costs), (i = 5.25%)							
			650 m^3	1300 m^3	1950 m^3	2600 m^3	3900 m^3	5200 m^3	6500 m^3	7800 m^3
2015	25,000		**80,736.02**	86,550.62	93,039.33	100,436.81	117,270.70	133,957.50	154,167.42	175,653.83
2020	27,602	2.0	**90,009.66**	95,527.87	102,419.78	108,208.15	124,139.92	143,368.25	160,920.22	181,098.72
2025	30,475	2.0	**109,732.36**	**112,575.99**	117,823.31	122,011.44	140,475.50	156,163.72	174,312.17	191,823.85
2030	33,647	2.0	123,603.84	**124,819.88**	132,849.33	135,507.80	149,337.81	168,694.39	185,486.89	203,405.83
2035	37,149	2.0	142,755.79	**152,550.68**	**162,495.25**	166,334.50	173,301.21	190,193.12	206,732.09	221,678.21
2040	41,015	2.0	164,454.78	178,853.42	**181,940.96**	190,451.96	192,112.74	207,130.56	223,084.50	239,843.36
2045	45,284	2.0	215,658.39	227,475.20	**230,894.62**	**234,713.18**	241,059.75	242,260.05	260,935.87	279,216.63
2050	49,997	2.0	247,554.58	262,720.08	254,084.46	**267,145.99**	**262,155.23**	275,800.46	286,468.79	305,127.99
2055	55,201	2.0	333,948.89	347,966.87	357,961.69	346,545.42	**358,182.03**	**355,568.36**	375,200.64	376,917.96
2060	60,946	2.0	385,171.43	400,532.06	396,685.34	398,204.06	406,686.38	**419,775.40**	424,362.08	430,102.18
2065	67,290	2.0	559,342.02	574,133.51	584,739.61	594,874.13	612,557.66	**571,999.76**	**569,113.71**	**550,207.50**
2070	74,293	2.0	647,099.24	654,209.56	665,292.41	700,125.36	648,753.81	668,877.25	661,506.09	652,469.27
2075	82,026	2.0	1,011,858.19	1,017,561.93	1,051,455.07	1,025,035.32	1,060,087.58	1,081,006.34	1,032,730.69	1,016,866.41
2080	90,563	2.0	1,156,727.80	1,162,412.32	1,172,161.01	1,164,169.93	1,213,547.87	1,156,505.25	1,187,515.88	1,173,469.53
2085	99,989	2.0	1,892,779.18	1,911,278.20	1,914,710.56	1,931,604.91	1,930,771.08	1,880,427.31	1,991,214.27	2,015,384.51

Transition Because of the Annual Cost
Tank Final Level Violation Only
Pump Starts, Pressure and Tank Final Level Violation

Table 5.19. Total Annual Costs for i = 17.00%

Year	Population	c	Total Annual Costs (TL) (Daily Energy + Tank + Pump Yearly Costs), (i = 17.00%)							
			650 m^3	1300 m^3	1950 m^3	2600 m^3	3900 m^3	5200 m^3	6500 m^3	7800 m^3
2015	25,000		**114,382.75**	139,505.11	165,342.65	192,144.35	247,910.96	303,521.51	362,869.91	423,572.62
2020	27,602	2.0	**124,221.61**	149,029.51	175,294.83	200,389.35	255,198.85	313,505.84	370,034.29	429,349.37
2025	30,475	2.0	**145,964.61**	**167,934.91**	192,455.40	215,852.15	273,348.29	327,899.40	385,060.69	441,546.40
2030	33,647	2.0	160,681.54	**180,925.05**	208,397.24	230,171.10	282,750.75	341,193.81	396,916.50	453,834.30
2035	37,149	2.0	182,094.90	**211,440.14**	**240,944.17**	263,970.77	309,268.81	365,096.97	420,550.69	474,314.47
2040	41,015	2.0	205,116.43	239,346.00	**261,575.08**	289,558.17	329,226.89	383,066.73	437,899.76	493,586.77
2045	45,284	2.0	260,900.58	292,390.97	**314,972.16**	**337,976.81**	382,616.90	421,797.06	479,517.88	536,819.54
2050	49,997	2.0	294,740.82	329,783.99	339,575.40	**372,386.37**	404,998.14	457,381.74	506,607.01	564,310.17
2055	55,201	2.0	388,337.96	422,163.67	451,721.03	**458,562.30**	**508,814.86**	543,948.59	602,684.15	642,412.85
2060	60,946	2.0	442,682.46	477,932.66	492,804.84	513,369.48	**560,275.50**	612,069.00	654,841.94	698,838.60
2065	67,290	2.0	630,016.45	664,662.82	694,868.70	724,574.27	**781,242.31**	**776,119.15**	810,963.90	828,812.08
2070	74,293	2.0	723,122.39	749,619.43	780,331.12	836,240.47	819,644.58	**878,901.23**	908,987.51	937,306.61
2075	82,026	2.0	1,113,420.15	1,138,424.88	1,193,337.12	1,184,260.48	1,259,355.85	**1,319,456.29**	**1,306,144.99**	1,327,220.51
2080	90,563	2.0	1,267,119.43	1,292,103.77	1,321,399.99	1,331,875.21	1,422,169.40	1,399,556.80	**1,470,364.21**	1,493,368.45
2085	99,989	2.0	2,052,251.21	2,090,831.08	2,113,425.99	2,150,303.39	2,187,325.45	2,171,819.99	2,327,266.02	2,390,816.13

Transition Because of the Annual Cost
Tank Final Level Violation Only
Pump Starts, Pressure and Tank Final Level Violation

5.13.5. Results of the Total Annual Costs

Table 5.20 shows the summary of the interest rate calculations of this study. The final shifts occurred earlier when the interest rates are low. This means that the investments return profit earlier for these interest rates. In addition, final shift of 0.05% interest rate occurs when the annual cost is 290,517.94 TL. Annual cost of 17.00% interest rate is 1,306,144.99 TL when the final shift occurs. The annual cost of 0.05% interest rate is the 22.24% of the annual cost of 17.00% interest rate when the final shift occurs. This means that the investment of 0.05% interest rate returns into profit with less cost than 17.00% interest rate. Another conclusion of the Table 5.20 is about the annual costs at the year 2075. Annual cost of 0.05% interest rate is 68.71% of the 17.00% interest rate annual cost at the year 2075. The difference occurred because of the interest rate of the regions. Daily energy, storage tank and pump costs increase when the interest rate increases.

Table 5.20. Summary of the Interest Rate Calculations

Interest Rate (%)	**Year of Final Shift**	**Population - Final Shift Year**	**Annual Cost - Final Shift Year**	**Annual Cost - Year 2075** *(7800 m^3)*
0.05	2055	55,201	290,517.94	911,922.94
0.25	2055	55,201	293,162.45	915,265.36
5.75	2065	67,290	550,207.50	1,016,866.41
7.75	2065	67,290	604,557.68	1,077,743.82
17.00	2075	82,026	1,306,144.99	1,327,220.51

The Keynesian theory of investment places emphasis on the importance of interest rates in investment decisions. Changes in interest rates should have an effect on the level of planned investment undertaken by private sector businesses in the economy. A fall in interest rates should decrease the cost of investment relative to the potential yield and as a result planned capital investment projects on the margin may become worthwhile. The inverse relationship between investment and the rate of interest can be shown in a diagram (see Figure 6.31). The relationship between the two variables is represented by the marginal efficiency of capital investment (MEC) curve. A fall in the rate of interest from R1 to R2 causes an expansion of the planned investment (Sirishakuntumalla, 2015).

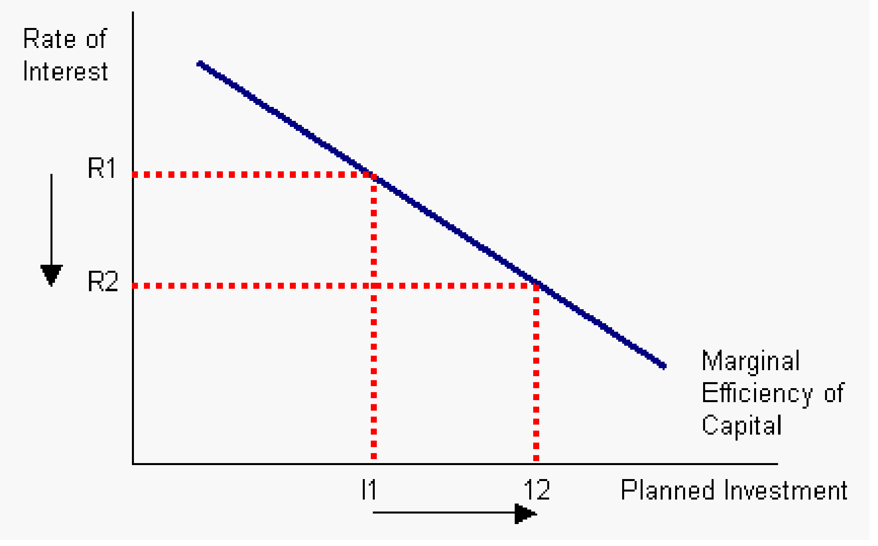


Figure 5.31. Marginal Efficiency of Capital Curve (Sirishakuntumalla, 2015)

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

One of the most important factors in lowering the costs of water is the storage tank capacity. If the storage tank volume increases, more water can be stored, and the water distribution system works more efficiently in terms of the annual costs. The conditions of the area, such as population growth, interest rate, the cost of the water distribution system elements, must be taken into account while designing the water distribution systems. The storage tank size selection process must include the optimization of the water supply system and pump scheduling. In addition, the annual cost of the water distribution system has to be calculated to minimize energy costs.

In Chapter 5, the pump scheduling analyses were performed, and the water levels of the storage tank were analysed. The optimization process cannot meet the requirements of the network in some scenarios so that violations occurred in the water distribution system. Mostly, the water level of the storage tank cannot provide the maximum water level constraint in these scenarios. The water requirements of the water supply system were changed according to the population projection of the area. The beginning year was selected as 2015, and the study was carried on 70 years. The water demand values in following years were taken from the codes of Bank of Provinces, and to find the intermediate values the third order polynomial curve was drawn. The water requirements were changed in every 5 years and the pumps were assumed to be replaced in every 10 years. Pump flow and head values were calculated by the water demand values of the N8.3 area.

The daily energy costs were calculated for the years between 2015 and 2085. Results showed that if the storage tank size increases, the daily energy costs of the network decrease. Pumps in the P23 pump station can store more water so that in the highest price periods the storage tanks can feed the network for a longer period. Annual costs of the storage tanks and pumps were included to the annual costs of daily energy costs of the system. The results of the calculations indicated that the annual costs of the water distribution network were decreased, when the storage tank size was increased. In addition, while calculating the annual costs, the interest rate was taken as 7.75% for Turkey.

The effects of the interest rates to the annual cost were examined within this study. Annual cost calculations were performed with different interest rates. Selected interest rates for this study are 0.05%, 0.25%, 5.75%, 17.00% respectively. These interest rates were selected in order to understand the interest rate effect on the annual costs. The result of the analyses showed that when the interest rates are low, the requirement of the larger tanks occurred earlier. The annual costs of the storage tanks were high when the interest rates are high and they were much greater than the daily energy costs. Therefore, the daily energy cost comparison with the storage tank costs becomes unnecessary.

Generally, in the countries that have low interest rates, the time deposit accounts in the bank profit less than the investments such as buying a property, factory construction, share dealing etc. As a result of this, institutions tend to make investments. When the interest rate increases, the investment begins to lose its meaning. The rate of return of investment must be higher than the interest rate in order to make a profit. If the country has high interest rate, the investor tends to put the money to the time deposit account in the bank.

To perform optimization calculations of water distribution system, genetic algorithm method was used in this study. Some variable values that vary over time were determined to be fixed in the optimization process. Population, storage tanks and pumps were assumed as variable in this study. Also, energy prices were changed with respect to time period of the day (Multi-tariff). According to these, 120 scenarios were optimized and the annual costs of these scenarios were calculated. The effects of the population and the storage tank to the annual costs of the water distribution system were discussed. In addition to these, the study was performed with different interest rates.

The storage tank costs, pump costs, energy prices, interest rates, growth rate, roughness coefficient of pipes and diameters of the pipes are assumed to be fixed in this study. Also the energy prices will vary during the 70 years period. The growth rate of the study area vary with respect to the time. The roughness coefficient of pipes will be decreased according to the pipe material and corrosion. The most sensitive parameter is the growth rate between these. A small change in the growth rate will change shifts in the tables. Increase in the growth will increase the water requirements and daily energy costs of the water distribution network. Consequently, shifts can occur earlier in the total annual cost tables.

The storage tank economic life is assumed to be 40 years in this study. But, the storage tank used for 70 years. At the 40th year, renewal or maintenance works will be needed for the storage tank. This will increase the annual costs at the 40th year. Therefore, the shifts in the tables can change according to the cost calculations. In addition, the pumps of the network were working at the operating point continuously along 70 years in this study. Pumps efficiencies will decrease with respect to time. The efficiency curves must be defined to the pumps during the optimization process. This will cause an increase in the daily energy costs of the network so that the shifts in the tables will occur earlier according to the annual costs of the water distribution network.

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