REHABILITATION OF WATER SUPPLY SYSTEMS

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submitted by **NEVZAT TOĞRUL** in partial fulfillment of the requirements for the degree of **Master of Science in Civil Engineering Department**, **Middle East Technical University** by,

Prof. Dr. Gülbin Dural Ünver ____________________
Dean, Graduate School of **Natural and Applied Sciences**

Prof. Dr. Ahmet Cevdet Yalçıner
Head of Department, **Civil Engineering** ____________________

Assoc. Prof. Dr. Nuri Merzi
Supervisor, **Civil Engineering Dept., METU** ____________________

Examining Committee Members:

Prof. Dr. Zuhal Akyürek ____________________
Civil Engineering Dept., METU

Assoc. Prof. Dr. Nuri Merzi ____________________
Civil Engineering Dept., METU

Assoc. Prof. Dr. Yakup DARAMA ____________________
Civil Engineering Dept., Atılım University

Assoc. Prof. Dr. Mete Köken ____________________
Civil Engineering Dept., METU

Asst. Prof. Dr. M.Tuğrul Yılmaz
Civil Engineering Dept., METU ____________________

Date: 10.12.2015

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

Name, Last name: Nevzat Toğrul

Signature :

ABSTRACT

REHABILITATION OF WATER SUPPLY SYSTEMS

Toğrul, Nevzat
M. S. Department of Civil Engineering
Supervisor: Assoc. Prof. Dr. Nuri Merzi

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Management of water supply systems by an economic and efficient way is a significant issue for water authorities. Selection and operation of water supply elements appropriately to satisfy water need affects the energy consumption of the system. This study aims to constitute a long term rehabilitation plan for water supply elements (only storage tanks, pumps and transmission line pipes are in the scope of the study). A case study has been performed on N8.3 pressure zone of Ankara water distribution network. By considering different combinations of these water supply elements, 168 different scenarios were created. By using genetic algorithm based software WaterCAD Darwin Scheduler, optimum pump schedules for each scenario were determined within the frame of target hydraulic performance requirements. The energy costs obtained according to these pump schedules were evaluated with the initial investment costs, repair and maintenance costs of the system elements used in the scenarios. A rehabilitation plan was introduced by performing cost analyses within the frame of economic life times of the system elements. The study also shows how the rehabilitation plan can be changed in case of unexpected population growth.

Keywords: Pump Scheduling, Rehabilitation, Water Supply System, Transmission Line, Storage Tank

ÖZ

SU TEMİNİ SİSTEMLERİNİN REHABİLİTASYONU

Toğrul, Nevzat
Yüksek Lisans, İnşaat Mühendisliği Bölümü
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Su temini sistemlerinin ekonomik ve verimli bir şekilde yönetilmesi su idareleri için önemli bir konudur. Su ihtiyacının karşılanması için uygun elemanların seçilmesi ve işletilmesi sistemin enerji tüketimini etkilemektedir. Bu çalışma, su temini elemanlarının (yalnız su depoları, pompalar ve iletim hattı boruları çalışma kapsamındadır) uzun dönem rehabilitasyon planını oluşturmayı amaçlamaktadır. Ankara su dağıtım şebekesinin N8.3 basınç bölgesi üzerinde bir çalışma gerçekleştirilmiştir. Su temini elemanlarının farklı kombinasyonları göz önünde bulundurularak, 168 farklı senaryo oluşturulmuştur. Genetik Algoritma tabanlı WaterCAD Darwin Scheduler yazılımı kullanılarak her bir senaryonun hedef hidrolik performans gereksinimleri çerçevesinde optimum pompa çalışma programları belirlenmiştir. Bu programlara göre elde edilen enerji maliyetleri, senaryolarda kullanılan sistem elemanlarının ilk yatırım maliyetleri, tamir ve bakım maliyetleriyle birlikte değerlendirilmiştir. Sistem elemanlarının ekonomik ömürleri çerçevesinde yapılan maliyet analizlerine göre bir rehabilitasyon planı ortaya konulmuştur. Çalışma aynı zamanda beklenmeyen nüfus gelişimi durumlarında rehabilitasyon planının nasıl değişebileceğini göstermektedir.

Anahtar Kelimeler: Pompa Planlaması, Rehabilitasyon, Su Temini Sistemi, İletim Hattı, Su Deposu

This thesis is dedicated to my wife “Kübra” and our newborn son "Kerem”

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AW: Annual worth

BoP: Bank of Provinces

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

EPS: Extended Period Simulation

FW: Future worth

h_f: Head loss (m)

H_p: Pump system 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

PW: Present 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 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 tank 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 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_{dav} : Daily average water need

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

WDN: Water Distribution Network

CHAPTER 1

INTRODUCTION

1.1 General

Water demand throughout the world is increasing by economic developments, urbanization and population increase. In addition to this, half of the people lives in urban areas and within twenty years nearly 60 percent of the world's population will be living in cities ("International Decade for Action 'Water for Life' 2005-2015. Focus Areas: Water and cities," 2015, November 20). This situation makes water supply issue more important for water authorities. Providing steady clean water to the public can be more complex than estimated due to the fact that many factors such as physical characteristics of land surfaces, population to be served, consumer behavior, industrial demands, economic sectors like tourist activities, storage of water and transport need to be considered while managing a water supply system.

Water resources are required to be managed effectively to prevent urban water crises at every stage starting from supply of water to its different usage points. Today, water authorities are trying to find alternative ways to meet the water demand of consumers by good planning, good design and effective operation. To achieve this task, new investments, improved operation and maintenance capability are needed. The policies related to operation and maintenance of water supply systems have important roles on effectiveness of the system. Even if a water system is well designed, the efficiency of the system may be low because of poor operating policy. The maintenance and rehabilitation of the hydraulic elements have to be carried out by considering the current condition of the system.

High energy consumption of the water supply systems during operation period is a common problem for water authorities because of limited capital resources. Thus, it is essential for planners and managers to find a cost-effective rehabilitation strategy. However, this is quite complicated to perform smoothly because long term rehabilitation planning and upgrading involves consideration of many factors such as storage tanks, pipelines, pumps, valves, water needs, energy costs and hydraulic performance requirements.

Components of water supply systems have different economic life times. Generally, storage tanks and pipes are considered as having 30-35 years economic lifetime while pumps are considered as 10-15 years economic life time. At design stage, these components are designed by considering their economic life time and they are supposed to be changed at the end of this period. On the other hand, engineer should also think about the performance of these components in the upcoming years. Because unexpected population growth can make system components operate inefficiently. A storage tank may be changed before the end of economic lifetime as the storage capacity becomes insufficient or a pump may be changed because of decreased efficiency due to over designed flow rate and high energy consumption. These types of conditions make rehabilitation a current issue for the system components.

Rehabilitation of existing water distribution systems is becoming an inevitable need to provide an effective and economical operation. Thus, a comprehensive methodology should be developed to assist planners and decision makers in determination of the most cost-effective rehabilitation policy.

1.2 Purpose of the Study

This study aims to provide a rehabilitation plan for the existing water supply system which is in the N8.3 pressure zone of Ankara water distribution system. The components of the system which are storage tanks, pumps and transmission line are examined in scope of this study. The hydraulic model of the water supply system is adapted from the study of Şendil (2013).

Within the frame of target hydraulic performance requirements, 168 different scenarios were created by the combinations of storage tank, pumps and transmission line pipes of the system. By using genetic algorithm based software WaterCAD Darwin Scheduler, optimum pump schedules and energy costs of each scenario were determined. The energy costs and initial investment costs of the system elements are evaluated within the frame of economic life times by performing economic analyses.

This thesis contains four chapters. In the first chapter, brief information was given about the thesis. In the second chapter, the methodology of the study was explained by giving information about the hydraulic system elements of the system, economic considerations in engineering point of view and operation logic of the optimization technic, genetic algorithm. The case study took part in chapter three and this chapter covered all the technical calculations, solutions and results of the study. Finally, in the last chapter, results of the study were discussed and some recommendations were given.

CHAPTER 2

METHODOLOGY

2.1 Technical Considerations

Water distribution systems are composed of basically several hydraulic components such as pump(s), pipes, storage tank(s) and valves.

2.1.1 Components of Water Distribution Systems

2.1.1.1 Pumps

Pumps are the machines working by mechanical action to overcome elevation differences and head losses due to pipe friction and fittings. They are important components of water distribution systems to supply needed mechanical power for transportation of water.

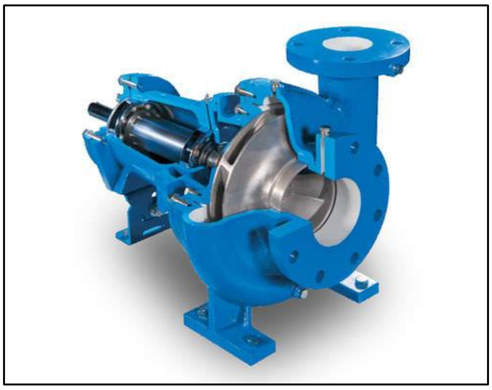


Figure 1 A Centrifugal Pump ("Centrifugal Pump Aurora,"2015,November 20)

There are different types of pumps for different requirements. Pump types can changed according to system requirements, pressure requirements, flow capacities and available space. In this study, centrifugal pumps are selected while designing the system. The impellers of the centrifugal pumps are in circular shape that is mounted on the center of the shaft. An example of centrifugal pump is shown in Figure 1.

Although pumps have lower initial investment cost than other components, they consume highly considerable amount of electrical energy. In this context, selecting the appropriate pump for a unique system is very important. Pumps have characteristics that as the discharged amount increase, total head decreases. On the other hand, while discharge amount increases, head losses in the system become larger. To find the best operating point, Figure 2 can be used as a guide.

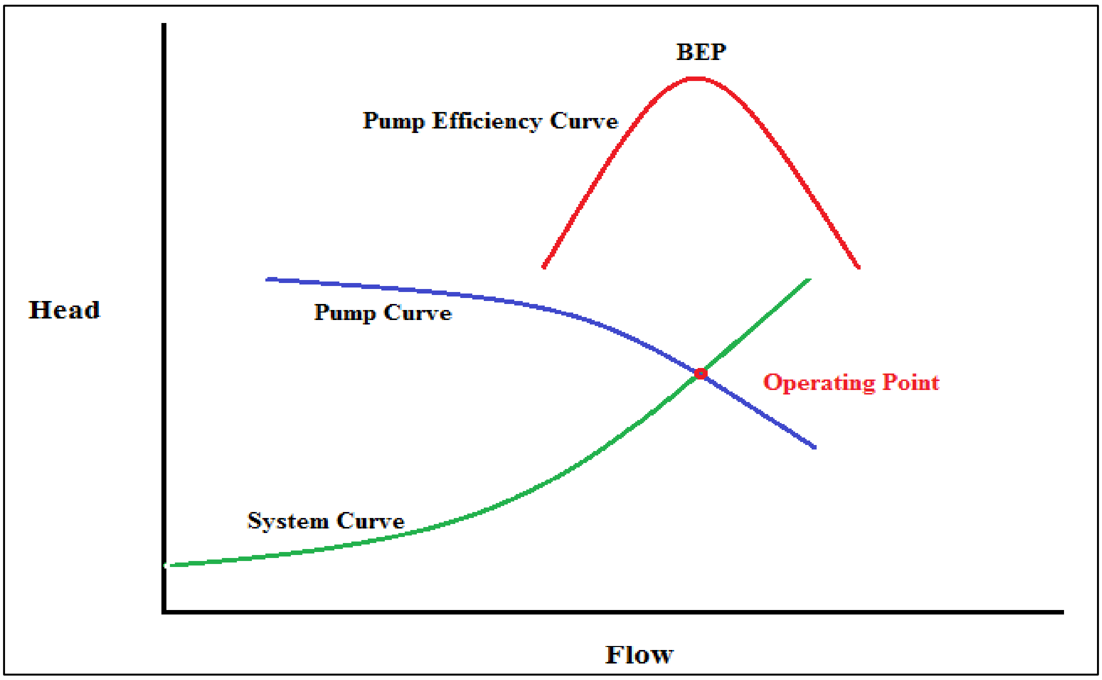


Figure 2 Pump Head-Flow Diagram

Pumps are manufactured according to some specific design criteria and efficiency. While selecting the appropriate pump for the system, the best efficiency point (BEP) should be taken into consideration. This is necessary as the pump works in out of the design range, the efficiency of the pump decreases.

2.1.1.2 Storage Tanks

Storage tank makes easy to deal with demand management, supplies water in a condition of failure, for emergencies such as fire and helps for pump flow rate modulation. When properly designed and located, storage tanks are a cost-effective means of improving overall network performance (Boulos et al., 2002).

Storage tanks usually placed on high level topography to transfer water by gravitational forces. Elevation of the tank should be so selected that water pressures in the system remain in the allowed interval. According to water demand, water level of the tank may fluctuate. In peak hours, tank supplies water to the system and in low demand times, water is stored in the tank. For some cases such as firefighting and other emergency cases, there should be adequate amount water available in the tank.

Figure 3 A Storage Tank with Cylindrical Shape (“Water storage tanks - WaterWorld,” 2015,November 20)

Storage tanks are available in many shapes: vertical or horizontal cylindrical shape; prismatic shape and open top or closed top. The construction material of storage tanks can be plastics, reinforced concrete, stone, fiberglass or steel. An example for cylindrical shape storage tank is shown in Figure 3. In Turkey, storage tanks are generally constructed by reinforced concrete. The storage tank used in this study is an underground reinforced concrete storage tank with a prismatic shape.

2.1.1.3 Pipes

Pipes have a role of transferring water in a closed conduit in water distribution system. Pipes make connections between pumps, storage tanks, valves and reservoirs. There are various pipe alternatives which are poly vinyl chloride (pvc) pipes, high density polyethylene (hdpe) pipes, low-density polyethylene (ldpe) pipes, concrete pipes, cast iron pipes, ductile iron pipes and steel pipes.

Pipes are selected according to their characteristics such as, diameter, composition material, friction coefficient and maximum allowable working pressures. In water supply systems, pipelines are designed for transmission lines, distribution network and service to households.

Pipes of transmission line are generally bigger diameter because they transfers huge amount of water between pump station, storage tanks and network nodes. In Figure 4, an example for pipeline is shown. Service connection pipes are small in diameter, transfers water between household and network node. Distribution network pipes transfer water between overall networks.

Figure 4 An Example of Transmission Pipeline System (“Water Pipe - mydropintheocean,” 2015, December 02)

2.1.1.4 Valves

Valves control the movement of the flow in water distribution systems. When any repair is necessary in pipelines of the network, valves can be used to stop supply. There are various type of valves, some of which are air valves, check valves, flow control valves, isolation valves, pressure reducing valves and drain valves.

2.1.1.5 Fire Hydrants

Fire hydrant is an important component of a water distribution system. Because, it can be used for various needs. The first usage purpose is to fight against fire. Locating a fire hydrant nearby the fire area is very important for water authorities. It is also used for air release at high level points and for flushing to improve the water quality in the pipes. As fire hydrants are designed to provide huge amount of water and high pressure, they are usually placed on larger diameter pipes of the system.

2.1.2 Extended Period Simulation (EPS)

Extended Period Simulation (EPS) shows the hydraulic analysis carried out for a defined time period. It is the simulation of basically storage tank, pump and demand behavior in specified period such as 24 – 144 hours. The reactions of the system components upon different water demands, such as how tank levels fluctuate during the day, when and how pumps are running, the cost and water quality of the water distribution system, can be monitored by means of EPS.

In this study, 24 hour period simulation was executed and 1 hour hydraulic time step was chosen to collect data. The more hydraulic time step is shorten the more data can be collected as the solution space increases depending on the time interval. As a result, it gives more accurate results for the system.

2.1.3 Rehabilitation of Water Supply Systems

In the advancing years, water supply systems age and experience some problems such as deteriorating infrastructure, water loss, service cut, head loss problems loosing carrying capacity, pipe breakage or cracks, pump being out of service at pipes and insufficiency of storage tank, pump capacity and pipe diameter. Addition of unexpected population brings unexpected water demands. To overcome all these problems, a well thought rehabilitation policy is required to prevent performance loss.

Performance of the systems is mostly related with the sufficiency and reliability of the system components. Thus, rehabilitation of the water system appears to be inevitable on upcoming years. Improvement of the performance can be achieved through planning of repair and maintenance of the network components. Provision of replacing, duplicating or repairing of the water supply components shall increase the efficiency and performance of the system.

A comprehensive cost analysis on existing system components especially pumps, storage tanks and transmission lines must be performed by considering initial investment costs and energy cost of the system together. By this way, a long term rehabilitation plan can be achieved to prevent performance loss on upcoming years.

2.2 Engineering Economy

Economy has an important role in engineering decisions. To assess the pertinence of alternatives, engineers need to use economic analysis for their projects. Engineering economy helps on formulation, evaluation and estimation from an engineering stand point. Engineering economy mostly deal with the future time frame. Calculation of what is expected takes part in economic analysis and it affects engineering decision. Some terminologies explained in this section are present worth, future worth and annual worth of money in addition to concepts of interest rate and economic life.

2.2.1 Interest Rate

Interest is the price of money that is borrowed for a time period. This price is calculated by interest rate on the basis of principal given for a defined period of time. Interest rate is calculated by dividing the amount of interest by the amount of principal. For long time frame, the interest period is generally taken as 1 year. Sub periods of quarters, months, weeks and days can also be considered.

In this study, interest rate of Central Bank, which is updated as 7.5% on February 24th, 2015, was taken into consideration for the calculation of cost analysis.

2.2.2 Economic Life

Economic life of an asset can be defined as the period of time to be usable with normal repair and maintenance. It can also be called as useful life or service life. Time frame is usually expressed in years. In economic analysis, assets are evaluated with their economic life. In this study, economic life of pumps is considered as 12 years and for tank and pipes of the water distribution systems are considered as 36 years.

2.2.3 Present Worth

Present worth is the value of an asset in current time. Because the time value of money, earning potential, it is always less than or equal to the future value. The calculation formula of present value is shown below. Eq. 3.1 shows the calculation of the present worth from annual value and Eq. 3.2 shows the calculation of present worth from the future value.

$$PW = AW * \frac{(1+i)^n - 1}{i * (1+i)^n} \tag{3.1}$$

$$PW = \frac{FW}{(1+i)^n} \tag{3.2}$$

Where,

PW: Present Worth

AW: Annual Worth

FW: Future Worth

i: Interest Rate

n: Number of Years

An example of present worth calculation can be seen in Figure 5;

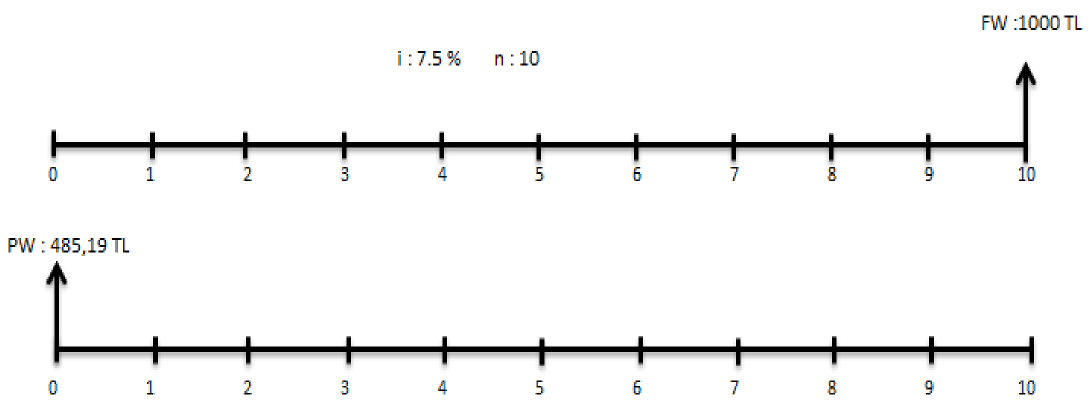


Figure 5 Calculation of the Present Value from the Future Value

2.2.4 Annual Worth

Annual worth of an asset is the equivalent uniform worth during economic life. To evaluate the alternatives economically, annual worth calculation gives chance to evaluate the operating and maintaining cost together with owning cost.

The annual worth calculation formulas are shown in the below equations. Eq. 3.3 shows the calculation of the annual cost from the present value and Eq. 3.4 shows the calculation of the annual cost from the future value.

$$AW = \frac{PW}{\frac{(1+i)^n - 1}{i * (1+i)^n}} \tag{3.3}$$

$$AW = \frac{FW * i}{(1+i)^n - 1} \tag{3.4}$$

Where,

AW: Annual Worth

PW: Present Worth

FW: Future Worth

i: Interest Rate

n: Number of Years

An example of annual worth calculation can be seen in Figure 6;

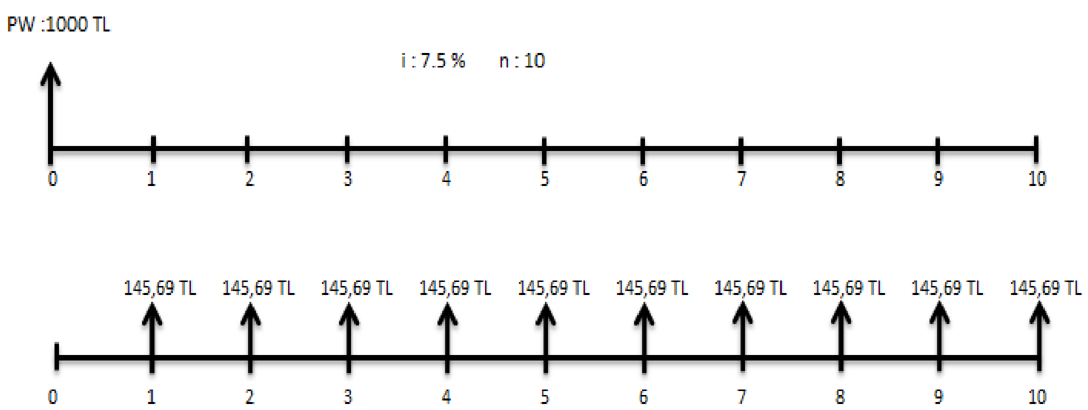


Figure 6 Calculation of the Annual Cost from the Present Value

2.2.5 Future Value

As the time passes, money decreases in value. Future worth of an asset shows the future value after a specified time period. For a given future time and interest rate, future value is calculated by below equations. Eq. 3.5 shows the calculation of the future worth from annual value and Eq. 3.6 shows the calculation of future worth from present value.

$$FW = \frac{AW * ((1+i)^n - 1)}{i} \tag{3.5}$$

$$FW = PW * (1+i)^n \tag{3.6}$$

Where,

FW: Future Worth

AW: Annual Worth

PW: Present Worth

i: Interest Rate

n: Number of Years

An example of annual worth calculation can be seen in Figure 7;

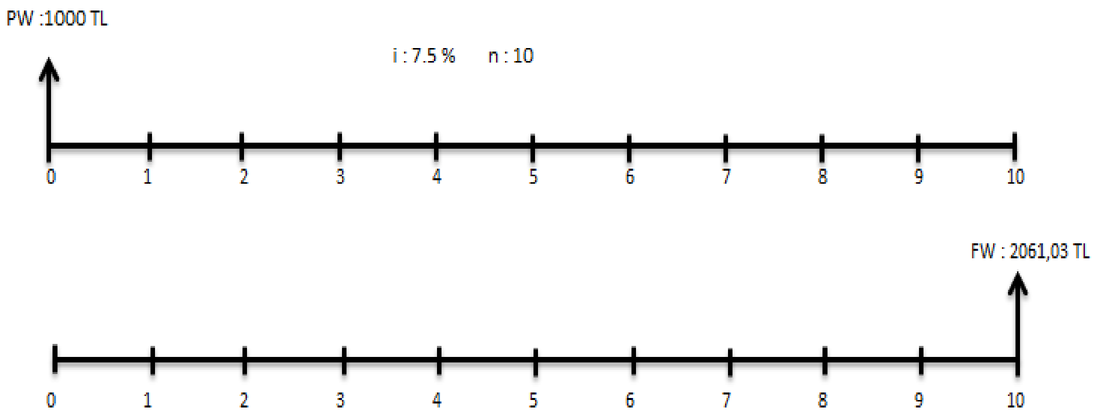


Figure 7 Calculation of the Future Value from the Present Value

2.3 An Optimization Method: Genetic Algorithm

Growing population, changing water demands, different types and capacity of pumps, different diameters of network pipes and tanks connected to each other make operation issue more complex and more difficult. To deal with this complexity and difficulty, some optimization methods are used to find the optimal operation of the systems. However which method performs better cannot be determined because none of them succeed in all optimization problems.

Pumps work by consuming electrical energy for transfer of water. To make pump operation cost minimum, optimal pump schedule should be performed. In this study, pumps were considered to work in 3 different time period which are subject to 3 different energy prices. To achieve the cheapest energy cost, pumping schedule of the pumps were found by the help of genetic algorithm based WaterCAD Darwin Scheduler.

2.3.1 Genetic Algorithm

Genetic Algorithm is an optimization method that bases on the logic of Darwinian selection. If one understands how the selection of population takes over time due to the environmental conditions then the logic of the GA can be understood (Van Rooyen and Van Vuuren, n.d.).

The working steps of Genetic Algorithm can be summarized as below:

- All possible solutions in the searching space are coded as series.
- A solution space is chosen randomly and it is accepted as initial population.
- For all series a convenience value is calculated and this value shows the quality of solution.
- A group of series is randomly selected according to its probability value and reproduction is executed.
- After convenience value of new individuals are calculated, crossing and mutation processes are executed.
- These processes continue until reaching to the predetermined generation number.

- Iteration is stopped upon reaching to the generation number and the most convenient series are selected according to objective function.

Objective function of this study is the minimization of the pumping cost. (Boulos et al., 2002) defines a function to find the minimum cost as below.

Objective Function (Fitness Function):

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

Where, N represents the number of pumps; T is control time span; $C_n(t)$ is unit energy cost of pump n at schedule time; $E_n(t)$ is the energy consumption during the schedule time interval from t to t + 1 with a pump control setting; $Emax_n^{bp}$ is maximum energy consumption of pump n during billing period bp; $C_n(bp)$ is the maximum demand charge for pump n during billing period bp and NBPn designates the number of billing periods for pump n.

While trying to find the minimum energy cost, hydraulic conditions must also be considered. One can define constraints to satisfy the requirements of the water distribution system. Three types of constraints can be defined in genetic algorithm. These are implicit system constraints, implicit bound constraints and explicit variable constraints. In water supply systems, implicit system constraints are used. These constraint are generally the hydraulic requirements of the system and user defined constraints are also viable.

Constraints:

The constraints that are considered in this study are as below;

I. Nodal Constraints

Nodes in the system must be in a predefined pressure interval that is called $P_{max,j}$ for maximum pressure and $P_{min,j}$ for minimum pressure values at node j and time t. The pressure at the node j is $P_j(t)$ and the mathematical expression is as below;

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

II. Pipe Constraints

Velocity of flow has considerable effects on pipes. So a limitation must be considered for the velocity of flow in pipes. In the below equation Vmax shows the maximum velocity and Vj (t) is the velocity of any pipe j during the time interval t.

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

III. Storage Tank Constraints

Storage tanks must always some volume in case of firefighting and emergency conditions. Tanks also must not overflow. To adjust this situation, water level must stay in allowable levels. TL_{min} and TL_{max} are minimum and maximum tank level at time t. TL_k (t) is the water level in storage k at time interval t.

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

To provide the continuity of the simulation for every day, the final level of the tanks must not be lower than the initial tank level. For this reason, another constraint must be defined as below;

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

Here, the final and initial water level of the storage tank k represented by TL^{final} and $TL^{initial}$ respectively; and ΔTL_k is the allowable tolerance of the final water level for the storage tank k.

IV. Pump Switch Constraints

There is a direct relationship with Pump maintenance cost and pump switches. To minimize the wear effect, the maximum number of pump switched must be defined. The constraint for the limitation of switches can be expressed as below:

$$SW_k \leq SW_{max,k}(t) \qquad \forall k \qquad (4.6)$$

Here, SW_k represents the number of pump switch for pump k; and $SWmax_k$ represents the maximum allowable number of pump switches for pump k.

In pumping schedule, the explicit variable constraints are used to control setting values. By considering the physical characteristics such as pump capacity, location and control tank, pumps must be grouped together. The pumps within a group gain an identical operation (Boulos et al., 2002).

For identical pump groups, the pump control setting can only be on or off in a defined time t. It can be defined as:

$$\forall \mathrm{k}, \forall \mathrm{t}, \forall S_k(t) \in S^0 = \{1, 0\} \quad (4.7)$$

Where, S_k (t) represents the control setting of pump k at the time interval t.

The working mechanism of the genetic algorithm can be shown in Figure 8.

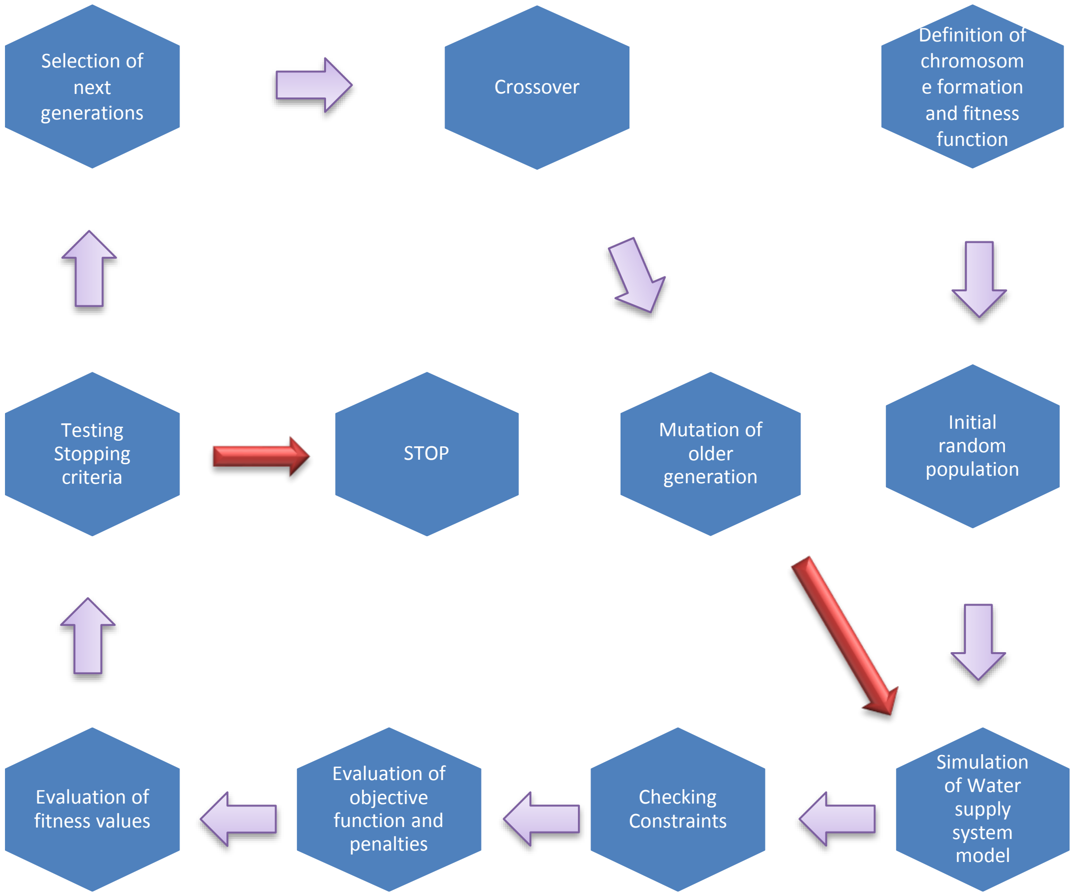


Figure 8 Flow Diagram of Genetic Algorithm

2.3.2 Parameters and Definitions

To find optimum solution, genetic algorithm is used in the software, WaterCAD Darwin Scheduler. The parameters were defined as follows (Şendil, 2013):

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

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

Number of Crossover Points = 4: It shows the number of cut points in each parent chromosome during crossing over

Probability of Crossover = 95%: It is the probability of crossover operation which is performed at the cut points.

Probability of Mutation = 1.5%: It is the probability of random change in solution.

Probability of Creeping Mutation = 0.1%: It is the occurrence chance of creeping mutation to generate child chromosome.

Probability of Creeping Down = 65%: The probability that a gene in a child chromosome will mutate to a smaller value.

Probability of Elite Mate = 0.5: It is the selection probability of an elite chromosome for the usage of next generation.

Probability of Tournament Winner = 95%: It is the probability of selecting the fit chromosome within two chromosome tournament.

<u>Stopping Criteria:</u>

Maximum Generations = 1000: It is the maximum generation number to run the genetic algorithm optimization.

Maximum Trials = 100000: It is the maximum number of trials wanted the optimized run to process before stopping.

Maximum Non Improvement Generations = 200: It is the maximum number of non-improvement generations.

Penalty Factors:

Pressure Penalty: 1000

Velocity Penalty: 1000

Pump Starts Penalty: 10000

Tank Final Level Penalty: 10000

Tank High/Low Level Penalty: 1000

CHAPTER 3

CASE STUDY

The operation of existing systems can be troublesome for water authorities. Increasing water demands, unsatisfactory performance of the system components and uneconomic operation schedule make authorities reconsider the structure of the system. By replacement, rehabilitation, duplicating or repairing of system components, system's performance can be improved. Addition of new components can also help to increase the performance of the system (Walski et al., 2003).

In this chapter, a rehabilitation strategy has been followed by performing cost-efficiency analysis. Initial investment costs of alternative system components (pumps, transmission line pipes and storage tanks) were evaluated with associated energy costs within the frame of hydraulic performance requirements.

3.1 Study Area

The study area is located within the boundaries of Keçiören and Yenimahalle districts of Ankara, the capital of Turkey. According to TurkStat, (2015b), Ankara has a population of 5,150,072 by the end of year 2014 and the growth rate of population was 2.06%. According to TurkStat, (2015a), Keçiören has a population of 872,025. The amount of water drawn in Ankara was 217 liters per day per capita (TurkStat, 2012).

The region selected for this study is N8.3 pressure zone of Ankara water distribution system. The location of the study area is shown as white area in Figure 9. It is located in the northern water supply zone of the city. There are six District Metered Areas (DMA's) in the region which are East Çiğdemtepe, West Çiğdemtepe, Şehit Kubilay, North Sancaktepe, South Sancaktepe and Yayla Districts.

Figure 9 Location of Study Area

N8.3 pressure zone of the water distribution system supplies water to the area which is located between 1075 m - 1115 m elevation intervals. In this area, there is a pump station named by P23 which contains 3 parallel identical centrifugal pumps and feeds N8.3 network completely. The storage tank of the system is T53. Water need of the area is supplied by pump station and storage tank together.

The reservoir of N8.3 zone has an elevation of 1,106.81 m. The storage tank height is 6.5 meters and the base elevation of the tank is 1,149.82 m. The tank is an underground rectangular base reinforced concrete storage tank. The WaterCAD based hydraulic model of the network is adapted from the study of Şendil (2013).

3.2 Flowchart

The methodology of the study is shown as flowchart in Figure 10.

Figure 10 Flowchart of the Study

3.3 Population Projection

The population of the region is assumed to be 50,000 in 2015. The growth rate was selected as 2.5 because of construction of high residential buildings and increasing immigration rate to the region. The population estimation of the region determines the water requirements of the inhabitants for each study years. Estimated populations were calculated for 3 year interval by the method of Bank of Provinces.

$N_g = N_y \times (1 + (c/100))^{(30 + n)}$ where, (5.1)

N_g: Future population

N_y: New census

c: Growth rate (assumed as 2.5)

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

Here, as the construction time was not considered in this study, the value of "n" was taken as zero and the start year is considered as 2015. The calculated future populations are listed in Table 1.

Table 1 Estimated Future Populations of the Region

Years	Future Population (Ng)
2015	50,000
2018	53,845
2021	57,985
2024	62,443
2027	67,244
2030	72,415
2033	77,983
2036	83,979
2039	90,436
2042	97,390
2045	104,878
2048	112,943
2051	121,627

3.4 Water Requirements

The water requirements of the system according to different population ranges were tabulated in Table 2 according to Technical Specifications of Bank of Provinces, 2013.

Table 2 Water Requirement Values (İller Bankası A.Ş., 2013)

Beginning Population	**Domestic Water Consumption (lt/day/cap)**
N<=50000	80-100
50000<N<=100000	100-120
100000<N	120-140

As it is seen on Table 2, domestic water consumption amount is defined as an interval for the defined population interval. To determine a specific value for each year, a first order trend line was drawn as shown in Figure 11.

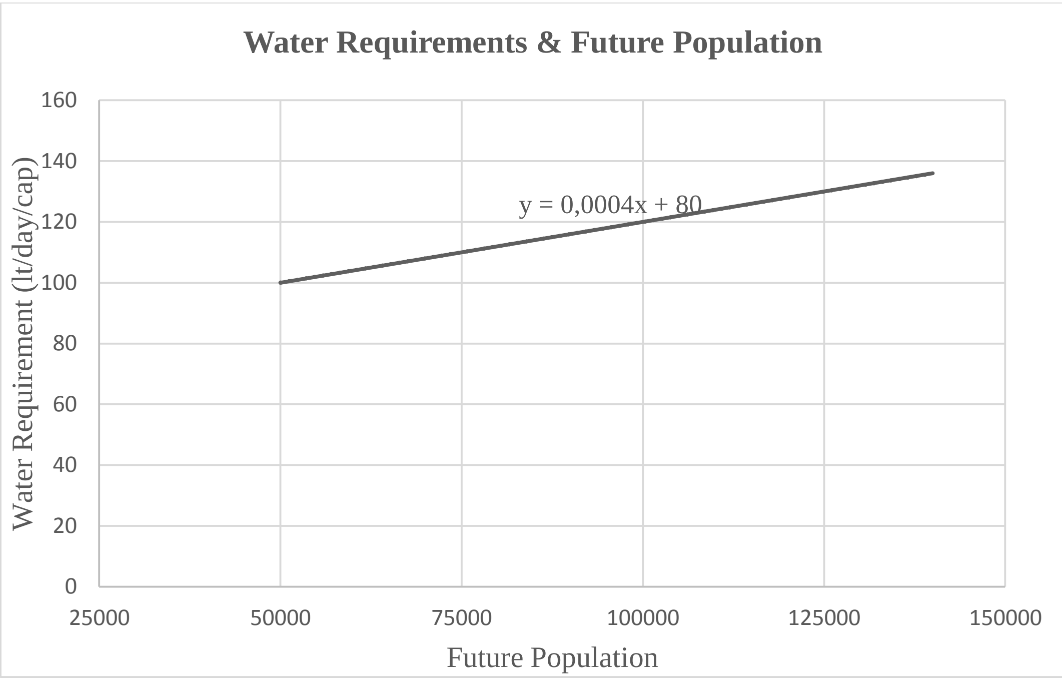


Figure 11 Water Requirements Trend Line

The annual daily demand values and characteristic discharge values for each estimated population were calculated by using below equations:

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

$$Q_{max} = Q_{annual} \times 1.5 \quad (5.3)$$

Where,

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

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

According to the trend line in Figure 11, the specific water requirements can be calculated. The water requirements for each study years can be seen in Table 3.

Table 3 Calculated Water Demands of N8.3 Region.

Water Demands of N8.3 Region				
Year	**Future Population**	**Demands (lt/day/cap)**	**Demands (lt/s), Q_{annual}**	**Demands (lt/s), Q_{max}**
2015	50,000	100.00	57.87	86.81
2018	53,845	101.54	63.28	94.92
2021	57,985	103.19	69.26	103.88
2024	62,443	104.98	75.87	113.80
2027	67,244	106.90	83.20	124.80
2030	72,415	108.97	91.33	136.99
2033	77,983	111.19	100.36	150.54
2036	83,979	113.59	110.41	165.61
2039	90,436	116.17	121.60	182.40
2042	97,390	118.96	134.09	201.13
2045	104,878	121.95	148.03	222.05
2048	112,943	125.18	163.63	245.45
2051	121,627	128.65	181.10	271.66

3.5 Demand Patterns

Demand pattern is a kind of model to show the trend of water need for each time and each node. The demand pattern of each node can change in time. To express the nodal demand pattern of each district, Şendil (2013) had recorded the water demand of the system in his study. These nodal demand patterns are shown in Figure 12.

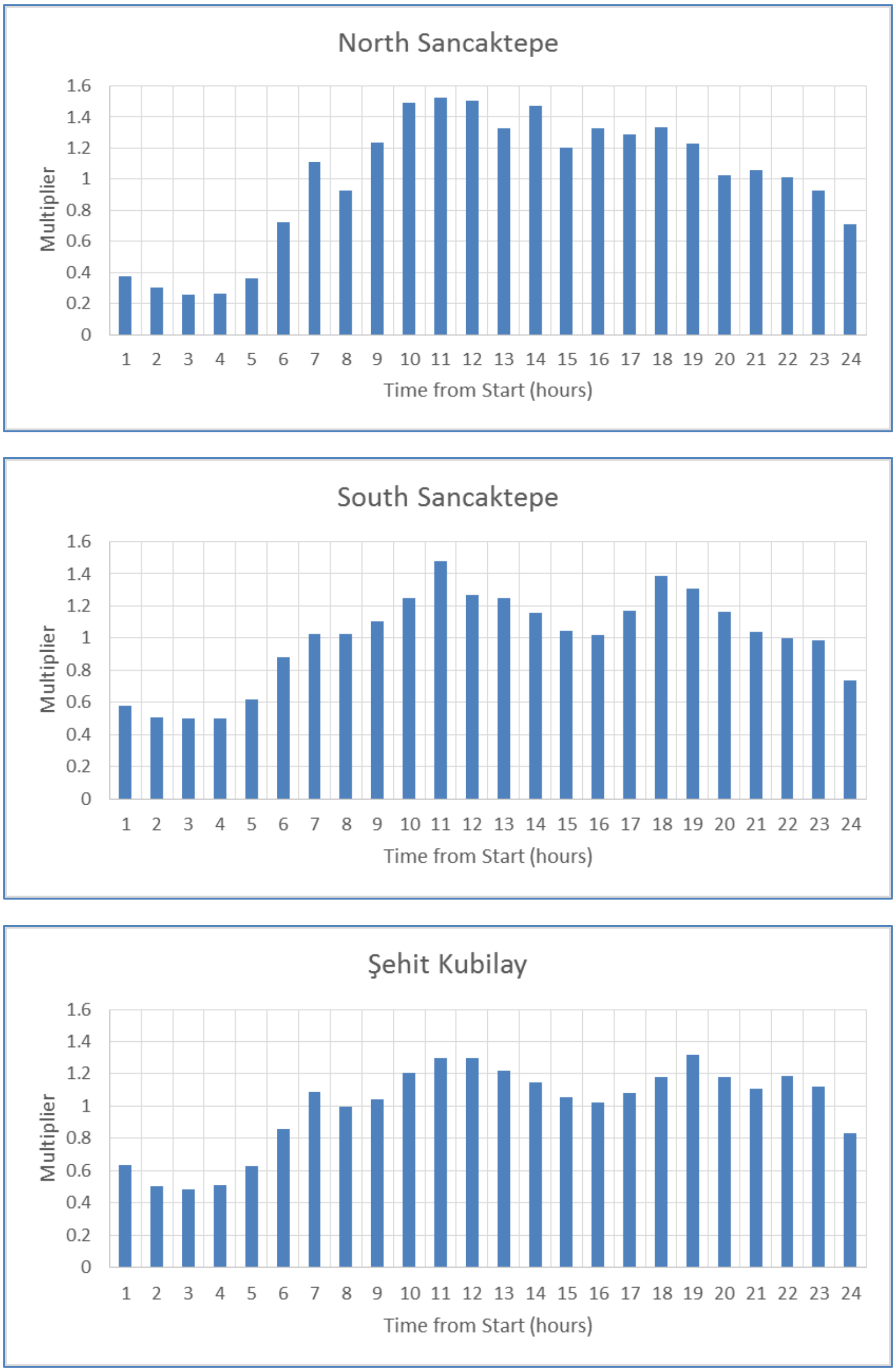
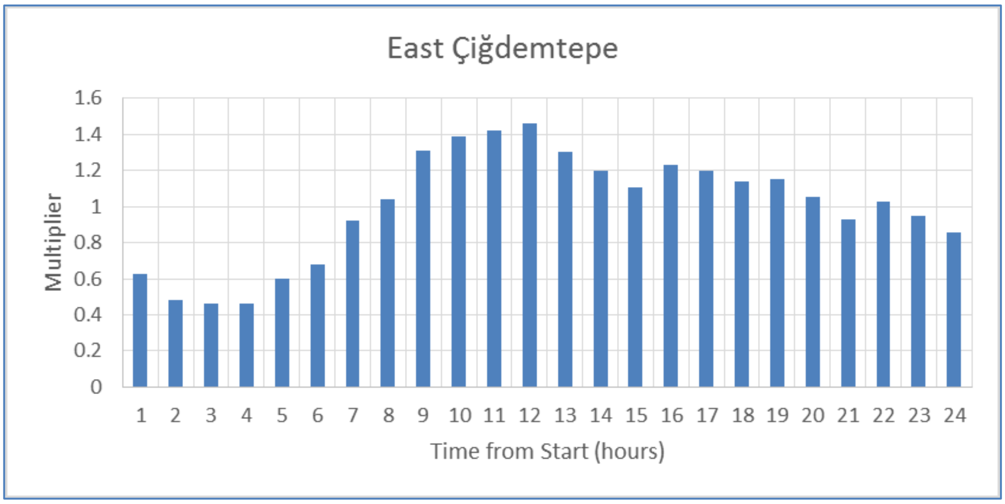
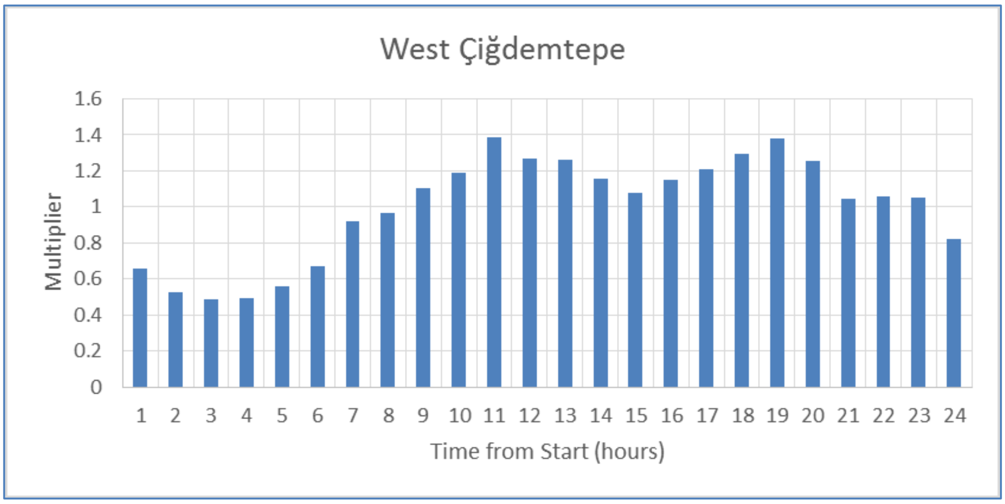


Figure 12 Demand Patterns of N8.3 Zones (Şendil, 2013)





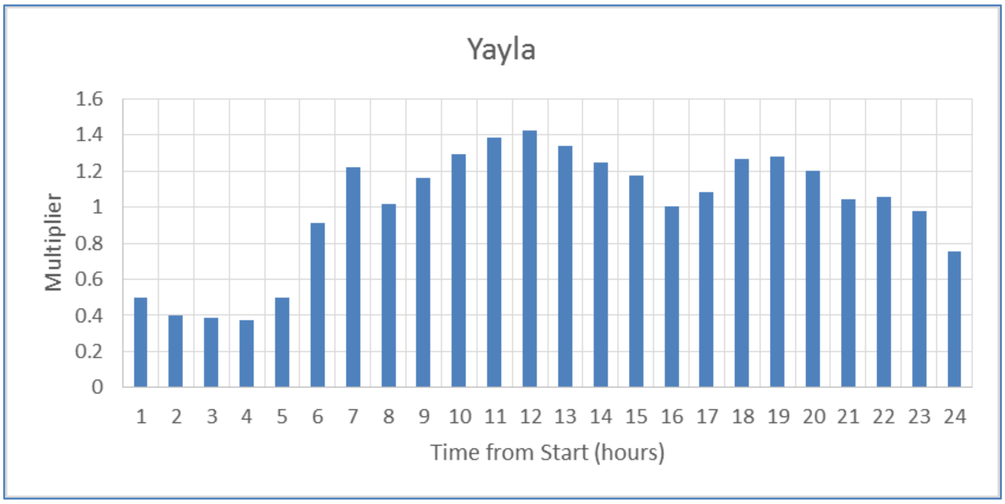


Figure 12 (cont'd) Demand Patterns of N8.3 Zones (Şendil, 2013)

3.6 Energy Prices

The electricity distribution of Ankara is provided by Başkent Electricity Distribution Company. The pricing policy is made by two tariffs which are fixed price and multi priced tariff. In this study, to calculate the energy cost of the system, multi tariff energy prices were used. According to energy prices updated on April 2015, the last applied commercial multi tariff prices are listed in Table 4;

Table 4 Multi Tariff Energy Prices (“Türkiye Elektrik Dağıtım A.Ş.” 2015, May 20)

Time Interval		Multi Tariff Energy Price (TL/kWh)
Day	06:00 - 17:00	0.2943
Peak	17:00 - 22:00	0.4479
Night	22:00 - 06:00	0.1787

3.7 Transmission Line

Transmission lines deliver water from source to the point of use and/or to the storage tanks. In the water distribution system as it is seen from the Figure 13, transmission line - blue line - is feeding both the storage tank and the network directly.

Characteristics of the pipes have a crucial role concerning the performance of the water distribution system. Because it affects pump design, energy consumption, hydraulic requirements and maintenance of the system. In this study, the material of the transmission pipeline is selected as ductile iron with an economic life time of 36 years. This type of pipes requires little maintenance and has long economic life. It withstands severe conditions like high-pressure applications, heavy earth and traffic conditions.

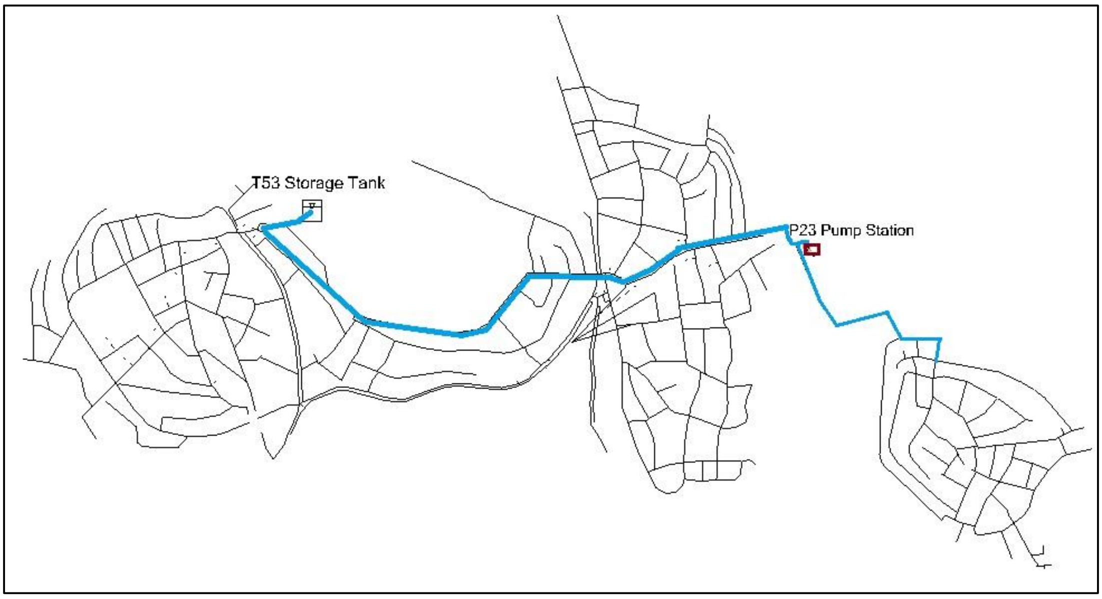


Figure 13 N8.3 Water Distribution System Including Transmission Line

Another issue about pipes is the pipe diameter and length. Transmission line length was measured as 2,726.08 m. At the beginning of the study, the diameter of the transmission line pipes was selected as 300 mm, 400 mm and 500 mm respectively. By making a cost-effectiveness analysis, it was seen that the cheapest alternative is the usage of pipe with 400 mm diameter. Then, the pipe diameter was selected as 400 mm and pump design calculations were made according to this.

While building scenarios, pipe diameter of the transmission line was also wanted to be changed but in this condition replacing a bigger diameter of pipe with the existing one was not practical and applicable. For this reason, as a second alternative, laying a second pipe with 400 mm diameter was preferred. In this study, 2 options were considered concerning the transmission line; one pipe with 400 mm diameter and two pipes side by side with 400 mm diameter each.

3.8 Pumps

Pumps are used to move fluids in the pipes by mechanical power. They operate by a mechanism that consumes energy to transfer the fluid. In this study, three identical and parallel connected centrifugal pumps were used. These pumps were designed by 6 years look ahead and assumed to have a life time of 12 years. The pumps used in the system were designed and selected in every 3 years.

In this study, pumps were assumed to have an average maximum efficiency of 85%. All the pumps were chosen according to the catalog values of SMS (Samsun Makine Sanayi) Company. The characteristics of the pumps were entered to the software, WaterCAD as "three-point pump". The flow vs head curves of the pumps were drawn as similar to the catalog graphs of SMS Company.

The design heads of the pumps are directly related to the pipe diameter, pipe length, pipe friction coefficient and discharge. As it is stated in Section 5.7, the pipe diameter is selected as 400 mm in 2015 and pump design calculations were made according to this pipe diameter.

Before the calculation of the pump system head, the friction loss in the pipe was calculated according to Hazen - Williams's equation as shown below:

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

Where,

h_f: Head Loss (m)

C: Pipe Roughness Coefficient, 130

L: Length of Pipe (m), Transmission Line Length = 2,726.08 m

Q: Discharge (m^3/s)

D: Diameter (m)

To calculate the pump head, the equality of energy must be written;

$$H_p = H_s + h_f \quad \text{where,} \quad (5.5)$$

H_p: Pump System Head (m)

H_s: The Static Head, difference between storage tank and reservoir (m)

Elevation of N8.3 reservoir = 1106.81 m

Elevation of storage tank = 1149.82 m,

The height of the storage tank = 6.50 m

Pump design flows and pump design heads were calculated for each 3-year interval as in Table 5.

Table 5 Pump Characteristics by Each Study Year

Pumps	**Design Flow (lt/s)**	**Design Flow (m^3/h)**	**Design Head (m)**
P_{2015}	103.88	373.98	54.21
P_{2018}	113.80	409.69	55.07
P_{2021}	124.80	449.27	56.11
P_{2024}	137.00	493.17	57.35
P_{2027}	150.54	541.95	58.80
P_{2030}	165.61	596.21	60.60
P_{2033}	182.40	656.65	62.80
P_{2036}	201.13	724.07	65.46
P_{2039}	222.05	799.38	68.66
P_{2042}	245.45	883.61	72.56
P_{2045a}	271.66	977.96	77.32
P_{2045b}	271.66	977.96	57.22
P_{2048}	301.05	1,083.78	58.84
P_{2051}	334.06	1,202.62	60.82

Pump curves and efficiency curves of the designed pumps are shown in Figures 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26 and 27.

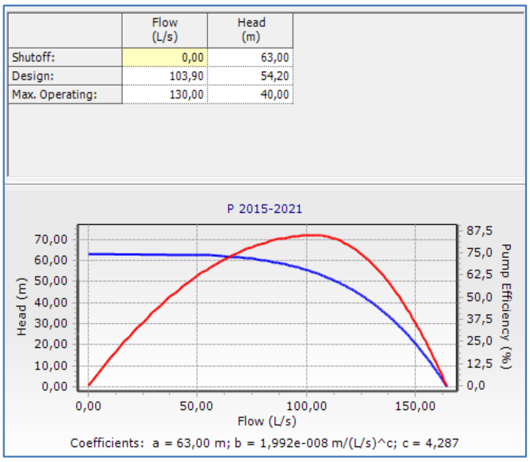


Figure 14 Pump Curve of the P_{2015}

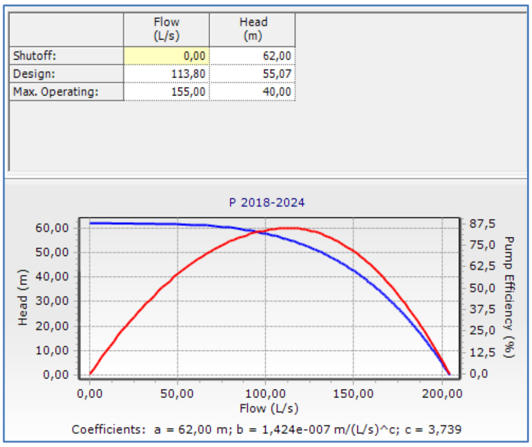


Figure 15 Pump Curve of the P_{2018}

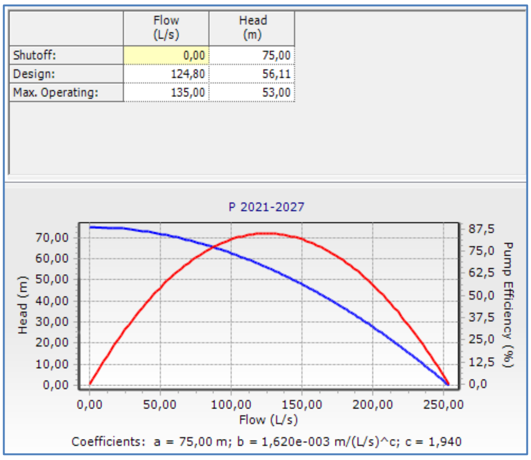


Figure 16 Pump Curve of the P_{2021}

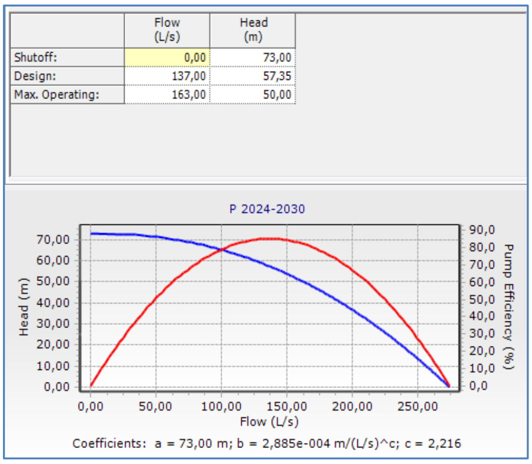


Figure 17 Pump Curve of the P_{2024}

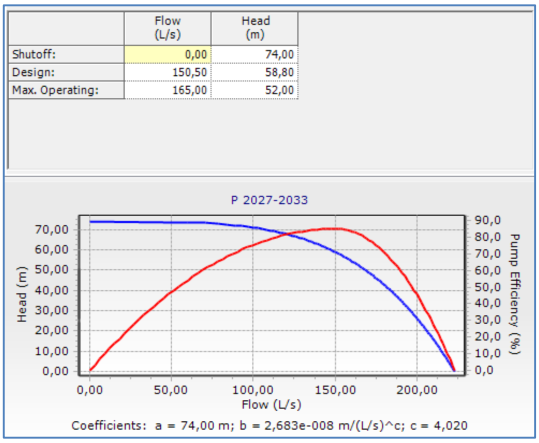


Figure 18 Pump Curve of the P_{2027}

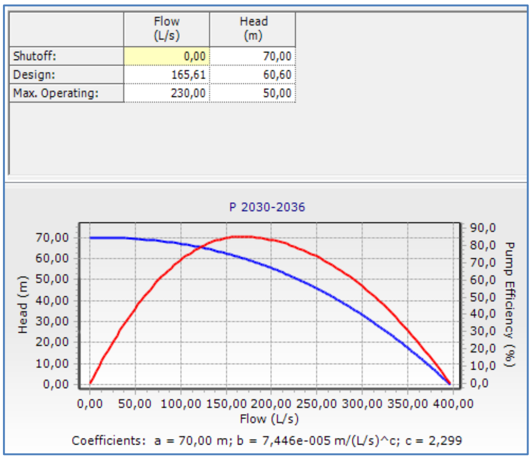


Figure 19 Pump Curve of the P_{2030}

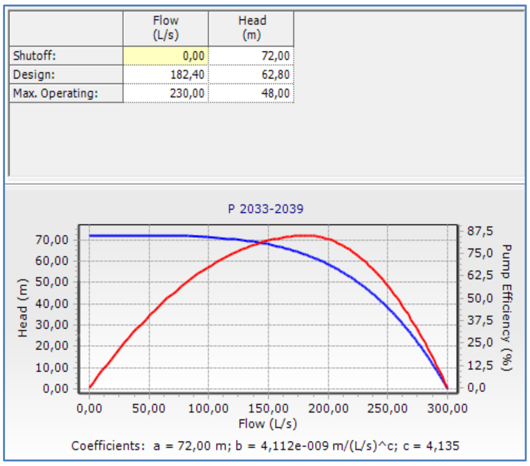


Figure 20 Pump Curve of the P_{2033}

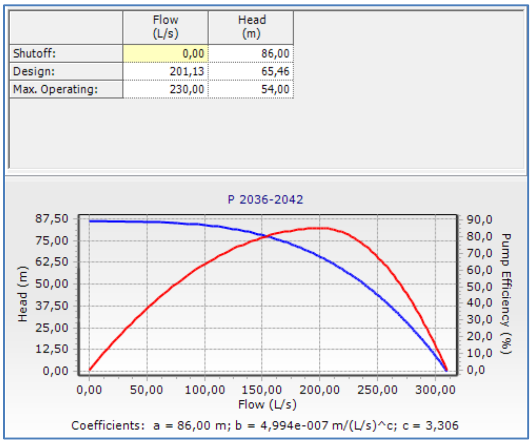


Figure 21 Pump Curve of the P_{2036}

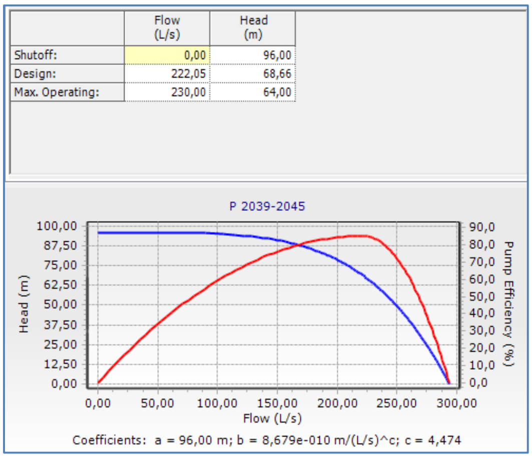


Figure 22 Pump Curve of the P_{2039}

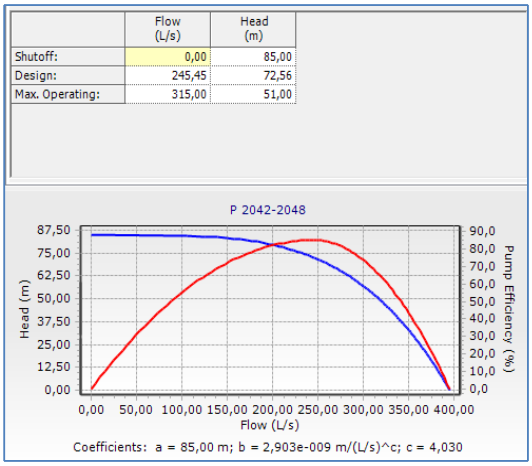


Figure 23 Pump Curve of the P_{2042}

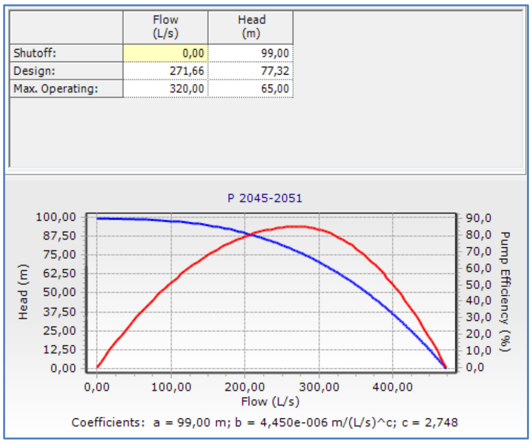


Figure 24 Pump Curve of the P_{2045a}

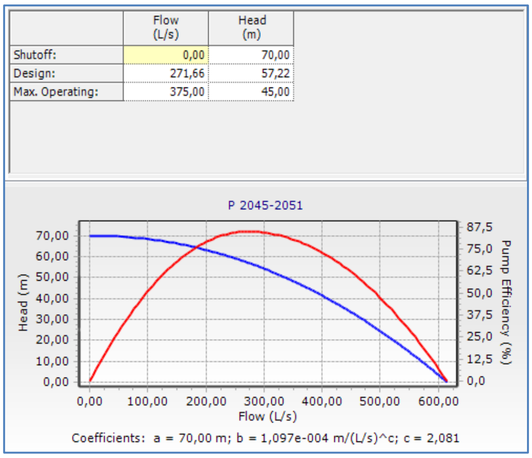


Figure 25 Pump Curve of the P_{2045b}

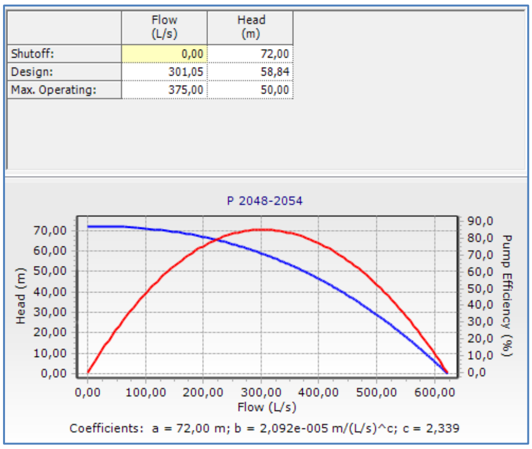


Figure 26 Pump Curve of the P_{2048}

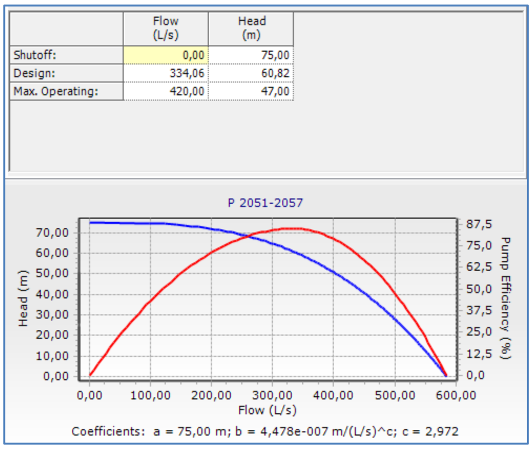


Figure 27 Pump Curve of the P_{2051}

3.9 Storage Tank

Storage tanks have some important duties such as storing water for assuring water supply in case of emergency and firefighting, adjusting pressure of the system and demand management.

Storage tanks have a small initial cost considering the overall system however they have significant effects on the energy cost of the system. Choosing the appropriate volume for the system can decrease the energy cost On the other hand, insufficient tank volume affects the operation of the pumps adversely and decreases the efficiency of the system. This situation also increases the maintenance cost of the pumps because of the increment in the number of switches of the pumps.

The size of the storage tanks are determined by considering daily and hourly water consumption, fire flow, emergency need and the efficiency variance of the reservoir (İller Bankası A.Ş., 2013).

According to The Specification of Bank of Provinces, storage tank volume can be calculated as follows;

$$V = V_{balance} + V_{fire} + V_{emergency} \qquad (5.6)$$

$$V = V_{dav}/3 + V_{fire} + V_{dav}*10/100 \qquad (5.7)$$

Where,

V : Needed volume of storage tank

V_{dav} : Daily average water need

$V_{balance}$: The balance volume, 1/3 of the daily average water need

V_{fire} : Firefighting water need, defined as 432 m^3 in the Table 5.1 of BoP Specification

$V_{emergency}$: Emergency water need, 10% of the daily average water need

The population of the region in year 2015 was selected as 50,000. According to the Table 5.3, average water demand for 50,000 people is 100 lt/day/cap. So daily average water need can be calculated as 5000 m^3.

According to the Eq. 5.7, the storage tank volume can be find as follows:

V = 5000/3 + 432 + 5000*10/100

V = 2598.67 m^3, the volume of the storage tank can be taken as 2600 m^3.

In this study, 4 different size of store tanks were considered while building different combinations of the components. These storage tanks have the capacity of 2600 m^3, 5200 m^3, 7800 m^3, 10400 m^3.

3.10 Initial Investment Costs

3.10.1 Pipe Cost

Within the scope of this study, only the transmission pipeline was analyzed by considering the water system pipes. Initial investment cost of the transmission line construction was calculated by the unit prices of BoP and Ministry of Environment and Urbanization. All the work items to construct the transmission line were considered and the quantity survey was done. As a result of the calculations, the unit price of laying 400 mm in diameter, 1 meter length, ductile iron pipe was found as 323.09 TL/m. The unit price of a 400 mm+ 400 mm diameter pipe side by side was calculated as 626.18 TL/m. By considering the length of the transmission line which is 2,726.08 meters, total initial investment cost can be calculated as in Table 6.

Table 6 Initial Investment Cost of Transmission line

Pipe Diameter (mm)	Unit Price (TL/m)	Length (m)	Total Cost (TL)
400	323.09	2,706.08	687,004.91
400 + 400	626.18	2,726.08	1,374,009.82

3.10.2 Pump Cost

As an initial cost, pump cost takes very small part in the budget of water distribution systems. In P23 pump station, there are 3 parallel pumps which are identical centrifugal pumps. The pumps and the prices are listed in the Table 7.

Table 7 Pump Costs

Pumps	Flow (lt/s)	Head (m)	Unit Price (1 piece) (TL)	Total Price (3 pieces) (TL)
P_{2015}	103.88	54.21	24,390.00	73,170.00
P_{2018}	113.80	55.07	25,590.00	76,770.00
P_{2021}	124.80	56.11	29,340.00	88,020.00
P_{2024}	136.99	57.35	30,000.00	90,000.00
P_{2027}	150.54	58.84	34,650.00	103,950.00
P_{2030}	165.61	60.64	37,725.00	113,175.00
P_{2033}	182.40	62.82	40,800.00	122,400.00
P_{2036}	201.13	65.46	41,940.00	125,820.00
P_{2039}	222.05	68.66	48,390.00	145,170.00
P_{2042}	245.45	72.56	55,980.00	167,940.00
P_{2045a}	271.66	77.32	63,570.00	190,710.00
P_{2045b}	271.66	57.22	59,550.00	178,650.00
P_{2048}	301.05	58.84	62,850.00	188,550.00
P_{2051}	334.06	60.82	66,750.00	200,250.00

3.10.3 Tank Costs

The storage tank used in this study is an underground reinforced concrete storage tank with a prismatic shape. Initial investment costs of storage tank construction were calculated with the unit prices of BoP and Ministry of Environment and Urbanization. All the work items to construct the storage tank were considered and the quantity survey was done. At the end of the calculations, the unit prices according to different tank sizes are listed in the Table 8.

Table 8 Storage Tank Prices

Storage Tank Volume (m^3)	Price (TL)
2600	946,599.00
5200	1,846,979.00
7800	2,747,359.00
10400	3,647,739.00

3.10.4 Operation and Maintenance Cost

There is a need of calculating the annual operation and maintenance cost of newly constructed plants. As it is understood from its name, operation and maintenance cost is that needed expenditure for every year to perform its expected function. Operation and maintenance cost and also renewing cost must be calculated separately for each component. Generally, operation and maintenance expenditures are calculated by multiplying the investment cost with a coefficient that is called as operation and maintenance factor (Karataban, 1976). Some of these coefficients that was used in this study can be listed as in Table 9.

Table 9 Operation and Maintenance Cost Coefficients (Karataban, 1976)

Network Components	Coefficient
Pump	0.015
Transmission Line Pipe	0.020
Storage Tank	0.010

3.11 Energy Cost

Energy cost of water distribution system generally constitutes the largest expenditure for Local Authorities worldwide and it may consume up to 65 percent of Authority's annual operating budget. Decreasing the energy cost of the system is a crucial task. To deal with this issue, decreasing the volume of water pumps by adjusting pressure zone boundaries, lowering pump head if it is possible, using the storage tanks affectively in the cheaper electricity tariff period (by scheduling of daily pump operations), provide pumps to work near their best efficiency points (Boulos et al., 2002).

In this study, to find the most economical way of operating the water distribution system of N8.3 region, various combinations of pumps, storage tanks and pipe diameters were tried to be found by building different scenarios.

3.12 Scenarios and Alternatives

Scenarios and Alternatives are the necessary tools of network modeling while building different combinations for combining the water distribution system components on the software WaterCAD.

Alternatives include different model data and they form the base for scenarios. All the information related with the components are recorded in different alternatives. Scenarios keep many alternatives. It makes easy to create and run different combinations of the WDS model. Building scenarios with different alternatives gives the answer of "what about in that case?" question. For example, to compare the result of two different combinations of pipe diameter "x" mm and "y" mm, two scenarios can be built by changing the pipe alternative within a single model. By this way, user can analyze the results of different scenarios easily.

3.12.1 Terminology

While building different scenarios, some terminologies were used to define the combinations.

Scenario Code: Txxxx, Yxxxx – #, (D)
Txxxx: Defines the volume of storage tank in m^3 unit
Yxxxx: Defines the considered projected year
"#": Defines the pump option, (1 or 2).
(D): The diameter of the pipe used

For example; the scenario "T5200, Y2018-1,(400)" represents the system with 5200 m^3 storage tank, 400 mm transmission pipeline and 1st pump option in the year 2018.

In this code, Pumps were designed for each projected year. For the beginning year, 2015, only one type of pump was designed and for the following years, there are 2 types of pumps (1st and 2nd) for each projected year. It is because to find the best pump for each projected year. By evaluating the pump and energy cost of 13 different projected years with 2 different pump option, the cheapest option was found and this pump was assumed as the best pump option and was used for the following projected year.

3.12.2 Constraints

Defining constrains to operate the system in allowable hydraulic limits was necessary while building the scenarios. The constraints used in this study are as follows:

- Service elevations were set between 1075 – 1115 meters to service the consumers in pressure zone N8.3.
- Minimum pressure constraint was set to 3 bars which is defined in the specification of BoP.
- Minimum tank level was set to 1.75 meters to be able supply water for the purpose of firefighting and managing emergency situations.
- Tank initial level was set to 2.5 meters and the final level of the tank was not allowed to be lower than 2.5 meters to provide the continuity of the schedule.
- The number of pump starts was set to maximum 3 to keep the maintenance cost of the pumps in allowable limits.

3.12.3 Considered Scenarios

The scenarios were built on the water supply system which is in the N8.3 pressure zone. Optimum pump schedules of each scenario were found and daily energy costs were calculated by the help of Darwin Scheduler (WaterCAD Software). Water levels in storage tank T53 and graphs of pump flows were obtained by 24 hours period simulation analyses.

In this study, 14 different pumps, 4 different sizes of tanks, 2 different pipe options for transmission line and 13 different demand combinations were considered while building scenarios. In this way, 168 different scenarios were built to see the effects of different combinations to the energy cost of the WDS.

3.12.4 Daily Energy Costs

Daily energy cost of the system is the cost of energy consumption of the pumps in the P23 pump station in 24 hours period. Pumps operate according to the pump schedule of each scenario to satisfy the water need. T53 storage tank and the network are fed by P23 pump station. As it was stated in section 3.12.2, to provide the continuity of the simulation for every day, the final level of the tank must not be lower than the initial tank level which is 2.50 m. Thus, in the condition that the final level of the tank is higher than 2.50 m, pumping cost of the overstored volume was reduced from the total energy cost of the scenario. In this section, some of the scenarios and their tank level and pump flow versus time graphs are explained.

Year 2015

The scenarios were built at starting year 2015. For this year, population of the study area was selected as 50,000 and the water demand was calculated as 86.81 lt/s. The WDN had been considered according to 4 different tank volumes which are 2600 m^3, 5200 m^3, 7800 $m^3$and 10400 m^3. While building scenarios, one type of pump named as P_{2015} which was designed by 6-year population projection and one transmission line pipe with diameter 400 mm were considered. By this way, 4 different scenarios had been composed which are “T2600, Y2015-1, (400)”, “T5200, Y2015-1, (400)”, “T7800, Y2015-1, (400)”, “T10400, Y2015-1, (400)”.

Scenario: T2600, Y2015-1, (400)

Optimum pump scheduling analysis was performed to find the minimum daily energy cost of the scenario. The minimum cost of the scenario was found as 327.93 TL without any violation. The optimization of the pump schedule was performed based on the multi tariff energy prices. As the cheapest price is between 22:00-06:00, the storage tank was filled in this period however to meet the midday demand, one pump started to operate and to hold the water level in allowable levels, pumps started to operate in the expensive period. In this scenario, all the pumps were started at least one time and totally 7,743.42 m^3 water was pumped in 24 hours. Pump operation period is shown in Figure 28.

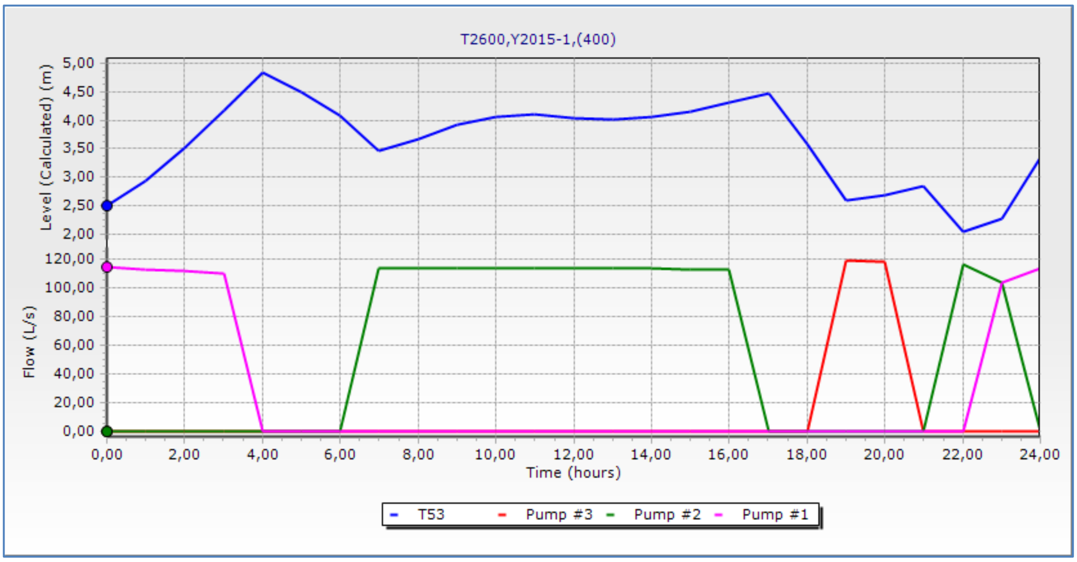


Figure 28 T53 Storage Tank Water Level and Pump Flow versus Time Graph – T2600, Y2015-1, (400)

Year 2018

There are two types of pump options for the year 2018. The first one is the pump which is used in 2015 with the name P_{2015} and the second one is newly designed with name P_{2018}. Additionally, a second pipe option was also considered by laying a 400 mm pipe near existing one. In this way, 400 mm + 400 mm transmission line option was also considered while composing the scenarios. 16 different alternatives were considered while building scenarios. According to population projection, the number of residents in the study area was calculated as 53,845 and 94.92 lt/s water need accordingly.

Scenario: T2600, Y2018-1, (400)

In this scenario, the pump, P_{2015}, were used in P23 pump station. They were used with the previous study year also however the water demand of the WDN was changed according to projected population in year 2018. As the pumped water amount increased pumps operated more and they consumed more energy. In this scenario, all the pumps were started two times and totally 8,507.50 m^3 water was pumped in 24 hours. As a result of the pumping schedule shown in Figure 29, the minimum daily energy cost of the scenario was found as 369.97 TL without any violation.

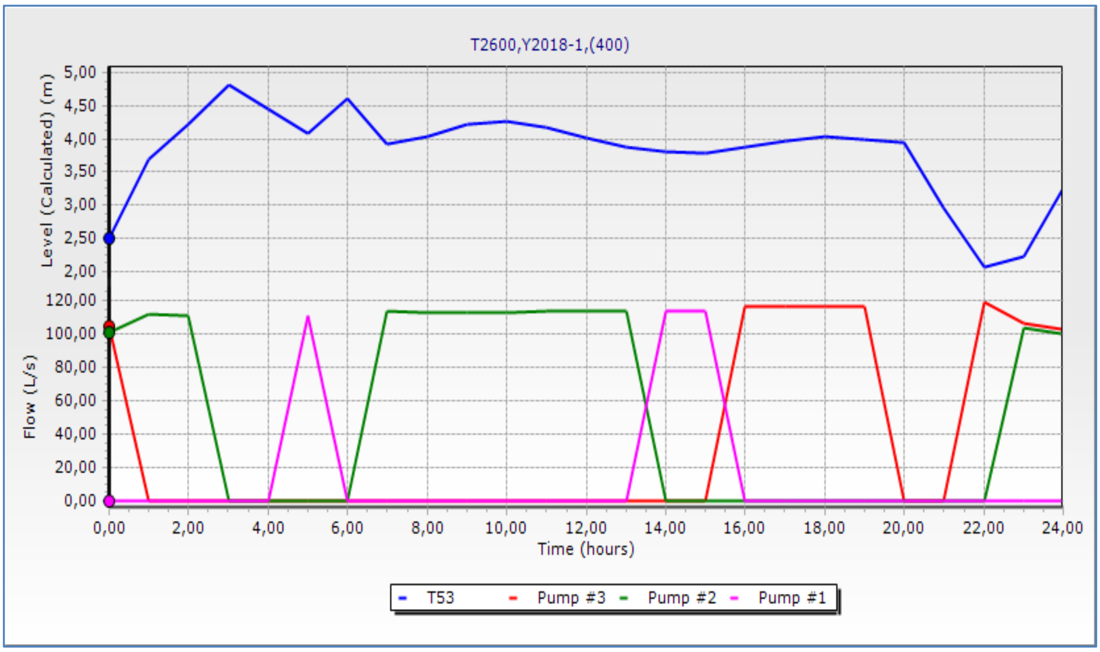


Figure 29 T53 Storage Tank Water Level and Pump Flow versus Time Graph – T2600, Y2018-1, (400)

Scenario: T2600, Y2018-2, (400)

The difference of this scenario from the previous one is the pump used. Here, a new pump, P_{2018}, was designed according to increased water demand in 2018. As the pumped water amount increased pumps operated more and they consumed more energy. In this scenario, pumps were used frequently and totally 9.018,97 m^3 water was pumped in 24 hours. As a result of the pumping schedule, the minimum daily energy cost of the scenario was found as 368.64 TL without any violation. Water level of the tank fluctuates all the day and maximum water level reaches to 4.95 m. Water levels in the tank and pump operation periods is shown in Figure 30.

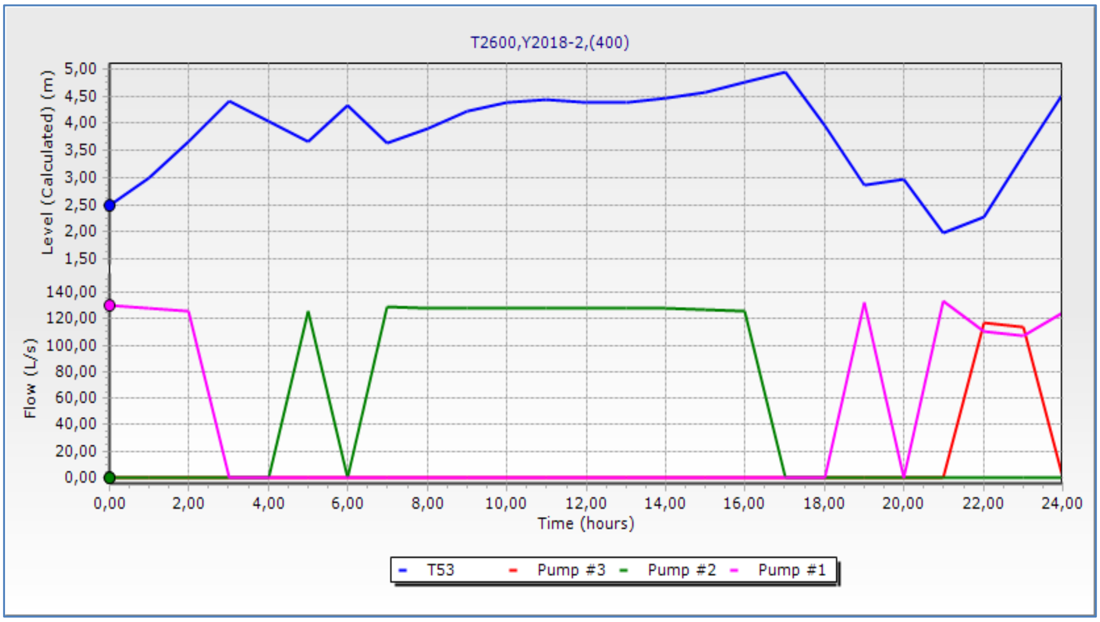


Figure 30 T53 Storage Tank Water Level and Pump Flow versus Time Graph – T2600, Y2018-2, (400)

Scenario: T2600, Y2018-2, (400+400)

In this scenario, another 400 mm pipe was laid beside the existing one. By this way, the same tank and pump, P_{2018}, with transmission line pipes 400 mm+ 400 mm option was evaluated. Using larger diameter pipe or multiple pipes ease the transfer of water by reducing the friction losses and lowering the pumping head. This scenario was built to check the effect of pipe diameter. After pump scheduling of the system, the daily energy cost of the scenario was calculated as 367.38 TL without any violation. In Figure 31, water level in the storage tank reaches to 4.66 m level and finishes the day at 2.57 m as final level.

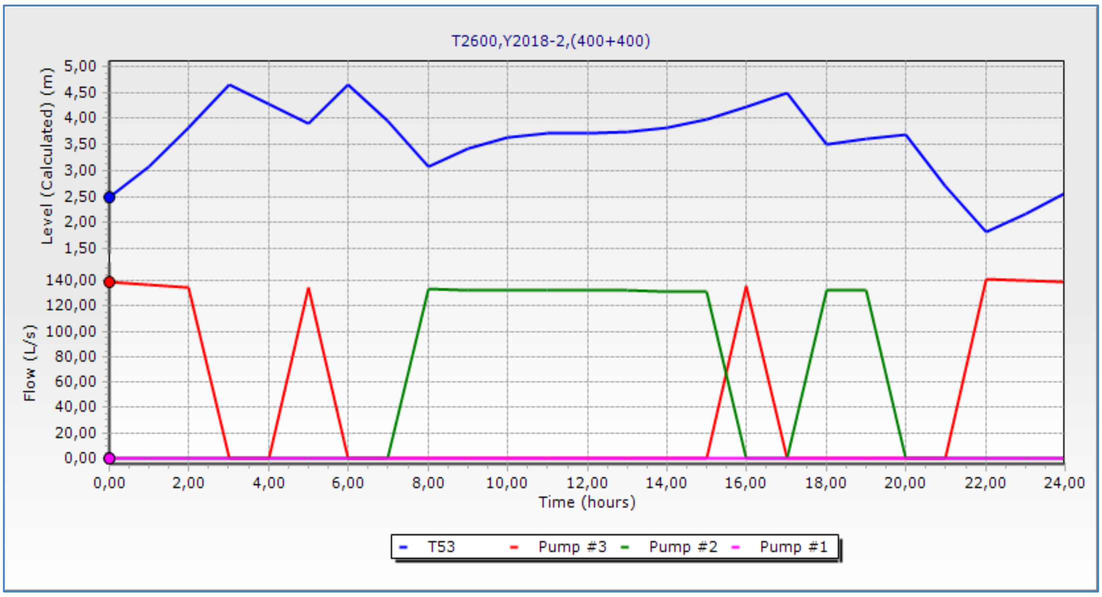


Figure 31 T53 Storage Tank Water Level and Pump Flow versus Time Graph – T2600, Y2018-2, (400+400)

Year 2021

There are 16 different scenarios built for this year. As the time past, water demand is increasing just as population. For this year, population of the study area was calculated as 57,985 and the water demand was calculated as 103.88 lt/s. There are two types of pumps evaluated which are P_{2015} and P_{2021}.

Scenario: T2600, Y2021-1, (400)

This scenario was composed by using 400 mm diameter transmission line pipe, P_{2015} pump and 2600 m^3 storage tank. To find the minimum energy cost of the system, optimum pump scheduling analysis was performed. The best solution of the optimization was calculated as 411.15 TL which is the daily energy cost of the scenario. The optimized schedule tends to fill the storage tank between 22:00 and 06:00 because of cheaper energy tariff so that the water level in storage tank increases at night period. In Figure 32, it is seen that water level reaches to 4.74 m during the day and schedule ends the day with final level 3.11 m. At the end of the day, totally 9.221,21 m^3 water is pumped to the tank and network.

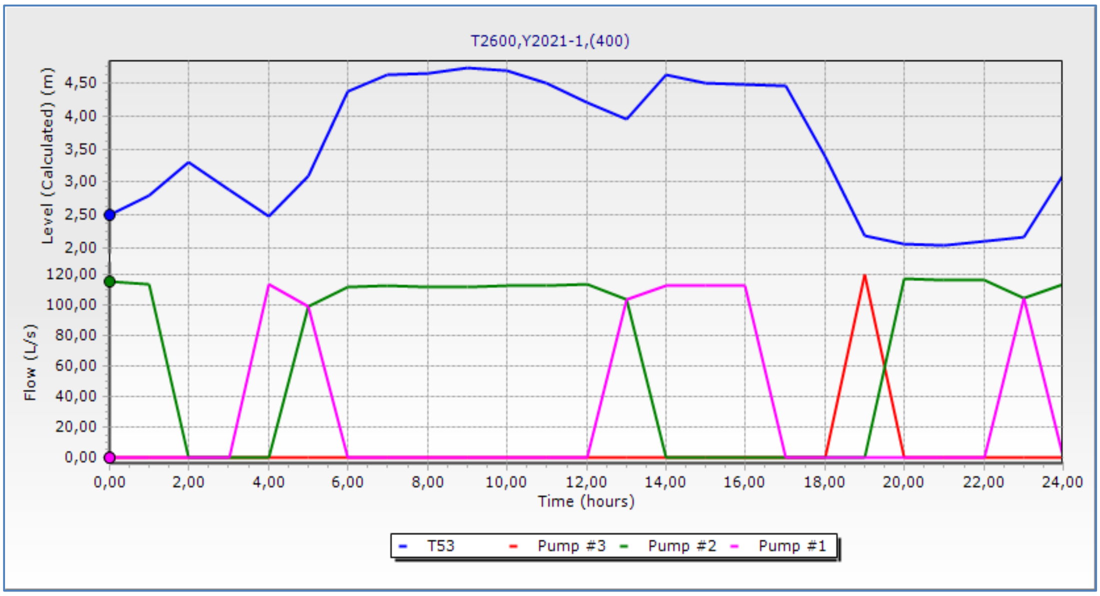


Figure 32 T53 Storage Tank Water Level and Pump Flow versus Time Graph – T2600, Y2021-1, (400)

Scenario: T2600, Y2021-1, (400+400)

This scenario was composed by using two pipes in 400 mm diameter each. The same pump P_{2015} and 2600 m^3 storage tank were also considered in this scenario. As a result of the pumping schedule, the minimum daily energy cost of the scenario was found as 405.43 TL without any violation.

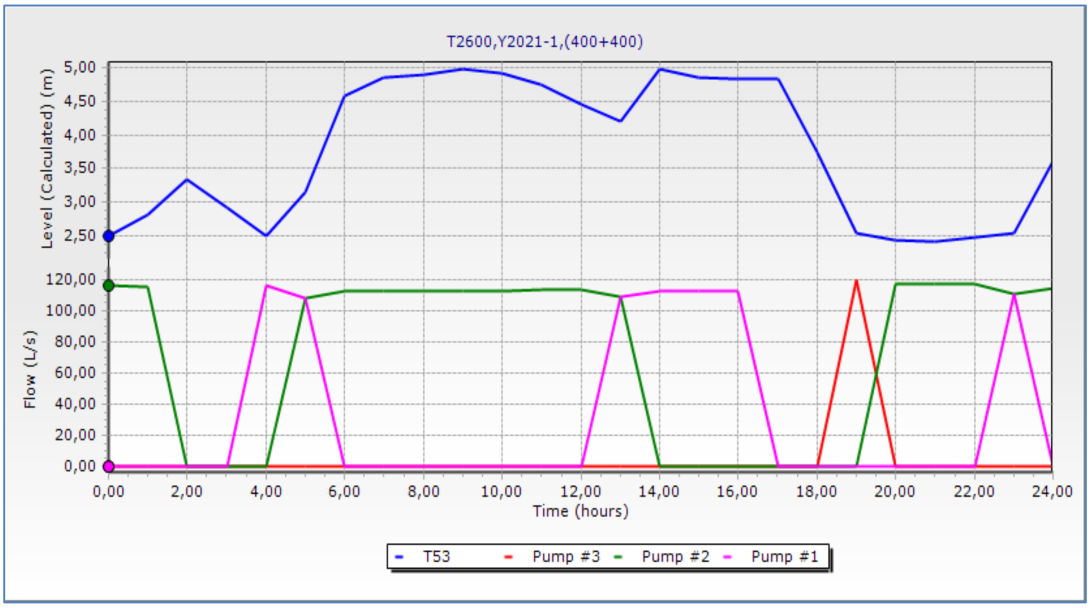


Figure 33 T53 Storage Tank Water Level and Pump Flow versus Time Graph – T2600, Y2021-1, (400+400)

The pump schedule of this scenario resembles to the previous one. However, the flow rates of the pumps are bigger. In Figure 33, it is seen that water level reaches to 4.98 m during the day and final water level becomes 3.61 m. At the end of the day, totally 9.417,61 m^3 water is pumped to the tank and network.

<u>Scenario: T2600, Y2021-2, (400+400)</u>

In this scenario, a new pump, P_{2021}, was designed to examine the effect of different pumps to the system. This pump has bigger pumping capacity by comparing the previous one which provides bigger pumping flow rate and filling storage tank quicker. After pump scheduling of the system, the daily energy cost of the scenario was calculated as 422.67 TL without any violation. Pump Schedule didn't feel the need to start the pumps between the time 02:00-05:00 and 20:00-22:00. It is seen in Figure 34 that while the 1st and the 3rd pump worked inflexibly for a long time, the 2nd pump was never started.

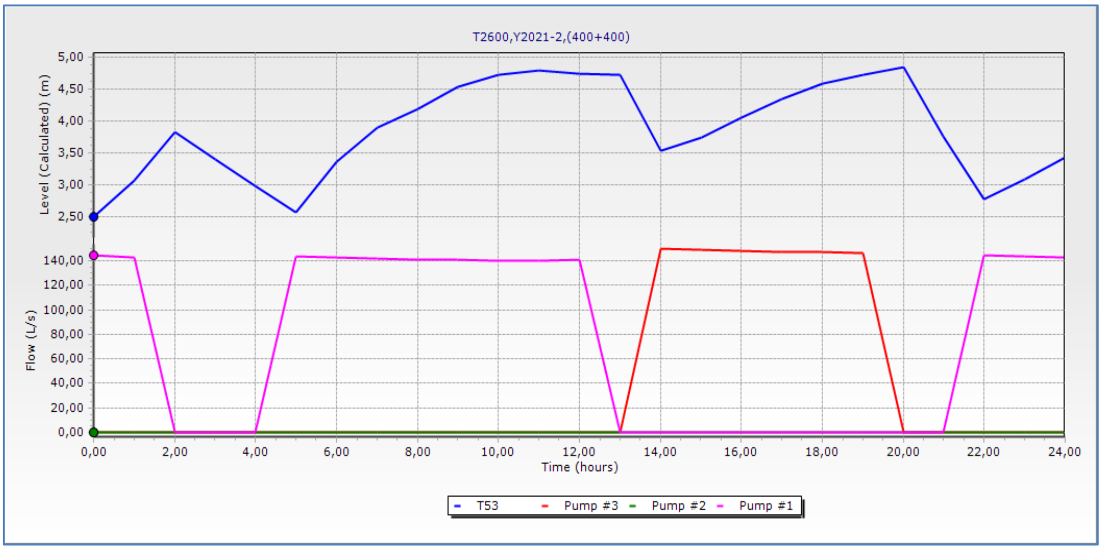


Figure 34 T53 Storage Tank Water Level and Pump Flow versus Time Graph – T2600, Y2021-2, (400+400)

Year 2024

In this year, the number of residents in the study area became 62,443 and the water demand was found as 113.80 lt/s. There are two types of pumps evaluated which are P_{2015} and P_{2024}. There are 16 scenarios calculated for this year by considering different combinations of the network components.

Scenario: T2600, Y2024-1, (400)

Because of the population increase, pump operation time is also increase with higher water demands. Pump P_{2015} was used to calculate the pumping schedule. As it is seen on Figure 35, to hold the water level in allowable limits, pumps are operating all the day. In this pump schedule, water reaches to 4.60 m as maximum level and 1.97 m as minimum level. Pump #1 and Pump #3 start to operate to prevent the water level drop under 2.50 m and final water level comes to 3.70 m. In this scenario, totally 10,184.34 m^3 of water was pumped in 24 hours to T53 storage tank and network. At the end of the pumping schedule, the energy cost was calculated as 445.40 TL without any violation.

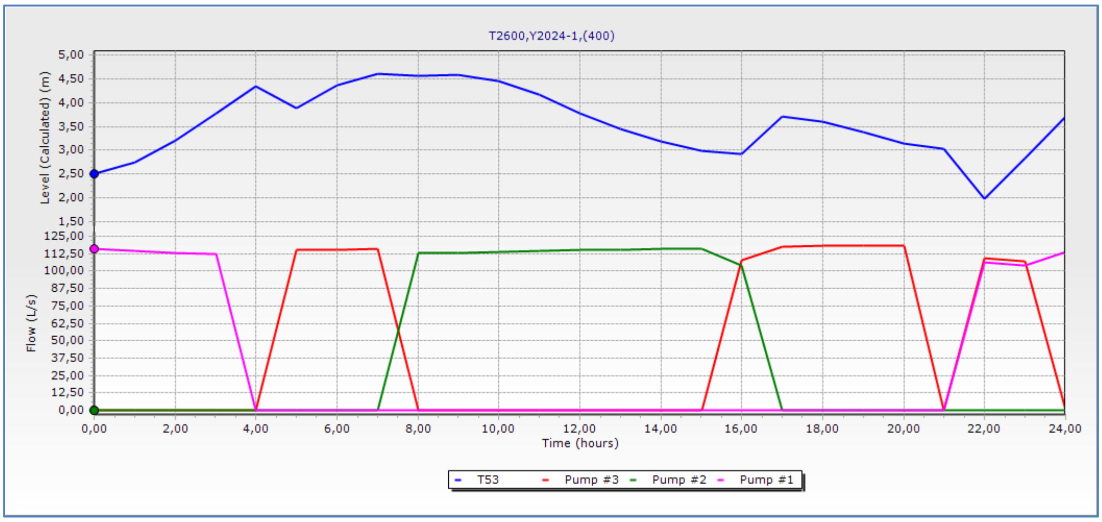


Figure 35 T53 Storage Tank Water Level and Pump Flow versus Time Graph – T2600, Y2024-1, (400)

Scenario: T2600, Y2024-2, (400)

A new pump which is P_{2024} was designed and considered to compose this scenario. After pump scheduling of the system, the daily energy cost of the scenario was calculated as 470.21 TL without any violation. All the pumps were operated in different times. In Figure 36, there are some rapid decline seen on water level where the pumps stops to operate. There is also some rapid increase when the pumps start to operate. As the water demand and pump capacities are higher water level fluctuates all day long and water level reaches to 4.97 m as maximum level and 2.38 m as minimum level. At the end of the day, totally 10,546.06 m^3 water is pumped from P23 pump station.

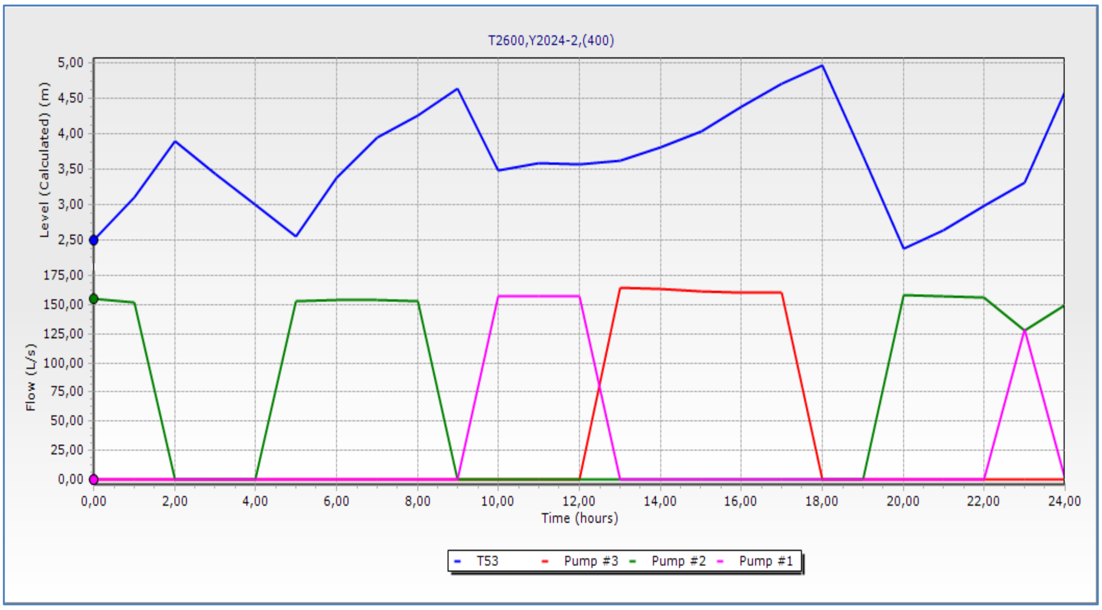


Figure 36 T53 Storage Tank Water Level and Pump Flow versus Time Graph – T2600, Y2024-2, (400)

Scenario: T2600, Y2024-2, (400+400)

In this scenario, another 400 mm pipe was laid beside the existing one. By this way, the same tank and pump, P_{2024}, with transmission line pipes 400 mm+ 400 mm option was evaluated. After pump scheduling of the system, the daily energy cost of the scenario was calculated as 450.07 TL without any violation.

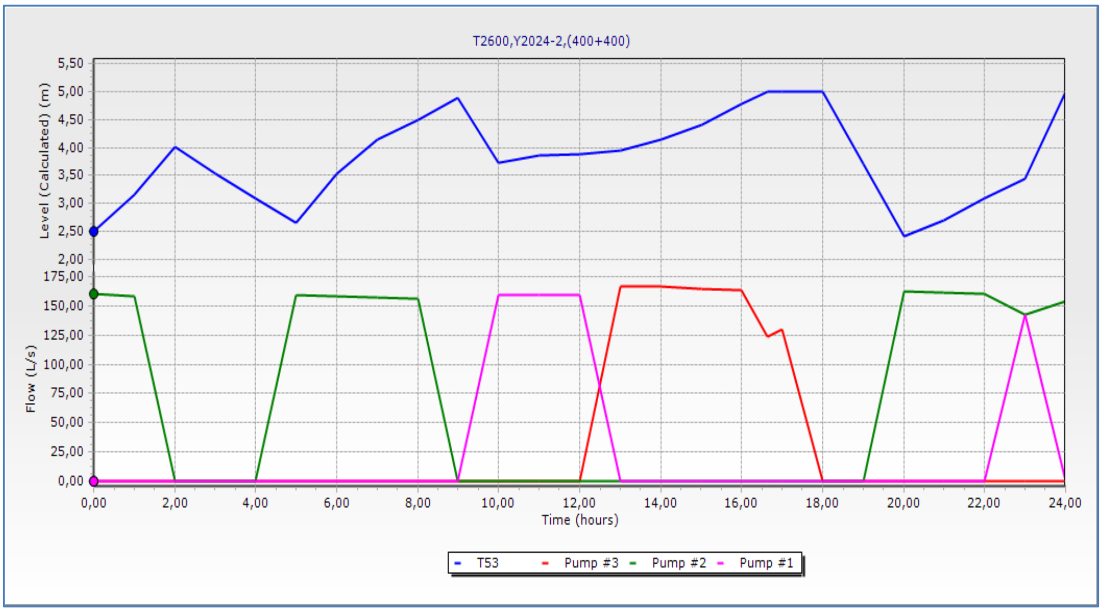


Figure 37 T53 Storage Tank Water Level and Pump Flow versus Time Graph – T2600, Y2024-2, (400+400)

In Figure 37, water level in the tank reaches to 5.00 m level and finishes the day at 2.89 m final level. Totally, 10,699.03 m^3 of water was pumped to the water distribution network at the end of 24 hours.

Year 2027

For this year, population of the study area was calculated as 67,244 and the water demand was calculated as 124.80 lt/s. It had been 12 years to use pump P_{2015}. Thus the economic lifetime of the pump was expired. Because of this reason, there is only one pump option in this year. A new pump, P_{2027}, was designed for this year. There are 8 scenarios calculated for this year by considering different combinations of one pump, 2 pipes and 4 storage tank alternatives.

Scenario: T2600, Y2027-1, (400)

This scenario was composed by using 400 mm diameter transmission line pipe, P_{2027} pump and 2600 m^3 storage tank. To find the minimum energy cost of the system, optimum pump scheduling analysis was performed and the best solution of the optimization was calculated as 451.98 TL which is the daily energy cost of the scenario.

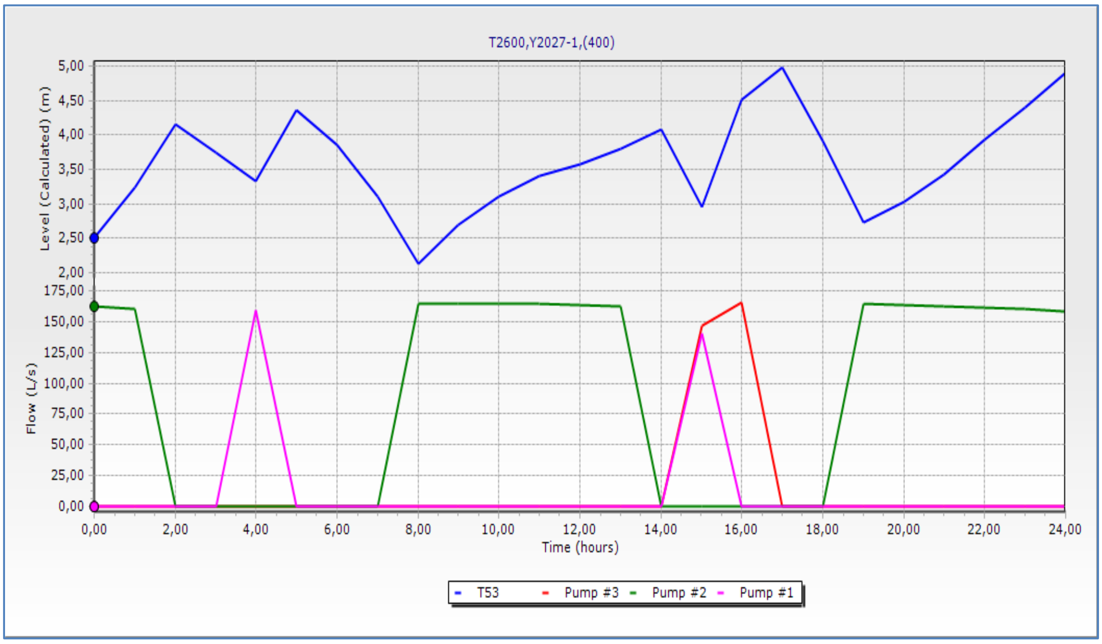


Figure 38 T53 Storage Tank Water Level and Pump Flow versus Time Graph – T2600, Y2027-1, (400)

In Figure 38, it is seen that the optimized schedule tends to fill the storage tank before 17:00 by two pumps operating simultaneously because more expensive energy tariff begins at 17:00. During the day, water level reaches to 4.98 m as maximum level and schedule ends the day with final level 4.90 m. At the end of the day, totally 9829.40 m^3 water is pumped to the system.

Year 2030

There are 72,415 people estimated according to population projection calculations in year 2030. The water need was also calculated as 136.99 lt/s. For this year, 16 different scenarios were composed to compare the effects of the network components. The pump P_{2027} which was designed last study year was also used in the scenarios and another pump P_{2030} was also designed and used in this year's scenarios.

Scenario: T2600, Y2030-1, (400)

In this scenario, pump P_{2027} was used to calculate the pumping schedule. As it is seen on Figure 39, water reaches to 4.95 m as maximum level and 1.81 m as minimum level. Pump #3 had to start to operate in the most expensive energy tariff period to prevent the water level drop under 1.75 m which is the minimum allowable water level.

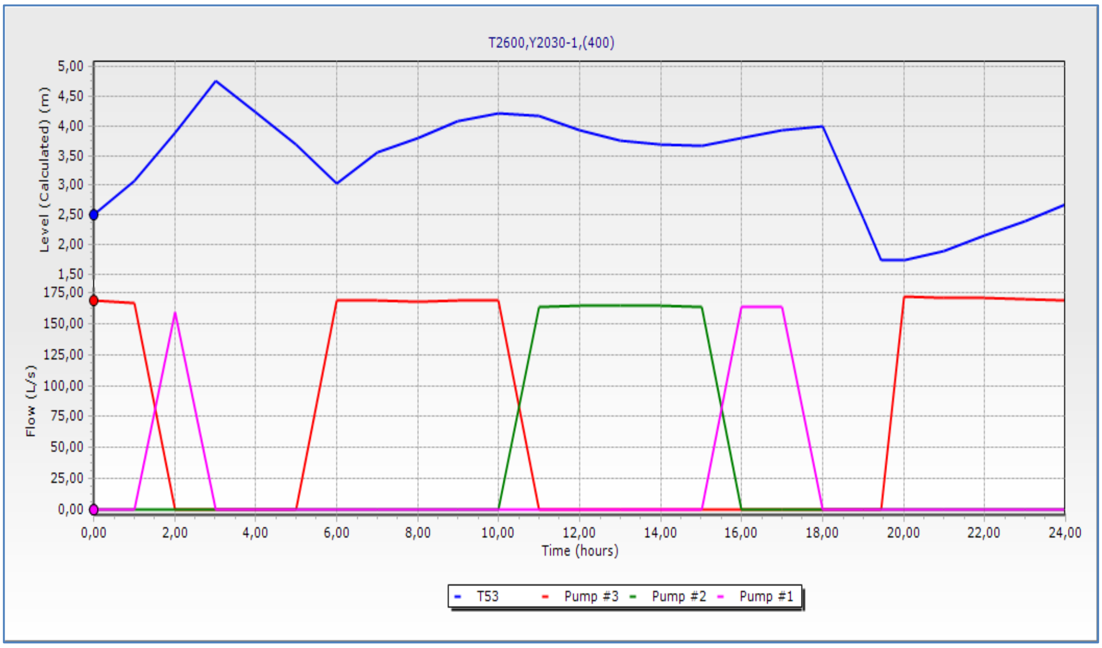


Figure 39 T53 Storage Tank Water Level and Pump Flow versus Time Graph – T2600, Y2030-1, (400)

Pump #3 continued to operate and final water level comes to 3.70 m at the end of the day. In this scenario, totally 11,407.43 m^3 of water was pumped in 24 hours to T53 storage tank and network. At the end of the pumping schedule, the energy cost was calculated as 608.63 TL without any violation.

Scenario: T2600, Y2030-1, (400+400)

The difference of this scenario from the previous one is that there are two pipes in 400 mm diameter each to transfer water from P23 pump station to the network. The same pump P_{2027} and 2600 m^3 storage tank were also considered in this scenario. The minimum daily energy cost of the scenario was found as 590.57 TL without any violation. In Figure 40 it is seen that, Pump #1 started to operate at 02:00 but not to exceed the maximum allowable water level, it had to stop at 03:00. At time 09:30, pump #1 starts to operate again to prevent the water level drop under 1.75 m level. Water level descended minimum 1.75 m and end the day at 2.60 m. Totally 10,920.91 m^3 water is pumped to the tank and network.

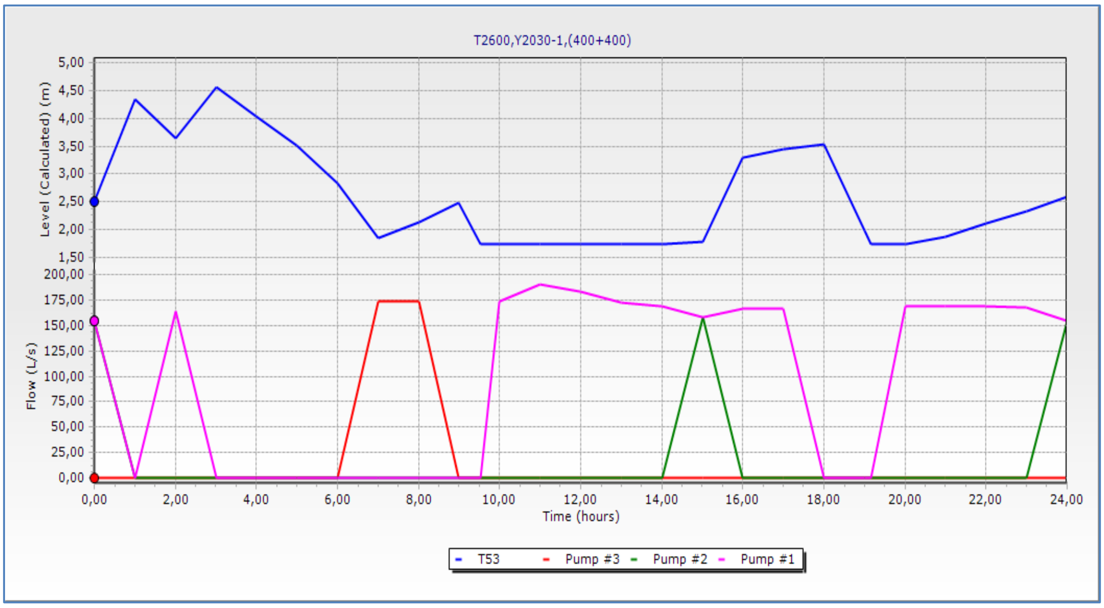


Figure 40 T53 Storage Tank Water Level and Pump Flow versus Time Graph – T2600, Y2030-1, (400+400)

Scenario: T2600, Y2030-2, (400)

A new pump which is P2030 was designed; one pipe with 400 mm diameter and 2600 m^3 storage tank were used to compose this scenario. As shown in Figure 41, the storage tank reaches to the maximum 5.00 meters water limit so that violation is occurred in this scenario due to the penalty applied. This means that this scenario failed to meet the requirements of the water distribution network in allowable limits. Water level descended to minimum 1.82 m and ended the day at 3.45 m. Totally 12,059.72 m^3 water is pumped to the system and the daily energy cost of the scenario was calculated as 604.54 TL with maximum tank level violation.

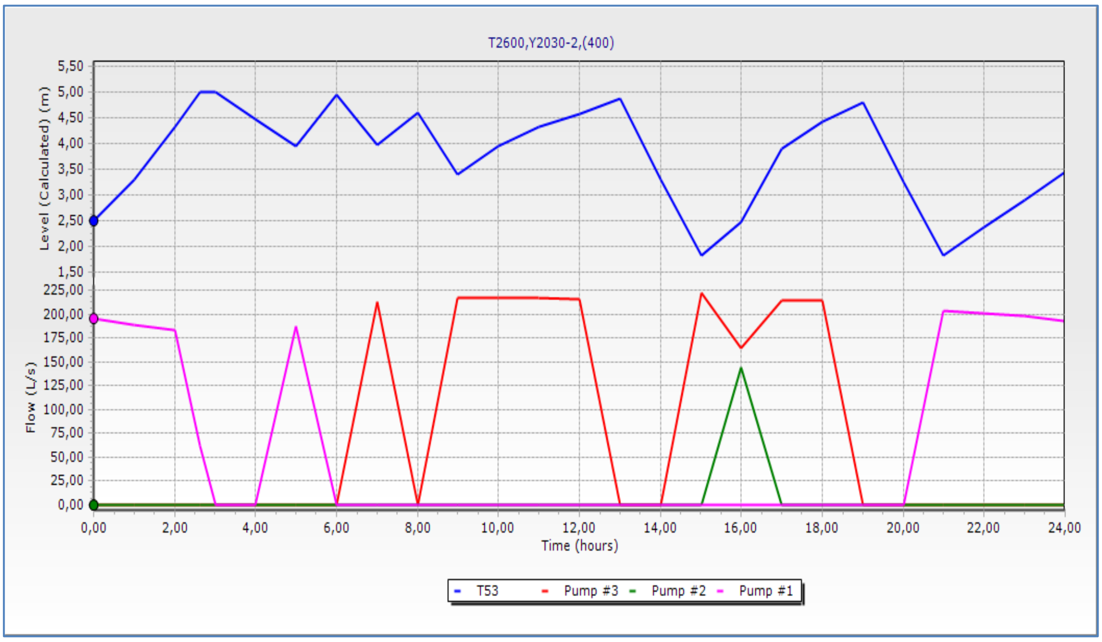


Figure 41 T53 Storage Tank Water Level and Pump Flow versus Time Graph – T2600, Y2030-2, (400)

<u>Year 2033</u>

In this year, the number of residents in the study area became 77,983 and the water demand was found as 150.54 lt/s accordingly. There are two types of pumps evaluated which are P_{2027} and P_{2033}. There are 16 scenarios calculated for this year by considering different combinations of the network components.

<u>Scenario: T2600, Y2033-1, (400)</u>

This scenario was composed by using 400 mm diameter transmission line pipe, P_{2027} pump and 2600 m^3 storage tank. To find the minimum energy cost of the system, optimum pump scheduling analysis was performed. At the end of the day, totally 13,104.97 m^3 water is pumped to the system and the daily energy cost of the scenario was calculated as 669.16 TL with minimum tank level violation. In Figure 42, water level of the storage tank descended to 1.75 m level between the times 18:00 and 21:00 thus this cause penalty. This scenario is not suitable to operate the system in allowable hydraulic limits.

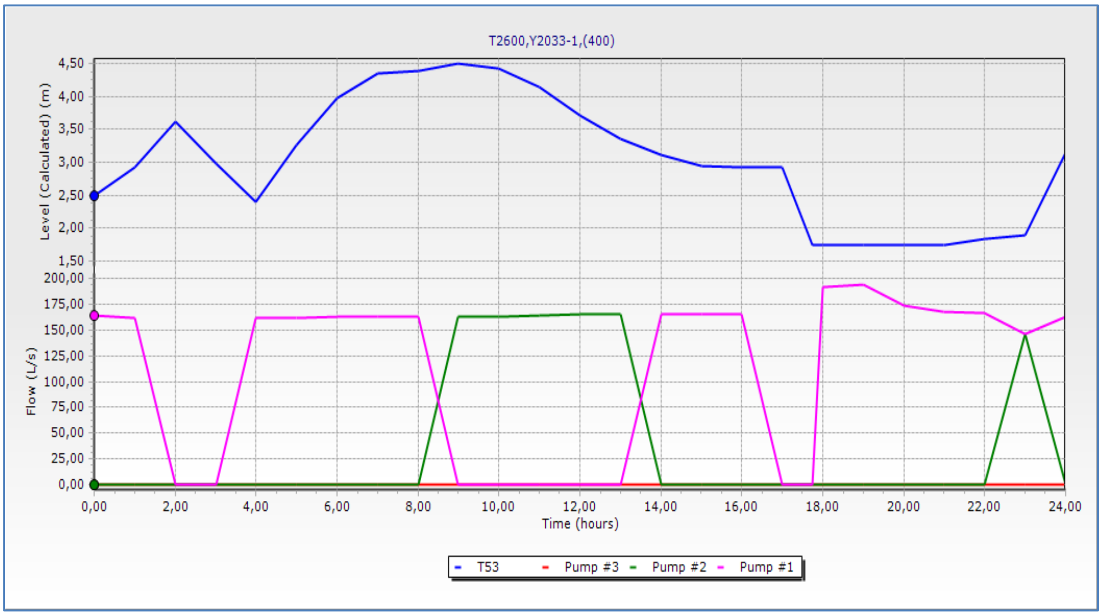


Figure 42 T53 Storage Tank Water Level and Pump Flow versus Time Graph – T2600, Y2033-1, (400)

Scenario: T2600, Y2033-2, (400)

A new pump which is P_{2033} was designed in this scenario. After pump scheduling of the system, the daily energy cost of the scenario was calculated as 727.95 TL without any violation. All the pumps were started 3 times which is the maximum pump start constraint. In Figure 43, there is some rapid decline seen on water level where the pumps stop to operate. Water level fluctuates all day long and water level reaches to 4.86 m as maximum level and 1.77 m as minimum level. At the end of the day, totally 13,648.17 m^3 water was pumped from P23 pump station.

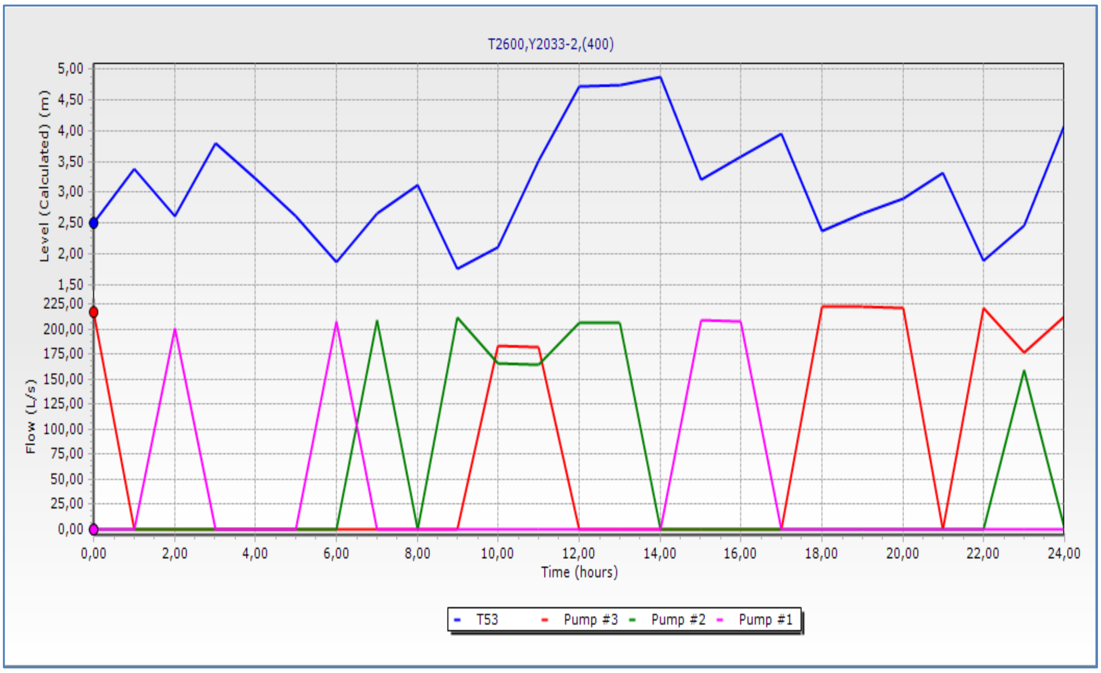


Figure 43 T53 Storage Tank Water Level and Pump Flow versus Time Graph – T2600, Y2033-2, (400)

Scenario: T2600, Y2033-2, (400+400)

In this scenario, another 400 mm pipe was laid beside the existing one. By this way, the same tank and pump, P_{2033}, with transmission line pipes 400 mm+ 400 mm option was evaluated. The daily energy cost of the scenario was calculated as 730.52 TL with maximum tank level violation. Totally, 13,795.71 m^3 of water was pumped to the system at the end of 24 hours. As shown in Figure 44, the storage tank reaches to the maximum 5.00 meters water limit between times 02:00 and 03:00 so that violation is occurred in this scenario due to the penalty applied. This situation shows that this scenario failed to meet the requirements of the water distribution network in allowable limits.

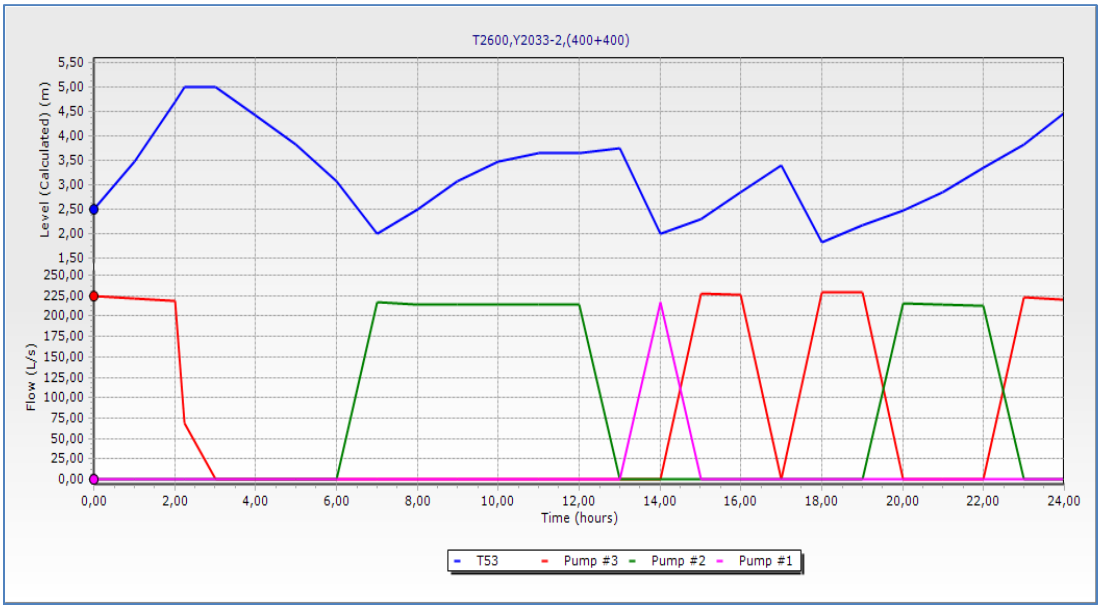


Figure 44 T53 Storage Tank Water Level and Pump Flow versus Time Graph – T2600, Y2033-2, (400+400)

Year 2036

The number of residents in the study area reached to 83,979 in this year. And the water need for the study area became 165.61 lt/s. There are two types of pumps evaluated which are P_{2033} and P_{2036} in overall 16 scenarios.

Scenario: T2600, Y2036-1, (400)

In this scenario, pump P_{2033} was used to calculate the pumping schedule. As it is seen on Figure 45, water reaches to 4.21 m as maximum level and 2.00 m as minimum level. Pump #3 had to start operating to hold water level in allowable water levels. Pump Schedule didn't feel the need to start Pump #1. While Pump #2 and Pump #3 worked inflexibly for a long time, Pump #1 was never started. In this scenario, totally 14,633.80 m^3 of water was pumped in 24 hours to the system. At the end of the pumping schedule, the energy cost was calculated as 792.93 TL without any violation.

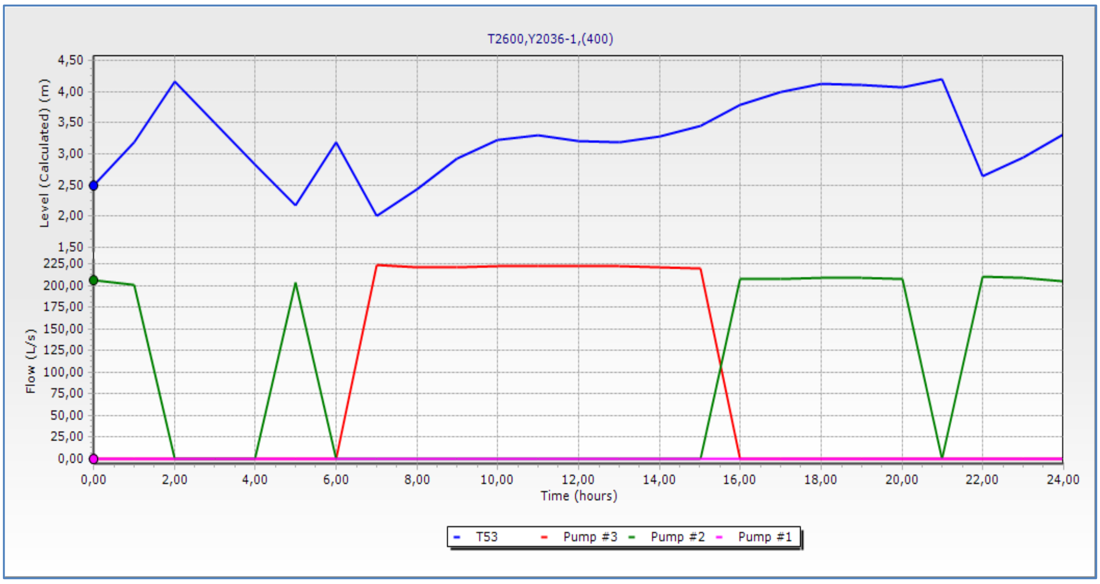


Figure 45 T53 Storage Tank Water Level and Pump Flow versus Time Graph – T2600, Y2036-1, (400)

Scenario: T2600, Y2036-1, (400+400)

By laying another 400 mm diameter pipe to the existing one and using pump P_{2033} in the scenario, the effect of transmission line pipe was evaluated by this scenario. The minimum daily energy cost of the scenario was calculated as 787.39 TL without any violation. In Figure 46, it is seen that, only two pumps are working all day long. Water level descended up to 1.84 m minimum at time 03:00 and Pump #2 starts to operate. At the end of the day, totally 14,946.17 m^3 water is pumped to the tank and network.

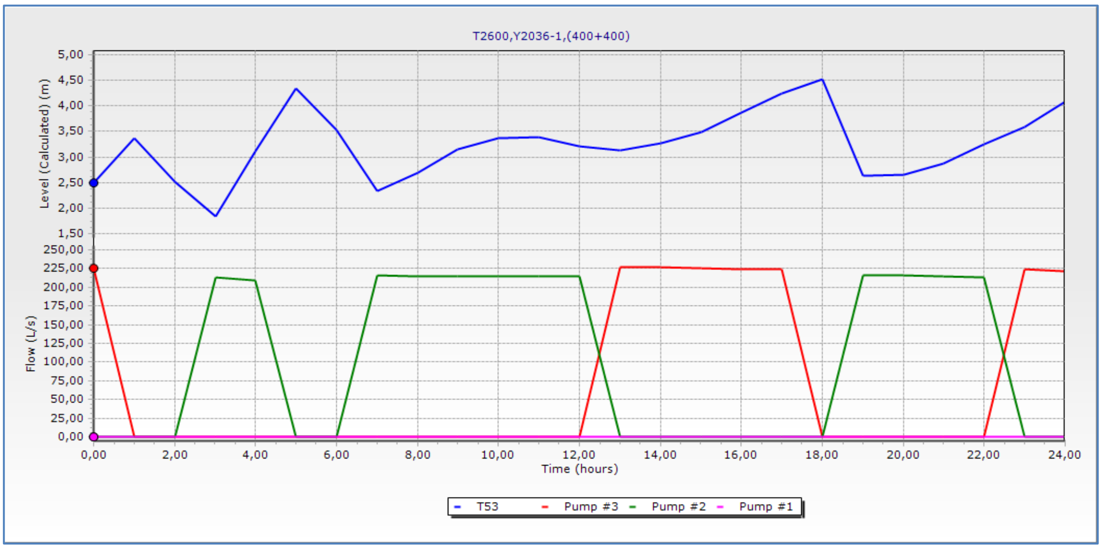


Figure 46 T53 Storage Tank Water Level and Pump Flow versus Time Graph – T2600, Y2036-1, (400+400)

Scenario: T2600, Y2036-2, (400+400)

In this scenario, pump P_{2036} is used to transfer water from pump station to the network. The daily energy cost of the scenario was calculated as 898.57 TL with maximum tank level violation. As it is seen in Figure 47, the storage tank reaches to the maximum 5.00 meters water level between times 11:00 and 24:00 so that violation is occurred in this scenario due to the penalty applied. This situation shows that as the pump capacity and water demand increase, the volume of the storage tank remains incapable. At the end of the day, 15,309.52 m^3 of water was pumped to the system.

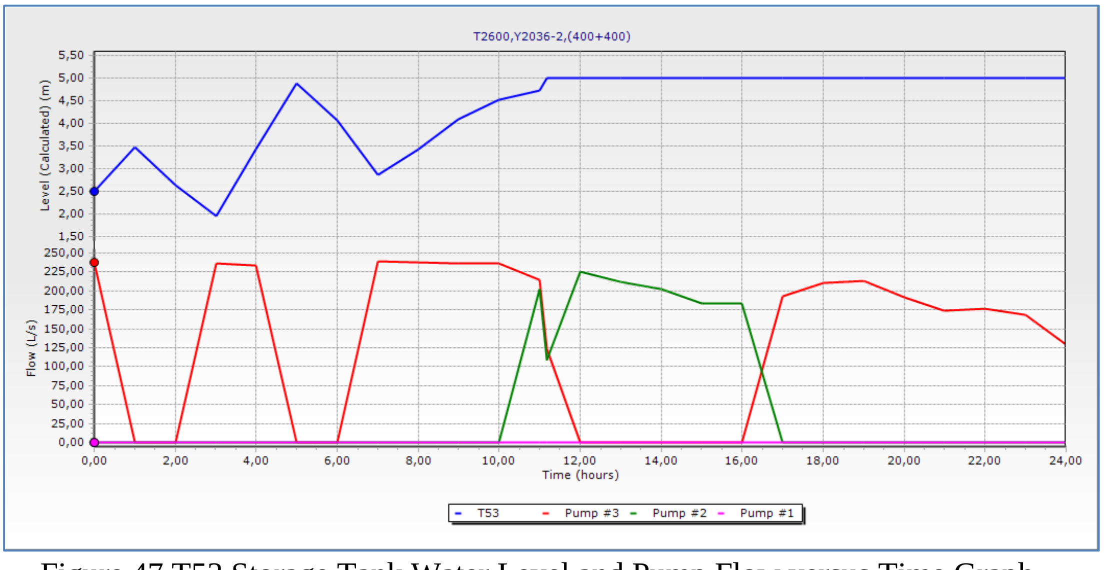


Figure 47 T53 Storage Tank Water Level and Pump Flow versus Time Graph – T2600, Y2036-2, (400+400)

Year 2039

In this year, the number of residents in the study area became 90,436 and the water demand was found as 182.40 lt/s accordingly. There are two types of pumps evaluated which are P_{2033} and P_{2039}. There are 16 scenarios calculated for this year by considering different combinations of the network components.

Scenario: T2600, Y2039-1, (400)

This scenario was composed by using 400 mm diameter transmission line pipe, P_{2033} pump and 2600 m^3 storage tank. At the end of the day, totally 16,512.88 m^3 water is pumped to the system and the daily energy cost of the scenario was calculated as 887.09 TL without any violation. At time 16:00, all the pumps are operating and water level of the tank rose to 4.95 m as maximum and it never drops under 2.50m. The changes in water level and pump operation periods are shown in Figure 48.

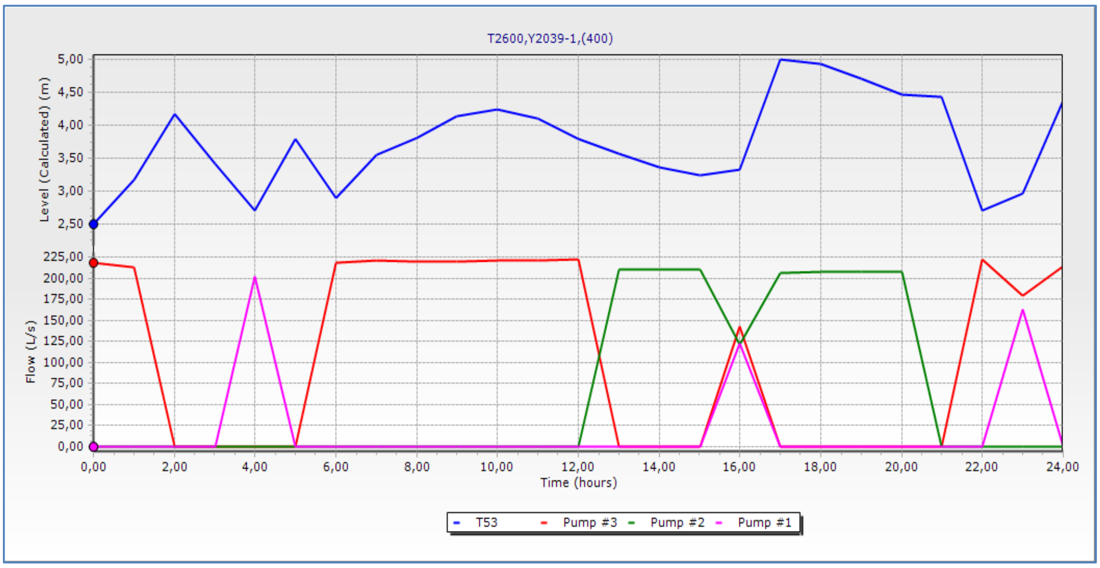


Figure 48 T53 Storage Tank Water Level and Pump Flow versus Time Graph – T2600, Y2039-1, (400)

<u>Scenario: T2600, Y2039-2, (400)</u>

A new pump which is P_{2039} was designed for this scenario. One pipe with 400 mm diameter and 2600 m^3 storage tank were also used. As shown in Figure 49, the storage tank reaches to the maximum 5.00 m water level so that violation is occurred in this scenario due to the penalty applied. Totally 16,153.62 m^3 water was pumped to the system and the daily energy cost of the scenario was calculated as 986.84 TL with maximum tank level violation. This is because not meeting the constraints of the system. Tank volume is becoming insufficient by concerning the operation of the system.

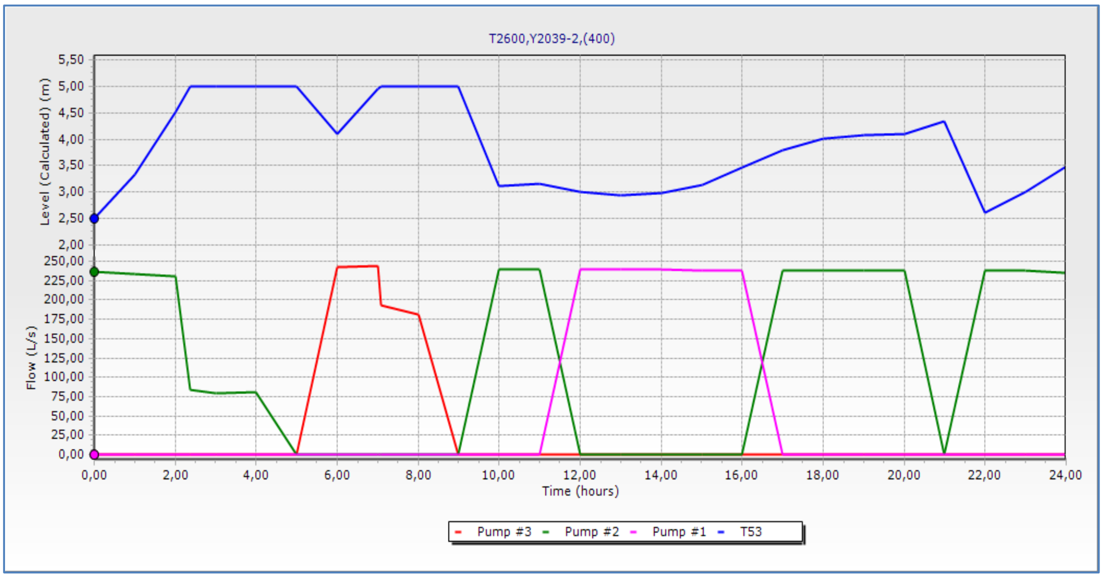


Figure 49 T53 Storage Tank Water Level and Pump Flow versus Time Graph – T2600, Y2039-2, (400)

Scenario: T2600, Y2039-2, (400+400)

The difference of this scenario from the previous one is the pipe used. Water is transferred to the system by two 400 mm diameter pipes. After pump scheduling of the system, the daily energy cost of the scenario was calculated as 909.50 TL with maximum tank level violation.

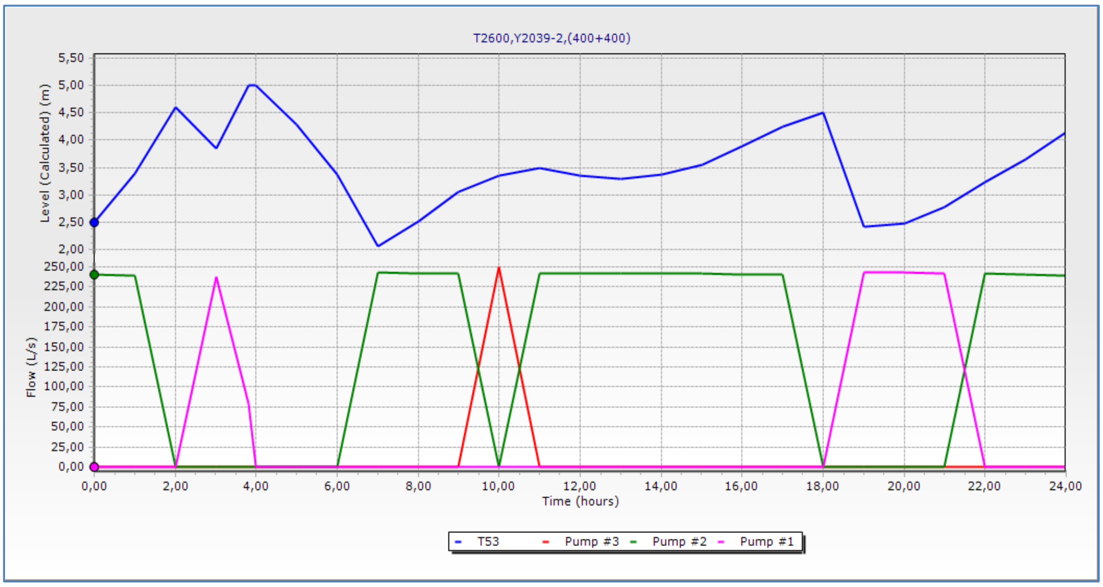


Figure 50 T53 Storage Tank Water Level and Pump Flow versus Time Graph – T2600, Y2039-2, (400+400)

In Figure 50, water level in the tank reaches to 5.00 m at 04:00. This situation shows that this scenario failed to meet the requirements of the water distribution network in allowable limits. Water level fluctuates all day long and water level drops 2.06 m as minimum level. At the end of the day, totally 16,421.55 m^3 water was pumped from P23 pump station.

Year 2042

The population of the study area became 97,390 in this year and the water demand was increased to 201.13 lt/s. In this scenario, there are two types of pump which are P_{2033} and P_{2042}. Other tank and pipe alternatives were also evaluated.

Scenario: T2600, Y2042-1, (400)

In this scenario, again pump P_{2033} was used to calculate the pumping schedule of the scenario. As it is seen on Figure 51, pumps are working every hour of the day and water reaches to 4.96 m and drops to 1.78 m during the day. In this scenario, totally 17,606.42 m^3 of water was pumped from P23 pump station. At the end of the day, the energy cost was calculated as 974.63 TL without any violation.

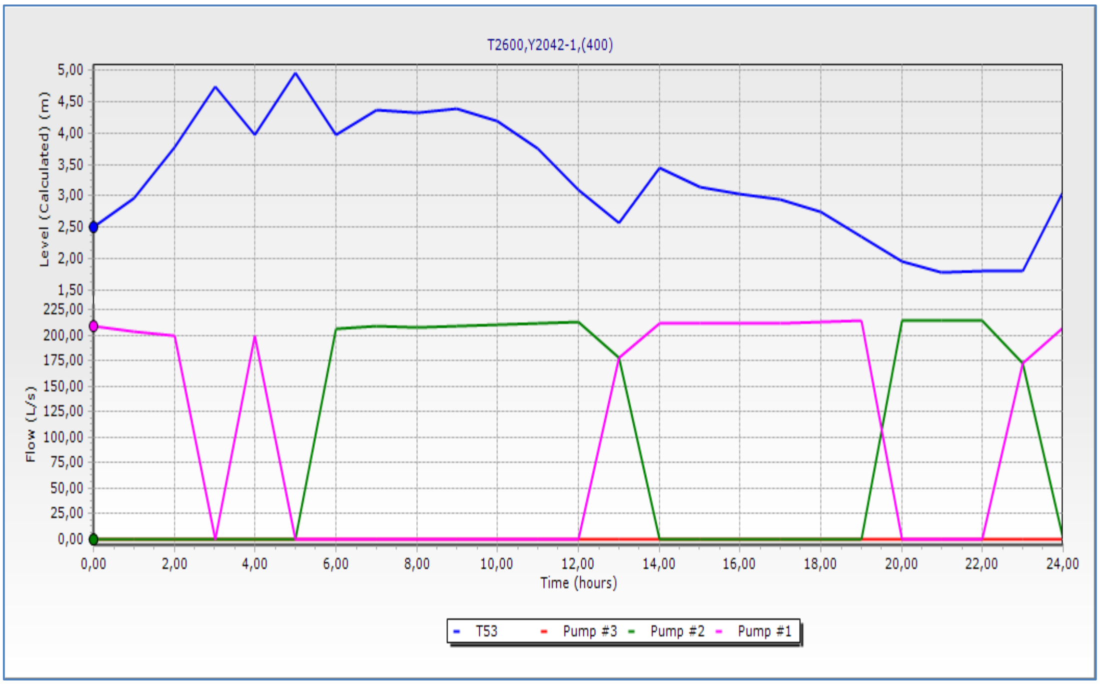


Figure 51 T53 Storage Tank Water Level and Pump Flow versus Time Graph – T2600, Y2042-1, (400)

Scenario: T2600, Y2042-2, (400)

By changing the pumps of the network with pump P_{2042}, the energy bill became 1141.84 TL. Additionally, as the water level reached to 5.00 m at different times of the day, maximum tank level violation occurred. It is seen that, Pump #3 did not need to be started because two of the pumps could supply adequate water with big flow rates capacity. The water level dropped to 1.76 m as minimum level and end the day at 4.35 m. Totally 18,119.47 m^3 water was pumped to the system.

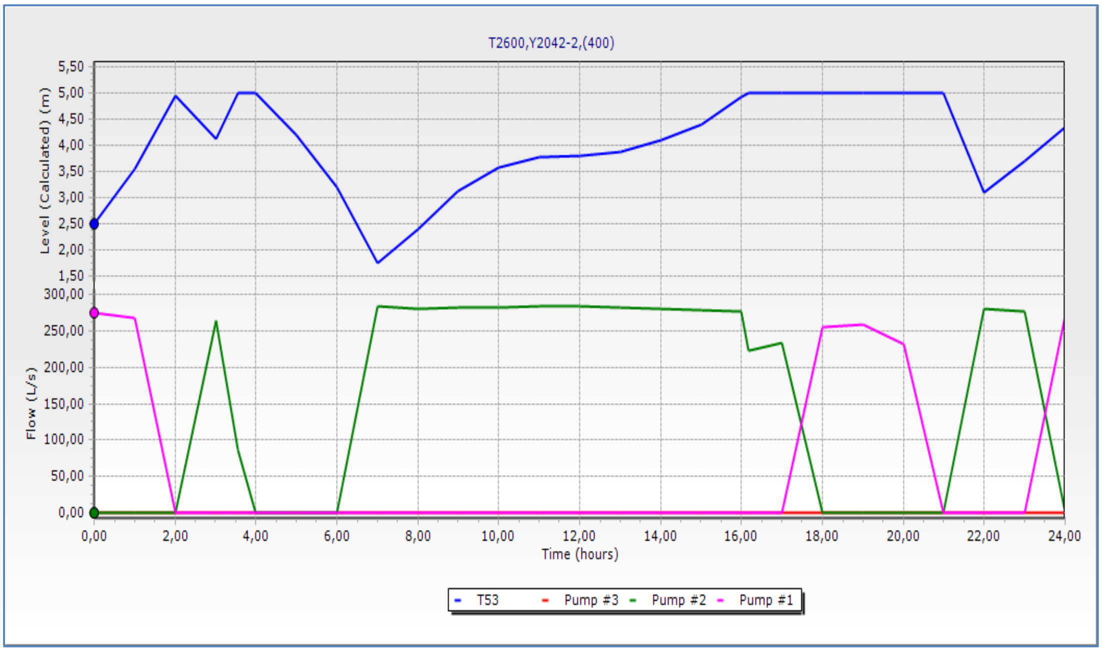


Figure 52 T53 Storage Tank Water Level and Pump Flow versus Time Graph – T2600, Y2042-2, (400)

Year 2045

For this year, population of the study area was calculated as 104,878 and the water demand was calculated as 222.05 lt/s. It had been 12 years to use pump P_{2033}. Thus the economic lifetime of the pump was expired. Because of this reason, normally there is only one pump option in this year which is designed according to pipe 400 mm diameter called as pump P2045-a. However, a second pump option also derived by designing a new pump according to two pipes with 400 mm diameter each. The pump is named as pump $P_{2045\text{-}b}$. There are 8 scenarios calculated for this year by considering different combinations of two pumps, 1 pipe option (400+400 mm) and 4 storage tank alternatives.

Scenario: T5200, Y2045-1a, (400)

Pump $P_{2045\text{-}a}$ was used in this scenario. The energy price became 1410.61 TL. Additionally, as the water level reached to 5.00 m at 18:00, maximum tank level violation occurred. It is seen that, Pump #2 worked most of the day and other pumps contribute very little. That is because one of the pumps could supply adequate water with big flow rates capacity. The water level dropped to 1.90 m as minimum level and end the day at 5.00 m. Totally 21,185.37 m^3 water was pumped to the system.

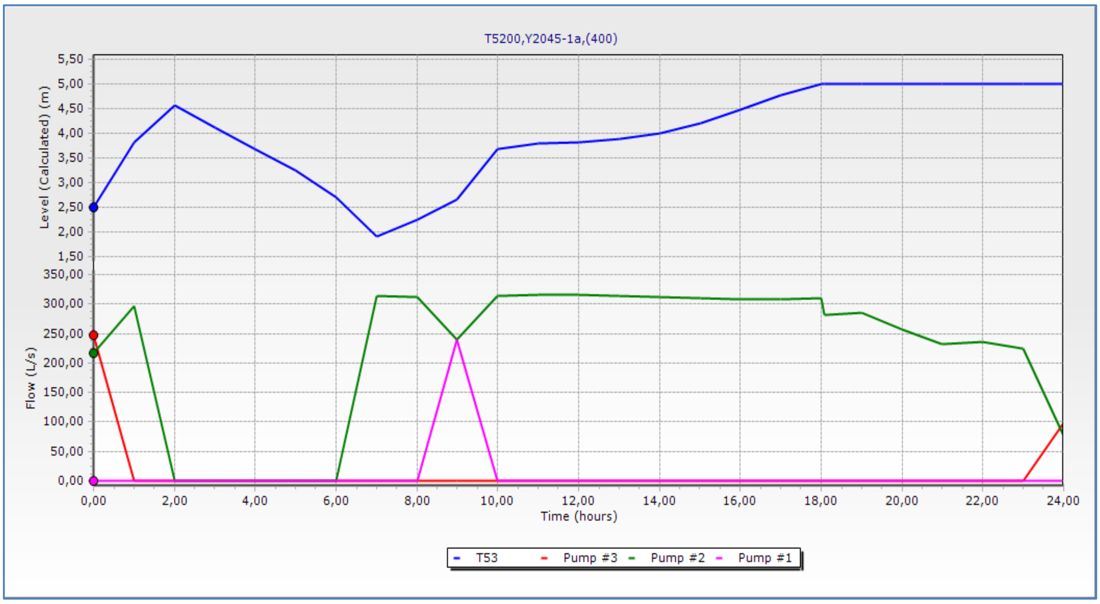


Figure 53 T53 Storage Tank Water Level and Pump Flow versus Time Graph – T5200, Y2045-1a, (400)

Scenario: T5200, Y2045-1a, (400+400)

By laying another 400 mm diameter pipe to the existing one and using pump $P_{2045\text{-}a}$ in the scenario, the effect of transmission line pipe was evaluated. The minimum daily energy cost of the scenario was calculated as 1219.87 TL without any violation. In Figure 54, it is seen that, all the pumps are working at least one time and the pump around 300 lt/s. Water level descended up to 1.79 m minimum at time 06:00 and Pump #3 starts to operate. At the end of the day, totally 20,874.72 m^3 water is pumped to the tank and network.

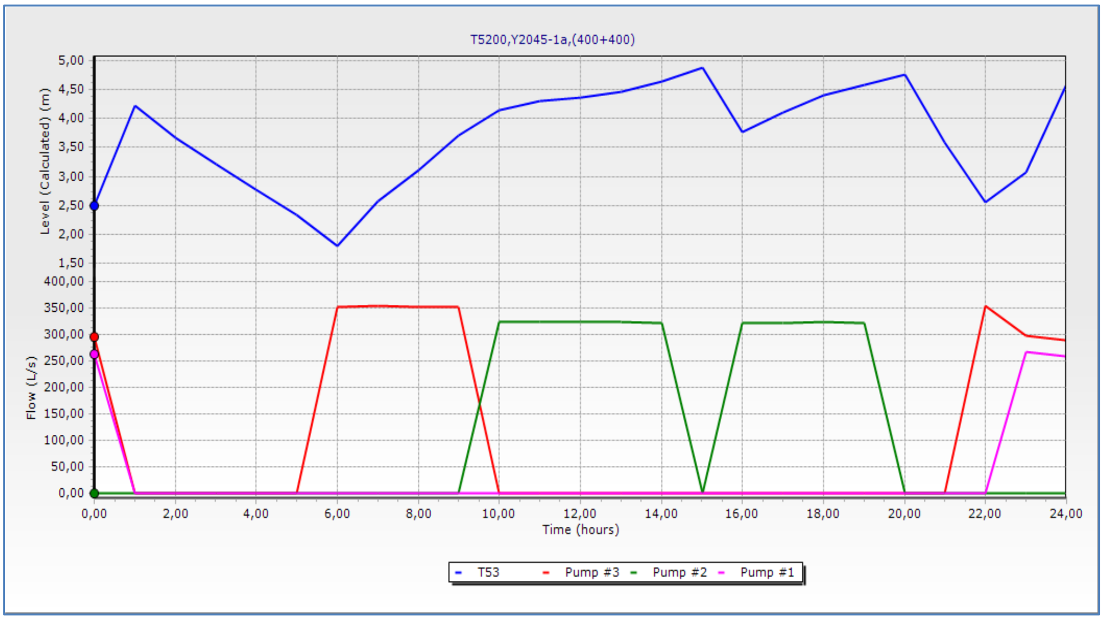


Figure 54 T53 Storage Tank Water Level and Pump Flow versus Time Graph – T5200, Y2045-1a, (400+400)

<u>Scenario: T2600, Y2045-1b, (400+400)</u>

In this scenario, a new pump, $P_{2045\text{-}b}$, was designed by considering transmission line with two parallel pipes. As water is transported by two pipes, the pump head will be lower than the pump $P_{2045\text{-}a}$. As a result of the pumping schedule, the minimum daily energy cost of the scenario was found as 1,066.65 TL without any violation.

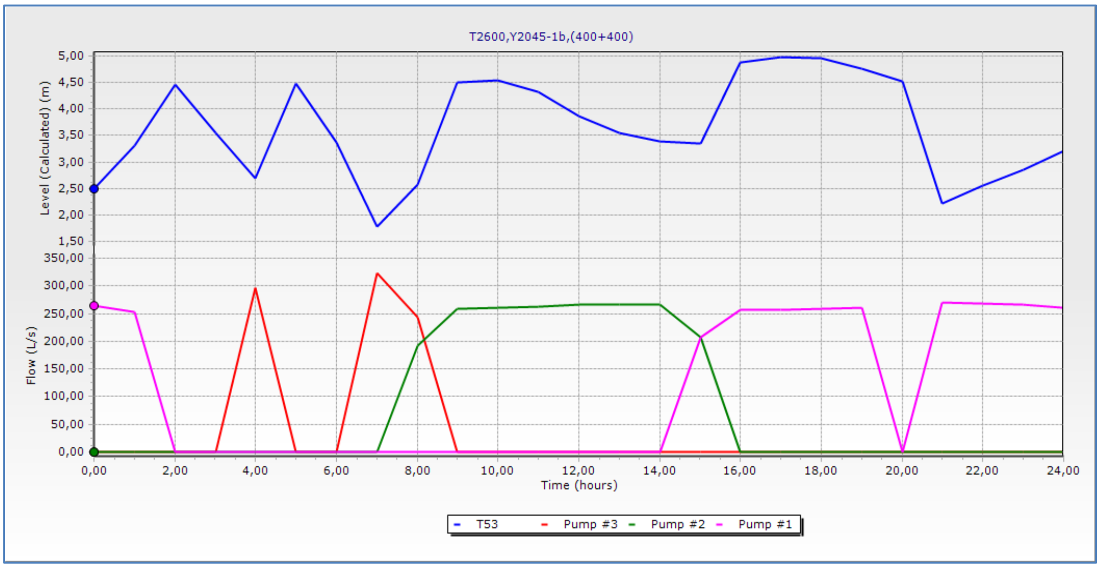


Figure 55 T53 Storage Tank Water Level and Pump Flow versus Time Graph – T2600, Y2045-1b, (400+400)

Water level in the tank fluctuates all the day and maximum water level reaches to 4.98 m at time 15:00 and drops to 1.78 m as minimum water level at time 06:00. Totally 19,472.97 m^3 water is pumped to the system.

Year 2048

There are 112,943 people estimated according to population projection calculations in year 2048. The water need was also calculated as 245.45 lt/s. For this year, 8 different scenarios were composed to compare the effects of the network components. The pump $P_{2045\text{-}b}$ which was designed last study year was also used in the scenarios and another pump P_{2048} was also designed and used in this year's scenarios.

Scenario: T2600, Y2048-1, (400+400)

This scenario was built by considering 2600 m^3 storage tank, pump $P_{2045\text{-}b}$ and two pipes with 400 mm diameter as transmission line. The daily energy cost of the scenario was calculated as 1,238.42 TL with maximum tank level violation. Totally, 22,091.30 m^3 of water was pumped to the system at the end of 24 hours.

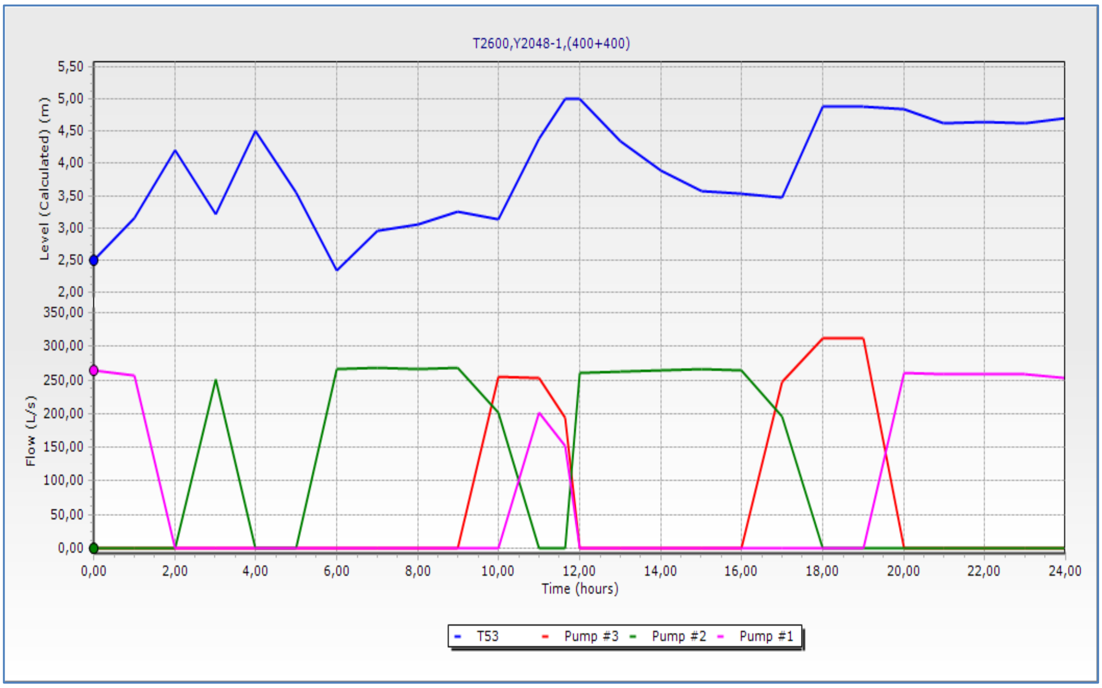


Figure 56 T53 Storage Tank Water Level and Pump Flow versus Time Graph – T2600, Y2048-1, (400+400)

Scenario: T5200, Y2048-1, (400+400)

The difference of this scenario from the previous one is the storage tank capacity. 5200 m^3 of tank was used to build this scenario. The minimum daily energy cost of the scenario was calculated as 1,222.75 TL without any violation. In Figure 57, it is seen that all the pumps are operating and working frequently all the day. The water level never drops under 2.50 m and ends the day with 4.47 m final level. At the end of the day, totally 22,781.10 m^3 water is pumped to the tank and network.

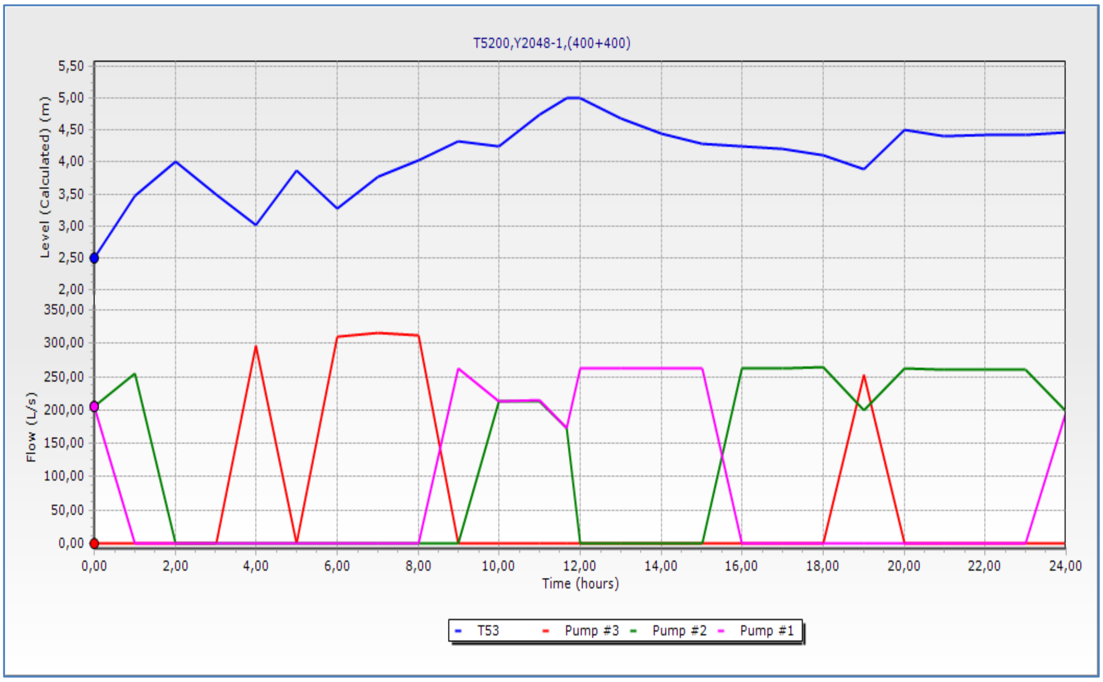


Figure 57 T53 Storage Tank Water Level and Pump Flow versus Time Graph – T5200, Y2048-1, (400+400)

Scenario: T5200, Y2048-2, (400+400)

In this scenario, pump P_{2048} and 5200 m^3 storage tank was used to calculate the pumping schedule. As it is seen on Figure 58, water reaches to 4.98 m as maximum level at 12:00 and 2.50 m as minimum level at time 07:00. In this scenario, totally 22,667.52 m^3 of water was pumped in 24 hours to the system. At the end of the pumping schedule, the energy cost was calculated as 1211.44 TL without any violation.

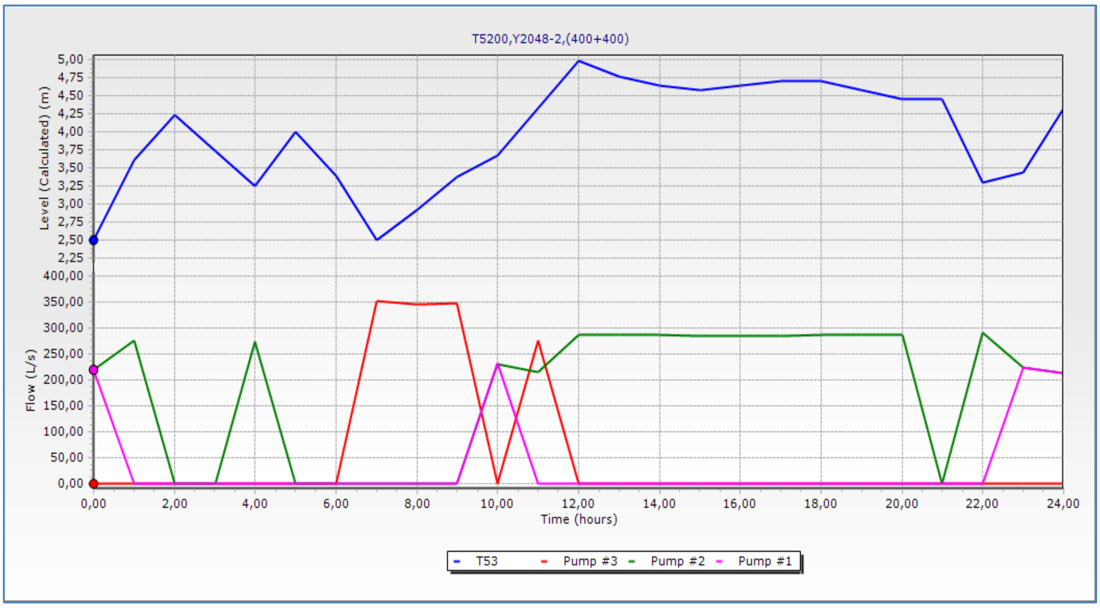


Figure 58 T53 Storage Tank Water Level and Pump Flow versus Time Graph – T5200, Y2048-2, (400+400)

Year 2051

In this year, the number of residents in the study area became 121,627 and the water demand was found as 271.66 lt/s accordingly. There are two types of pumps evaluated which are $P_{2045\text{-}b}$ and P_{2051}. There are 8 scenarios calculated for this year by considering different combinations of the network components.

Scenario: T7800, Y2051-1, (400+400)

In this scenario, the pump $P_{2045\text{-}b}$ was used again however the storage tank had been changed to 7800 m^3 volume tank. After executing the pumping schedule of the scenario, the energy price was calculated as 1,423.30 TL. In Figure 59, the water level never drop under 2.50 m level and raised to 5.00 m at different times of the day and maximum tank level violation occurred. It is seen that, pumps are operating simultaneously most of the time with different flow rates. Totally 26,210.68 m^3 water was pumped to the system.

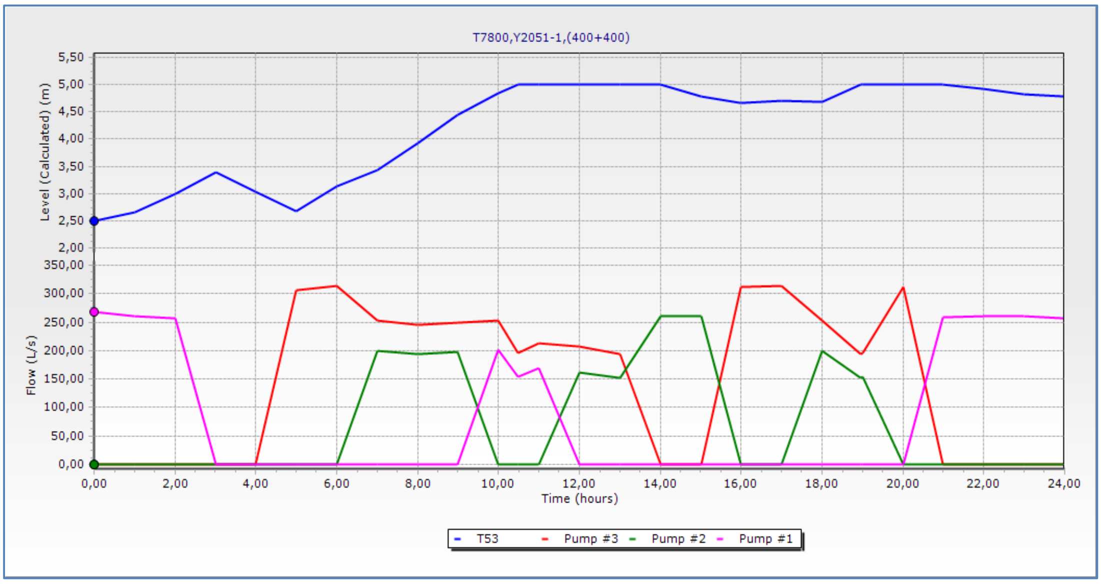


Figure 59 T53 Storage Tank Water Level and Pump Flow versus Time Graph – T7800, Y2051-1, (400+400)

<u>Scenario: T10400, Y2051-1, (400+400)</u>

The difference of this scenario from the previous one is the storage tank capacity. 10400 m^3 of tank was used to build this scenario. The minimum daily energy cost of the scenario was calculated as 1,736.70 TL without any violation. In Figure 60, it is seen that all the pumps are operating and working frequently all the day. The water level never drops under 2.50 m and ends the day with 4.72 m final level. At the end of the day, totally 27,023.48 m^3 water is pumped to the tank and network.

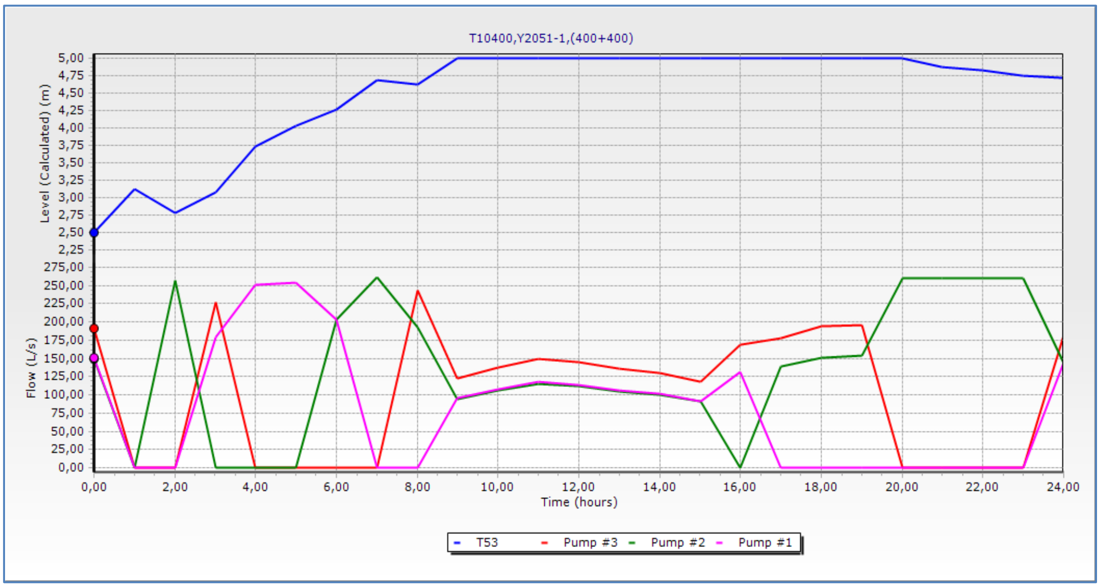


Figure 60 T53 Storage Tank Water Level and Pump Flow versus Time Graph – T10400, Y2051-1, (400+400)

Scenario: T10400, Y2051-2, (400+400)

In this scenario, the pump was changed to P_{2051} and the 10400 m^3 volume storage tank was used. The energy bill became 1,576.36 TL. The water level stayed at 5.00 m level after the time 13:00 and maximum tank level violation occurred. Totally 27,471.44 m^3 water was pumped to the system.

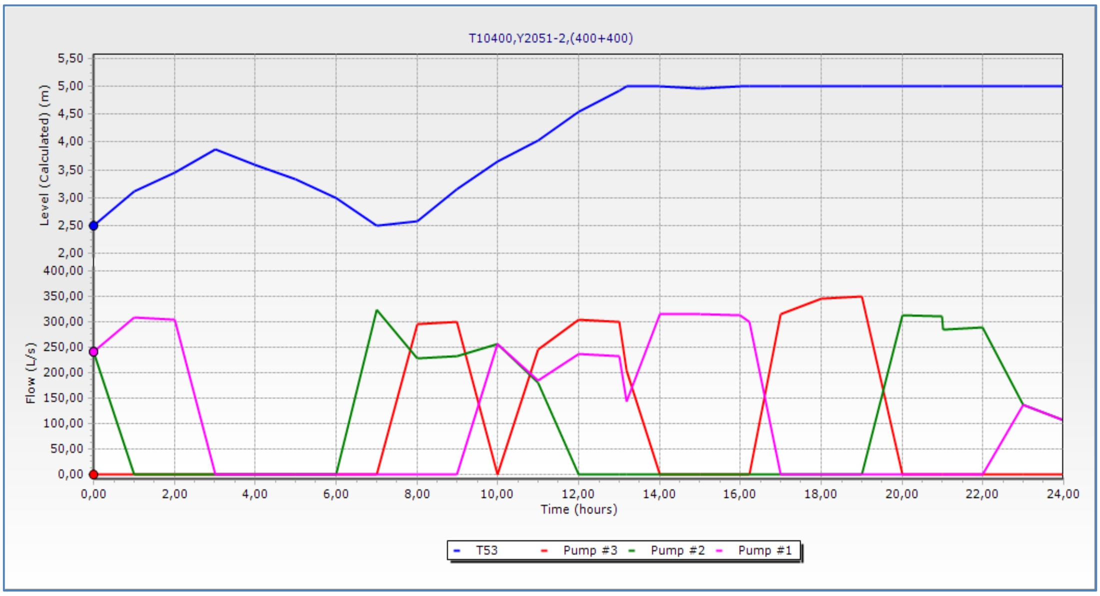


Figure 61 T53 Storage Tank Water Level and Pump Flow versus Time Graph – T10400, Y2051-2, (400+400)

3.13 Results of the Scenarios

To find the best alternative scenarios for each study year, 168 scenarios were built to with different combinations of WDN components. Storage tank level and pump flow versus time graphs were presented and evaluated individually. All the results of the scenarios can be seen at the Table 10.

It can be seen from the Table 10 that as the volume of the storage tank and pipe diameter increase, the daily energy cost decreases. But in terms of pump characteristics, same thing is not true. The scenarios which could not satisfy the specified hydraulic requirements were shown in the orange marked cells.

Table 10 Daily Energy Costs

NO	YEAR	PUMP	POPULATION	TANK VOLUME / PIPE DIAMETER							
				2600 m3		5200 m3		7800 m3		10400 m3	
				Ø400 mm	Ø400+Ø400 mm	Ø400 mm	Ø400+Ø400 mm	Ø400 mm	Ø400+Ø400 mm	Ø400 mm	Ø400+Ø400 mm
1	2015	P_{2015}	50.000	327,93		284,39		268,05		261,14	
2	2018	P_{2015}	53.845	369,97	370,83	320,62	315,08	305,83	296,02	299,09	276,36
		P_{2018}		368,64	367,38	324,75	320,44	308,62	298,71	301,55	278,13
3	2021	P_{2015}	57.985	411,15	405,43	359,52	353,55	342,46	327,54	336,57	313,37
		P_{2021}		427,73	422,67	361,69	352,86	344,41	335,14	334,09	311,73
4	2024	P_{2015}	62.443	445,40	440,52	389,79	398,18	372,46	357,37	370,20	348,36
		P_{2024}		470,21	450,07	411,11	398,40	385,01	371,98	375,24	352,40
5	2027	P_{2027}	67.244	451,98	428,97	373,40	371,68	356,32	344,41	346,79	326,44
6	2030	P_{2027}	72.415	608,63	590,57	550,98	513,56	507,31	471,54	496,60	451,44
		P_{2030}		604,54	598,06	548,34	550,94	501,20	490,25	497,43	467,83
7	2033	P_{2027}	77.983	669,16	636,40	603,19	595,75	567,30	540,61	565,75	523,33
		P_{2033}		727,95	730,52	663,74	626,91	603,05	574,96	592,25	551,70
8	2036	P_{2033}	83.979	792,93	787,39	741,94	729,76	714,18	645,94	715,99	627,53
		P_{2036}		844,33	898,57	744,92	729,79	721,76	674,90	711,81	623,14
9	2039	P_{2033}	90.436	887,09	853,18	852,60	808,25	822,06	759,59	837,36	694,38
		P_{2039}		986,84	909,50	900,65	829,83	868,80	782,00	851,07	725,65
10	2042	P_{2033}	97.390	974,63	963,58	955,54	913,69	923,23	830,42	918,52	822,14
		P_{2042}		1141,84	1136,97	1137,59	1021,50	1118,69	942,38	1124,79	918,63
11	2045a	P_{2045a}	104.878	1435,57	1403,47	1410,61	1219,87	1580,18	1169,31	1292,81	1159,10
11	2045b	P_{2045b}	104.878		1066,65		1014,88		1005,75		973,35
12	2048	P_{2045b}	112.943		1238,42		1222,75		1229,53		1141,15
		P_{2048}			1258,60		1211,44		1256,91		1.191,92
13	2051	P_{2045b}	121.627		1465,95		1491,35		1423,30		1.736,70
		P_{2051}			1639,20		1576,69		1702,90		1.576,36

Tank maximum or minimum level violation

3.14 Total Annual Costs of the Scenarios

In this section, total costs of all the scenarios were calculated. Total cost of a water supply system composed of initial investment cost, repair and maintenance cost and energy cost. As the economic life time of the components of the system differ from each other, all the costs associated with initial investment cost, repair and maintenance cost and energy cost were converted into annual costs and finally total costs of each scenario were calculated.

The annual worth of the storage tank, pumps, transmission line pipes and repair and maintenance costs were calculated as explained in Chapter 2. The interest rate was taken as 7.50%, which is the borrowing interest rate of Central Bank, for the calculation of the annual worth of initial investment costs. The life times of the storage tanks and pipes were taken as 36 years and 12 years was considered for pumps. The annual energy cost of P23 pump station was calculated as multiplying the daily energy cost with 365 days for a year.

The annual worth of the daily energy costs, initial investment cost and repair and maintenance costs of storage tank, pipes and pumps are shown in Table 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22 and 23. In these Tables, It is seen that the annual energy cost of the scenarios tends to be decreased as the tank size getting bigger or the number of transmission line pipe doubled. On the other hand, initial investment costs of these components are increasing in the same condition.

Table 11 Annual Costs of Daily Energy Costs, Tank Costs, Pipe Costs, Pump Costs and Repair&Maintenance Cost (TL) in 2015

2015	TANK VOLUME / PIPE DIAMETER			
	2600 m^3	5200 m^3	7800 m^3	10400 m^3
	Ø400 mm	Ø400 mm	Ø400 mm	Ø400 mm
Pump Cost (P_{2015})	73,170.00	73,170.00	73,170.00	73,170.00
Annual Pump Cost	9,459.26	9,459.26	9,459.26	9,459.26
Daily Energy Cost	327.93	284.39	268.05	261.14
Annual Energy Cost	119,695.55	103,803.81	97,838.25	95,317.56
Repair and maintenance Cost	1,097.55	1,097.55	1,097.55	1,097.55
Pipe Cost	687,004.91	687,004.91	687,004.91	687,004.91
Annual Pipe Cost	55,643.60	55,643.60	55,643.60	55,643.60
Repair and maintenance Cost	13,740.10	13,740.10	13,740.10	13,740.10
Tank Cost	946,599.00	1,846,979.00	2,747,359.00	3,647,739.00
Annual Tank Cost	76,669.28	149,595.08	222,520.88	295,446.68
Repair and maintenance Cost	9,465.99	18,469.79	27,473.59	36,477.39
Total Annual Cost	**285,771.32**	**351,809.19**	**427,773.22**	**507,182.13**

Table 12 Annual Costs of Daily Energy Costs, Tank Costs, Pipe Costs, Pump Costs and Repair&Maintenance Cost (TL) in 2018

2018	TANK VOLUME / PIPE DIAMETER							
	2600 m^3		5200 m^3		7800 m^3		10400 m^3	
	Ø400 mm	Ø400+Ø400 mm	Ø400 mm	Ø400+Ø400 mm	Ø400 mm	Ø400+Ø400 mm	Ø400 mm	Ø400+Ø400 mm
Pump-1 Cost (P_{2015})	73,170.00	73,170.00	73,170.00	73,170.00	73,170.00	73,170.00	73,170.00	73,170.00
Annual Pump Cost	9,459.26	9,459.26	9,459.26	9,459.26	9,459.26	9,459.26	9,459.26	9,459.26
Daily Energy Cost	369.97	370.83	320.62	315.08	305.83	296.02	299.09	276.36
Annual Energy Cost	135,039.05	135,352.95	117,024.48	115,003.11	111,627.22	108,047.67	109,166.39	100,871.40
Repair and maintenance Cost	1,097.55	1,097.55	1,097.55	1,097.55	1,097.55	1,097.55	1,097.55	1,097.55
Pump-2 Cost (P_{2018})	76,770.00	76,770.00	76,770.00	76,770.00	76,770.00	76,770.00	76,770.00	76,770.00
Annual Pump Cost	9,924.66	9,924.66	9,924.66	9,924.66	9,924.66	9,924.66	9,924.66	9,924.66
Daily Energy Cost	368.64	367.38	324.75	320.44	308.62	298.71	301.55	278.13
Annual Energy Cost	134,552.87	134,092.24	118,532.66	116,959.87	112,644.48	109,029.88	110,063.93	101,516.36
Repair and maintenance Cost	1,151.55	1,151.55	1,151.55	1,151.55	1,151.55	1,151.55	1,151.55	1,151.55
Pipe Cost	687,004.91	1,374,009.82	687,004.91	1,374,009.82	687,004.91	1,374,009.82	687,004.91	1,374,009.82
Annual Pipe Cost	55,643.60	111,287.19	55,643.60	111,287.19	55,643.60	111,287.19	55,643.60	111,287.19
Repair and maintenance Cost	13,740.10	27,480.20	13,740.10	27,480.20	13,740.10	27,480.20	13,740.10	27,480.20
Tank Cost	946,599.00	946,599.00	1,846,979.00	1,846,979.00	2,747,359.00	2,747,359.00	3,647,739.00	3,647,739.00
Annual Tank Cost	76,669.28	76,669.28	149,595.08	149,595.08	222,520.88	222,520.88	295,446.68	295,446.68
Repair and maintenance Cost	9,465.99	9,465.99	18,469.79	18,469.79	27,473.59	27,473.59	36,477.39	36,477.39
Total Annual Cost-1	**301,114.83**	**370,812.42**	**365,029.85**	**432,392.18**	**441,562.19**	**507,366.33**	**521,030.96**	**582,119.67**
Total Annual Cost-2	**301,148.05**	**370,071.11**	**367,057.43**	**434,868.34**	**443,098.85**	**508,867.95**	**522,447.90**	**583,284.02**

Table 13 Annual Costs of Daily Energy Costs, Tank Costs, Pipe Costs, Pump Costs and Repair&Maintenance Cost (TL) in 2021

2021	TANK VOLUME / PIPE DIAMETER							
	2600 m^3		5200 m^3		7800 m^3		10400 m^3	
	Ø400 mm	Ø400+Ø400 mm	Ø400 mm	Ø400+Ø400 mm	Ø400 mm	Ø400+Ø400 mm	Ø400 mm	Ø400+Ø400 mm
Pump-1 Cost (P_{2015})	73,170.00	73,170.00	73,170.00	73,170.00	73,170.00	73,170.00	73,170.00	73,170.00
Annual Pump Cost	9,459.26	9,459.26	9,459.26	9,459.26	9,459.26	9,459.26	9,459.26	9,459.26
Daily Energy Cost	411.15	405.43	359.52	353.55	342.46	327.54	336.57	313.37
Annual Energy Cost	150,069.75	147,982.68	131,226.26	129,045.02	124,996.44	119,552.10	122,847.32	114,380.05
Repair and maintenance Cost	1,097.55	1,097.55	1,097.55	1,097.55	1,097.55	1,097.55	1,097.55	1,097.55
Pump-2 Cost ($_{2021}$)	88,020.00	88,020.00	88,020.00	88,020.00	88,020.00	88,020.00	88,020.00	88,020.00
Annual Pump Cost	11,379.03	11,379.03	11,379.03	11,379.03	11,379.03	11,379.03	11,379.03	11,379.03
Daily Energy Cost	427.73	422.67	361.69	352.86	344.41	335.14	334.09	311.73
Annual Energy Cost	156,119.63	154,273.46	132,015.03	128,792.44	125,708.92	122,327.56	121,941.76	113,781.45
Repair and maintenance Cost	1,320.30	1,320.30	1,320.30	1,320.30	1,320.30	1,320.30	1,320.30	1,320.30
Pipe Cost	687,004.91	1,374,009.82	687,004.91	1,374,009.82	687,004.91	1,374,009.82	687,004.91	1,374,009.82
Annual Pipe Cost	55,643.60	111,287.19	55,643.60	111,287.19	55,643.60	111,287.19	55,643.60	111,287.19
Repair and maintenance Cost	13,740.10	27,480.20	13,740.10	27,480.20	13,740.10	27,480.20	13,740.10	27,480.20
Tank Cost	946,599.00	946,599.00	1,846,979.00	1,846,979.00	2,747,359.00	2,747,359.00	3,647,739.00	3,647,739.00
Annual Tank Cost	76,669.28	76,669.28	149,595.08	149,595.08	222,520.88	222,520.88	295,446.68	295,446.68
Repair and maintenance Cost	9,465.99	9,465.99	18,469.79	18,469.79	27,473.59	27,473.59	36,477.39	36,477.39
Total Annual Cost-1	**316,145.53**	**383,442.15**	**379,231.64**	**446,434.09**	**454,931.41**	**518,870.77**	**534,711.89**	**595,628.32**
Total Annual Cost-2	**324,337.93**	**391,875.45**	**382,162.93**	**448,324.04**	**457,786.42**	**523,788.76**	**535,948.85**	**597,172.24**

Table 14 Annual Costs of Daily Energy Costs, Tank Costs, Pipe Costs, Pump Costs and Repair&Maintenance Cost (TL) in 2024

2024	TANK VOLUME / PIPE DIAMETER							
	2600 m^3		5200 m^3		7800 m^3		10400 m^3	
	Ø400 mm	Ø400+Ø400 mm	Ø400 mm	Ø400+Ø400 mm	Ø400 mm	Ø400+Ø400 mm	Ø400 mm	Ø400+Ø400 mm
Pump-1 Cost (P_{2015})	73,170.00	73,170.00	73,170.00	73,170.00	73,170.00	73,170.00	73,170.00	73,170.00
Annual Pump Cost	9,459.26	9,459.26	9,459.26	9,459.26	9,459.26	9,459.26	9,459.26	9,459.26
Daily Energy Cost	445.40	440.52	389.79	398.18	372.46	357.37	370.20	348.36
Annual Energy Cost	162,572.46	160,790.90	142,271.89	145,336.43	135,947.54	130,440.42	135,124.46	127,152.86
Repair and maintenance Cost	1,097.55	1,097.55	1,097.55	1,097.55	1,097.55	1,097.55	1,097.55	1,097.55
Pump-2 Cost (P_{2024})	90,000.00	90,000.00	90,000.00	90,000.00	90,000.00	90,000.00	90,000.00	90,000.00
Annual Pump Cost	11,635.00	11,635.00	11,635.00	11,635.00	11,635.00	11,635.00	11,635.00	11,635.00
Daily Energy Cost	470.21	450.07	411.11	398.40	385.01	371.98	375.24	352.40
Annual Energy Cost	171,628.11	164,274.46	150,054.06	145,414.18	140,529.38	135,773.80	136,964.06	128,627.46
Repair and maintenance Cost	1,350.00	1,350.00	1,350.00	1,350.00	1,350.00	1,350.00	1,350.00	1,350.00
Pipe Cost	687,004.91	1,374,009.82	687,004.91	1,374,009.82	687,004.91	1,374,009.82	687,004.91	1,374,009.82
Annual Pipe Cost	55,643.60	111,287.19	55,643.60	111,287.19	55,643.60	111,287.19	55,643.60	111,287.19
Repair and maintenance Cost	13,740.10	27,480.20	13,740.10	27,480.20	13,740.10	27,480.20	13,740.10	27,480.20
Tank Cost	946,599.00	946,599.00	1,846,979.00	1,846,979.00	2,747,359.00	2,747,359.00	3,647,739.00	3,647,739.00
Annual Tank Cost	76,669.28	76,669.28	149,595.08	149,595.08	222,520.88	222,520.88	295,446.68	295,446.68
Repair and maintenance Cost	9,465.99	9,465.99	18,469.79	18,469.79	27,473.59	27,473.59	36,477.39	36,477.39
Total Annual Cost-1	**328,648.24**	**396,250.37**	**390,277.27**	**462,725.50**	**465,882.51**	**529,759.08**	**546,989.03**	**608,401.13**
Total Annual Cost-2	**340,132.08**	**402,162.12**	**400,487.63**	**465,231.44**	**472,892.55**	**537,520.66**	**551,256.83**	**612,303.92**

Table 15 Annual Costs of Daily Energy Costs, Tank Costs, Pipe Costs, Pump Costs and Repair&Maintenance Cost (TL) in 2027

2027	TANK VOLUME / PIPE DIAMETER							
	$2600\ m^3$		$5200\ m^3$		$7800\ m^3$		$10400\ m^3$	
	Ø400 mm	Ø400+Ø400 mm	Ø400 mm	Ø400+Ø400 mm	Ø400 mm	Ø400+Ø400 mm	Ø400 mm	Ø400+Ø400 mm
Pump Cost (P_{2027})	103,950.00	103,950.00	103,950.00	103,950.00	103,950.00	103,950.00	103,950.00	103,950.00
Annual Pump Cost	13,438.43	13,438.43	13,438.43	13,438.43	13,438.43	13,438.43	13,438.43	13,438.43
Daily Energy Cost	451.98	428.97	373.40	371.68	356.32	344.41	346.79	326.44
Annual Energy Cost	164,971.61	156,572.59	136,291.73	135,664.30	130,056.44	125,708.56	126,577.62	119,151.33
Repair and maintenance Cost	1,559.25	1,559.25	1,559.25	1,559.25	1,559.25	1,559.25	1,559.25	1,559.25
Pipe Cost	687,004.91	1,374,009.82	687,004.91	1,374,009.82	687,004.91	1,374,009.82	687,004.91	1,374,009.82
Annual Pipe Cost	55,643.60	111,287.19	55,643.60	111,287.19	55,643.60	111,287.19	55,643.60	111,287.19
Repair and maintenance Cost	13,740.10	27,480.20	13,740.10	27,480.20	13,740.10	27,480.20	13,740.10	27,480.20
Tank Cost	946,599.00	946,599.00	1,846,979.00	1,846,979.00	2,747,359.00	2,747,359.00	3,647,739.00	3,647,739.00
Annual Tank Cost	76,669.28	76,669.28	149,595.08	149,595.08	222,520.88	222,520.88	295,446.68	295,446.68
Repair and maintenance Cost	9,465.99	9,465.99	18,469.79	18,469.79	27,473.59	27,473.59	36,477.39	36,477.39
Total Annual Cost	**335,488.25**	**396,472.93**	**388,737.98**	**457,494.24**	**464,432.28**	**529,468.10**	**542,883.07**	**604,840.47**

Table 16 Annual Costs of Daily Energy Costs, Tank Costs, Pipe Costs, Pump Costs and Repair&Maintenance Cost (TL) in 2030

2030	TANK VOLUME / PIPE DIAMETER							
	2600 m^3		5200 m^3		7800 m^3		10400 m^3	
	Ø400 mm	Ø400+Ø400 mm	Ø400 mm	Ø400+Ø400 mm	Ø400 mm	Ø400+Ø400 mm	Ø400 mm	Ø400+Ø400 mm
Pump-1 Cost (P_{2027})	103,950.00	103,950.00	103,950.00	103,950.00	103,950.00	103,950.00	103,950.00	103,950.00
Annual Pump Cost	13,438.43	13,438.43	13,438.43	13,438.43	13,438.43	13,438.43	13,438.43	13,438.43
Daily Energy Cost	608.63	590.57	550.98	513.56	507.31	471.54	496.60	451.44
Annual Energy Cost	222,150.32	215,558.78	201,108.80	187,450.13	185,167.79	172,110.28	181,260.46	164,775.24
Repair and maintenance Cost	1,559.25	1,559.25	1,559.25	1,559.25	1,559.25	1,559.25	1,559.25	1,559.25
Pump-2 Cost (P_{2030})	113,175.00	113,175.00	113,175.00	113,175.00	113,175.00	113,175.00	113,175.00	113,175.00
Annual Pump Cost	14,631.02	14,631.02	14,631.02	14,631.02	14,631.02	14,631.02	14,631.02	14,631.02
Daily Energy Cost	604.54	598.06	548.34	550.94	501.20	490.25	497.43	467.83
Annual Energy Cost	220,658.20	218,291.90	200,142.64	201,094.56	182,938.73	178,940.16	181,563.05	170,756.49
Repair and maintenance Cost	1,697.63	1,697.63	1,697.63	1,697.63	1,697.63	1,697.63	1,697.63	1,697.63
Pipe Cost	687,004.91	1,374,009.82	687,004.91	1,374,009.82	687,004.91	1,374,009.82	687,004.91	1,374,009.82
Annual Pipe Cost	55,643.60	111,287.19	55,643.60	111,287.19	55,643.60	111,287.19	55,643.60	111,287.19
Repair and maintenance Cost	13,740.10	27,480.20	13,740.10	27,480.20	13,740.10	27,480.20	13,740.10	27,480.20
Tank Cost	946,599.00	946,599.00	1,846,979.00	1,846,979.00	2,747,359.00	2,747,359.00	3,647,739.00	3,647,739.00
Annual Tank Cost	76,669.28	76,669.28	149,595.08	149,595.08	222,520.88	222,520.88	295,446.68	295,446.68
Repair and maintenance Cost	9,465.99	9,465.99	18,469.79	18,469.79	27,473.59	27,473.59	36,477.39	36,477.39
Total Annual Cost-1	**392,666.96**	**455,459.12**	**453,555.04**	**509,280.07**	**519,543.63**	**575,869.82**	**597,565.91**	**650,464.38**
Total Annual Cost-2	**392,505.81**	**459,523.21**	**453,919.85**	**524,255.47**	**518,645.54**	**584,030.66**	**599,199.45**	**657,776.59**

Table 17 Annual Costs of Daily Energy Costs, Tank Costs, Pipe Costs, Pump Costs and Repair&Maintenance Cost (TL) in 2033

2033	TANK VOLUME / PIPE DIAMETER							
	2600 m^3		5200 m^3		7800 m^3		10400 m^3	
	Ø400 mm	Ø400+Ø400 mm	Ø400 mm	Ø400+Ø400 mm	Ø400 mm	Ø400+Ø400 mm	Ø400 mm	Ø400+Ø400 mm
Pump-1 Cost (P_{2027})	103,950.00	103,950.00	103,950.00	103,950.00	103,950.00	103,950.00	103,950.00	103,950.00
Annual Pump Cost	13,438.43	13,438.43	13,438.43	13,438.43	13,438.43	13,438.43	13,438.43	13,438.43
Daily Energy Cost	669.16	636.40	603.19	595.75	567.30	540.61	565.75	523.33
Annual Energy Cost	244,244.86	232,287.10	220,162.53	217,448.39	207,063.77	197,323.38	206,499.48	191,016.18
Repair and maintenance Cost	1,559.25	1,559.25	1,559.25	1,559.25	1,559.25	1,559.25	1,559.25	1,559.25
Pump-2 Cost (P_{2033})	122,400.00	122,400.00	122,400.00	122,400.00	122,400.00	122,400.00	122,400.00	122,400.00
Annual Pump Cost	15,823.61	15,823.61	15,823.61	15,823.61	15,823.61	15,823.61	15,823.61	15,823.61
Daily Energy Cost	727.95	730.52	663.74	626.91	603.05	574.96	592.25	551.70
Annual Energy Cost	265,701.39	266,639.07	242,264.01	228,822.15	220,111.79	209,861.13	216,171.25	201,369.77
Repair and maintenance Cost	1,836.00	1,836.00	1,836.00	1,836.00	1,836.00	1,836.00	1,836.00	1,836.00
Pipe Cost	687,004.91	1,374,009.82	687,004.91	1,374,009.82	687,004.91	1,374,009.82	687,004.91	1,374,009.82
Annual Pipe Cost	55,643.60	111,287.19	55,643.60	111,287.19	55,643.60	111,287.19	55,643.60	111,287.19
Repair and maintenance Cost	13,740.10	27,480.20	13,740.10	27,480.20	13,740.10	27,480.20	13,740.10	27,480.20
Tank Cost	946,599.00	946,599.00	1,846,979.00	1,846,979.00	2,747,359.00	2,747,359.00	3,647,739.00	3,647,739.00
Annual Tank Cost	76,669.28	76,669.28	149,595.08	149,595.08	222,520.88	222,520.88	295,446.68	295,446.68
Repair and maintenance Cost	9,465.99	9,465.99	18,469.79	18,469.79	27,473.59	27,473.59	36,477.39	36,477.39
Total Annual Cost-1	**414,761.51**	**472,187.44**	**472,608.77**	**539,278.33**	**541,439.62**	**601,082.92**	**622,804.93**	**676,705.32**
Total Annual Cost-2	**438,879.96**	**509,201.34**	**497,372.18**	**553,314.02**	**557,149.56**	**616,282.60**	**635,138.62**	**689,720.84**

Table 18 Annual Costs of Daily Energy Costs, Tank Costs, Pipe Costs, Pump Costs and Repair&Maintenance Cost (TL) in 2036

2036	TANK VOLUME / PIPE DIAMETER							
	2600 m^3		5200 m^3		7800 m^3		10400 m^3	
	Ø400 mm	Ø400+Ø400 mm	Ø400 mm	Ø400+Ø400 mm	Ø400 mm	Ø400+Ø400 mm	Ø400 mm	Ø400+Ø400 mm
Pump-1 Cost (P_{2033})	122,400.00	122,400.00	122,400.00	122,400.00	122,400.00	122,400.00	122,400.00	122,400.00
Annual Pump Cost	15,823.61	15,823.61	15,823.61	15,823.61	15,823.61	15,823.61	15,823.61	15,823.61
Daily Energy Cost	792.93	787.39	741.94	729.76	714.18	645.94	715.99	627.53
Annual Energy Cost	289,417.63	287,397.35	270,809.56	266,362.77	260,674.97	235,766.64	261,337.08	229,046.63
Repair and maintenance Cost	1,836.00	1,836.00	1,836.00	1,836.00	1,836.00	1,836.00	1,836.00	1,836.00
Pump-2 Cost (P_{2036})	125,820.00	125,820.00	125,820.00	125,820.00	125,820.00	125,820.00	125,820.00	125,820.00
Annual Pump Cost	16,265.74	16,265.74	16,265.74	16,265.74	16,265.74	16,265.74	16,265.74	16,265.74
Daily Energy Cost	844.33	898.57	744.92	729.79	721.76	674.90	711.81	623.14
Annual Energy Cost	308,179.72	327,978.78	271,896.53	266,374.08	263,442.04	246,337.77	259,808.83	227,446.10
Repair and maintenance Cost	1,887.30	1,887.30	1,887.30	1,887.30	1,887.30	1,887.30	1,887.30	1,887.30
Pipe Cost	687,004.91	1,374,009.82	687,004.91	1,374,009.82	687,004.91	1,374,009.82	687,004.91	1,374,009.82
Annual Pipe Cost	55,643.60	111,287.19	55,643.60	111,287.19	55,643.60	111,287.19	55,643.60	111,287.19
Repair and maintenance Cost	13,740.10	27,480.20	13,740.10	27,480.20	13,740.10	27,480.20	13,740.10	27,480.20
Tank Cost	946,599.00	946,599.00	1,846,979.00	1,846,979.00	2,747,359.00	2,747,359.00	3,647,739.00	3,647,739.00
Annual Tank Cost	76,669.28	76,669.28	149,595.08	149,595.08	222,520.88	222,520.88	295,446.68	295,446.68
Repair and maintenance Cost	9,465.99	9,465.99	18,469.79	18,469.79	27,473.59	27,473.59	36,477.39	36,477.39
Total Annual Cost-1	**462,596.20**	**529,959.62**	**525,917.73**	**590,854.63**	**597,712.74**	**642,188.11**	**680,304.45**	**717,397.69**
Total Annual Cost-2	**481,851.72**	**571,034.48**	**527,498.13**	**591,359.38**	**600,973.24**	**653,252.67**	**679,269.63**	**716,290.60**

Table 19 Annual Costs of Daily Energy Costs, Tank Costs, Pipe Costs, Pump Costs and Repair&Maintenance Cost (TL) in 2039

2039	TANK VOLUME / PIPE DIAMETER							
	2600 m^3		5200 m^3		7800 m^3		10400 m^3	
	Ø400 mm	Ø400+Ø400 mm	Ø400 mm	Ø400+Ø400 mm	Ø400 mm	Ø400+Ø400 mm	Ø400 mm	Ø400+Ø400 mm
Pump-1 Cost (P_{2033})	122,400.00	122,400.00	122,400.00	122,400.00	122,400.00	122,400.00	122,400.00	122,400.00
Annual Pump Cost	15,823.61	15,823.61	15,823.61	15,823.61	15,823.61	15,823.61	15,823.61	15,823.61
Daily Energy Cost	887.09	853.18	852.60	808.25	822.06	759.59	837.36	694.38
Annual Energy Cost	323,787.12	311,409.97	311,200.10	295,010.16	300,050.81	277,250.72	305,636.77	253,446.88
Repair and maintenance Cost	1,836.00	1,836.00	1,836.00	1,836.00	1,836.00	1,836.00	1,836.00	1,836.00
Pump-2 Cost (P_{2039})	145,170.00	145,170.00	145,170.00	145,170.00	145,170.00	145,170.00	145,170.00	145,170.00
Annual Pump Cost	18,767.26	18,767.26	18,767.26	18,767.26	18,767.26	18,767.26	18,767.26	18,767.26
Daily Energy Cost	986.84	909.50	900.65	829.83	868.80	782.00	851.07	725.65
Annual Energy Cost	360,194.78	331,966.04	328,737.62	302,886.86	317,112.73	285,428.18	310,642.01	264,863.35
Repair and maintenance Cost	2,177.55	2,177.55	2,177.55	2,177.55	2,177.55	2,177.55	2,177.55	2,177.55
Pipe Cost	687,004.91	1,374,009.82	687,004.91	1,374,009.82	687,004.91	1,374,009.82	687,004.91	1,374,009.82
Annual Pipe Cost	55,643.60	111,287.19	55,643.60	111,287.19	55,643.60	111,287.19	55,643.60	111,287.19
Repair and maintenance Cost	13,740.10	27,480.20	13,740.10	27,480.20	13,740.10	27,480.20	13,740.10	27,480.20
Tank Cost	946,599.00	946,599.00	1,846,979.00	1,846,979.00	2,747,359.00	2,747,359.00	3,647,739.00	3,647,739.00
Annual Tank Cost	76,669.28	76,669.28	149,595.08	149,595.08	222,520.88	222,520.88	295,446.68	295,446.68
Repair and maintenance Cost	9,465.99	9,465.99	18,469.79	18,469.79	27,473.59	27,473.59	36,477.39	36,477.39
Total Annual Cost-1	**496,965.69**	**553,972.24**	**566,308.27**	**619,502.02**	**637,088.58**	**683,672.18**	**724,604.14**	**741,797.94**
Total Annual Cost-2	**536,658.56**	**577,813.52**	**587,130.99**	**630,663.93**	**657,435.71**	**695,134.85**	**732,894.59**	**756,499.62**

Table 20 Annual Costs of Daily Energy Costs, Tank Costs, Pipe Costs, Pump Costs and Repair&Maintenance Cost (TL) in 2042

2042	TANK VOLUME / PIPE DIAMETER							
	2600 m^3		5200 m^3		7800 m^3		10400 m^3	
	Ø400 mm	Ø400+Ø400 mm	Ø400 mm	Ø400+Ø400 mm	Ø400 mm	Ø400+Ø400 mm	Ø400 mm	Ø400+Ø400 mm
Pump-1 Cost (P_{2033})	122,400.00	122,400.00	122,400.00	122,400.00	122,400.00	122,400.00	122,400.00	122,400.00
Annual Pump Cost	15,823.61	15,823.61	15,823.61	15,823.61	15,823.61	15,823.61	15,823.61	15,823.61
Daily Energy Cost	974.63	963.58	955.54	913.69	923.23	830.42	918.52	822.14
Annual Energy Cost	355,738.86	351,707.80	348,772.47	333,495.39	336,977.49	303,102.94	335,260.53	300,079.64
Repair and maintenance Cost	1,836.00	1,836.00	1,836.00	1,836.00	1,836.00	1,836.00	1,836.00	1,836.00
Pump-2 Cost (P_{2042})	167,940.00	167,940.00	167,940.00	167,940.00	167,940.00	167,940.00	167,940.00	167,940.00
Annual Pump Cost	21,710.92	21,710.92	21,710.92	21,710.92	21,710.92	21,710.92	21,710.92	21,710.92
Daily Energy Cost	1,141.84	1,136.97	1,137.59	1,021.50	1,118.69	942.38	1,124.79	918.63
Annual Energy Cost	416,771.24	414,994.05	415,220.72	372,848.96	408,323.31	343,968.34	410,546.53	335,300.32
Repair and maintenance Cost	2,519.10	2,519.10	2,519.10	2,519.10	2,519.10	2,519.10	2,519.10	2,519.10
Pipe Cost	687,004.91	1,374,009.82	687,004.91	1,374,009.82	687,004.91	1,374,009.82	687,004.91	1,374,009.82
Annual Pipe Cost	55,643.60	111,287.19	55,643.60	111,287.19	55,643.60	111,287.19	55,643.60	111,287.19
Repair and maintenance Cost	13,740.10	27,480.20	13,740.10	27,480.20	13,740.10	27,480.20	13,740.10	27,480.20
Tank Cost	946,599.00	946,599.00	1,846,979.00	1,846,979.00	2,747,359.00	2,747,359.00	3,647,739.00	3,647,739.00
Annual Tank Cost	76,669.28	76,669.28	149,595.08	149,595.08	222,520.88	222,520.88	295,446.68	295,446.68
Repair and maintenance Cost	9,465.99	9,465.99	18,469.79	18,469.79	27,473.59	27,473.59	36,477.39	36,477.39
Total Annual Cost-1	**503,875.34**	**555,487.88**	**569,834.75**	**610,201.27**	**630,965.57**	**652,734.62**	**702,174.41**	**722,637.12**
Total Annual Cost-2	**596,520.22**	**664,126.73**	**676,899.30**	**703,911.24**	**751,931.49**	**756,960.21**	**836,084.31**	**830,221.79**

Table 21 Annual Costs of Daily Energy Costs, Tank Costs, Pipe Costs, Pump Costs and Repair&Maintenance Cost (TL) in 2045

2045a	TANK VOLUME / PIPE DIAMETER							
	2600 m^3		5200 m^3		7800 m^3		10400 m^3	
	Ø400 mm	Ø400+Ø400 mm	Ø400 mm	Ø400+Ø400 mm	Ø400 mm	Ø400+Ø400 mm	Ø400 mm	Ø400+Ø400 mm
Pump Cost (P_{2045a})	190,710.00	190,710.00	190,710.00	190,710.00	190,710.00	190,710.00	190,710.00	190,710.00
Annual Pump Cost	24,654.58	24,654.58	24,654.58	24,654.58	24,654.58	24,654.58	24,654.58	24,654.58
Daily Energy Cost	1,435.57	1,403.47	1,410.61	1,219.87	1,580.18	1,169.31	1,292.81	1,159.10
Annual Energy Cost	523,981.23	512,266.92	514,871.92	445,250.73	576,764.61	426,797.79	471,876.75	423,071.14
Repair and maintenance Cost	2,860.65	2,860.65	2,860.65	2,860.65	2,860.65	2,860.65	2,860.65	2,860.65
Pipe Cost	687,004.91	1,374,009.82	687,004.91	1,374,009.82	687,004.91	1,374,009.82	687,004.91	1,374,009.82
Annual Pipe Cost	55,643.60	111,287.19	55,643.60	111,287.19	55,643.60	111,287.19	55,643.60	111,287.19
Repair and maintenance Cost	13,740.10	27,480.20	13,740.10	27,480.20	13,740.10	27,480.20	13,740.10	27,480.20
Tank Cost	946,599.00	946,599.00	1,846,979.00	1,846,979.00	2,747,359.00	2,747,359.00	3,647,739.00	3,647,739.00
Annual Tank Cost	76,669.28	76,669.28	149,595.08	149,595.08	222,520.88	222,520.88	295,446.68	295,446.68
Repair and maintenance Cost	9,465.99	9,465.99	18,469.79	18,469.79	27,473.59	27,473.59	36,477.39	36,477.39
Total Annual Cost	707,015.42	764,684.80	779,835.71	779,598.21	923,658.00	843,074.87	900,699.74	921,277.82

2045b	TANK VOLUME / PIPE DIAMETER							
	2600 m^3		5200 m^3		7800 m^3		10400 m^3	
	Ø400 mm	Ø400+Ø400 mm	Ø400 mm	Ø400+Ø400 mm	Ø400 mm	Ø400+Ø400 mm	Ø400 mm	Ø400+Ø400 mm
Pump Cost (P_{2045b})		178,650.00		178,650.00		178,650.00		178,650.00
Annual Pump Cost		23,095.48		23,095.48		23,095.48		23,095.48
Daily Energy Cost		1,066.65		1,014.88		1,005.75		973.35
Annual Energy Cost		389,327.98		370,432.66		367,098.39		355,274.21
Repair and maintenance Cost		2,679.75		2,679.75		2,679.75		2,679.75
Pipe Cost		1,374,009.82		1,374,009.82		1,374,009.82		1,374,009.82
Annual Pipe Cost		111,287.19		111,287.19		111,287.19		111,287.19
Repair and maintenance Cost		27,480.20		27,480.20		27,480.20		27,480.20
Tank Cost		946,599.00		1,846,979.00		2,747,359.00		3,647,739.00
Annual Tank Cost		76,669.28		149,595.08		222,520.88		295,446.68
Repair and maintenance Cost		9,465.99		18,469.79		27,473.59		36,477.39
Total Annual Cost		640,005.88		703,040.16		781,635.48		851,740.90

Table 22 Annual Costs of Daily Energy Costs, Tank Costs, Pipe Costs, Pump Costs and Repair&Maintenance Cost (TL) in 2048

2048	TANK VOLUME / PIPE DIAMETER							
	2600 m^3		5200 m^3		7800 m^3		10400 m^3	
	Ø400 mm	Ø400+Ø400 mm	Ø400 mm	Ø400+Ø400 mm	Ø400 mm	Ø400+Ø400 mm	Ø400 mm	Ø400+Ø400 mm
Pump-1 Cost (P_{2045b})		178,650.00		178,650.00		178,650.00		178,650.00
Annual Pump Cost		23,095.48		23,095.48		23,095.48		23,095.48
Daily Energy Cost		1,218.40		1,201.50		1,211.18		1,397.05
Annual Energy Cost		444,716.00		438,548.23		442,079.24		509,922.89
Repair and maintenance Cost		2,679.75		2,679.75		2,679.75		2,679.75
Pump-2 Cost (P_{2048})		188,550.00		188,550.00		188,550.00		188,550.00
Annual Pump Cost		24,375.34		24,375.34		24,375.34		24,375.34
Daily Energy Cost		1,258.60		1,211.44		1,249.47		1,560.61
Annual Energy Cost		459,387.54		442,175.60		456,057.28		569,621.19
Repair and maintenance Cost		2,828.25		2,828.25		2,828.25		2,828.25
Pipe Cost		1,374,009.82		1,374,009.82		1,374,009.82		1,374,009.82
Annual Pipe Cost		111,287.19		111,287.19		111,287.19		111,287.19
Repair and maintenance Cost		27,480.20		27,480.20		27,480.20		27,480.20
Tank Cost		946,599.00		1,846,979.00		2,747,359.00		3,647,739.00
Annual Tank Cost		76,669.28		149,595.08		222,520.88		295,446.68
Repair and maintenance Cost		9,465.99		18,469.79		27,473.59		36,477.39
Total Annual Cost-1		**695,393.90**		**771,155.73**		**856,616.34**		**1,006,389.58**
Total Annual Cost-2		**711,493.79**		**776,211.45**		**872,022.73**		**1,067,516.24**

Table 23 Annual Costs of Daily Energy Costs, Tank Costs, Pipe Costs, Pump Costs and Repair&Maintenance Cost (TL) in 2051

2051	TANK VOLUME / PIPE DIAMETER							
	2600 m^3		5200 m^3		7800 m^3		10400 m^3	
	Ø400 mm	Ø400+Ø400 mm	Ø400 mm	Ø400+Ø400 mm	Ø400 mm	Ø400+Ø400 mm	Ø400 mm	Ø400+Ø400 mm
Pump-1 Cost (P_{2045b})		178,650.00		178,650.00		178,650.00		178,650.00
Annual Pump Cost		23,095.48		23,095.48		23,095.48		23,095.48
Daily Energy Cost		1,870.68		1,791.02		1,792.71		1,726.68
Annual Energy Cost		682,797.11		653,720.48		654,338.79		630,237.47
Repair and maintenance Cost		2,679.75		2,679.75		2,679.75		2,679.75
Pump-2 Cost (P_{2051})		200,250.00		200,250.00		200,250.00		200,250.00
Annual Pump Cost		25,887.89		25,887.89		25,887.89		25,887.89
Daily Energy Cost		2,084.53		2,058.75		2,063.48		2,043.09
Annual Energy Cost		760,853.82		751,443.39		753,169.47		745,729.31
Repair and maintenance Cost		3,003.75		3,003.75		3,003.75		3,003.75
Pipe Cost		1,374,009.82		1,374,009.82		1,374,009.82		1,374,009.82
Annual Pipe Cost		111,287.19		111,287.19		111,287.19		111,287.19
Repair and maintenance Cost		27,480.20		27,480.20		27,480.20		27,480.20
Tank Cost		946,599.00		1,846,979.00		2,747,359.00		3,647,739.00
Annual Tank Cost		76,669.28		149,595.08		222,520.88		295,446.68
Repair and maintenance Cost		9,465.99		18,469.79		27,473.59		36,477.39
Total Annual Cost-1		**933,475.00**		**986,327.97**		**1,068,875.88**		**1,126,704.16**
Total Annual Cost-2		**1,014,648.11**		**1,087,167.28**		**1,170,822.97**		**1,245,312.41**

All these calculations were performed to overcome the difficulty of comparing the annual costs of the scenarios. In the Table 24, the comparison was made to find the most economical scenario while satisfying the hydraulic performance requirements.

As the time passes and population increases, the water demand of the region also increases. This condition affects the existing system negatively and some hydraulic insufficiencies are observed on the existing system. The orange colored cells in the Table 24 show that there is a violation on some of the constraints. It means that these scenarios are not suitable hydraulically for the N8.3 water supply system.

Table 24 Total Annual Costs of the Scenarios

NO	YEAR	PUMP	POPULATION	TANK VOLUME / PIPE DIAMETER							
				2600 m3		5200 m3		7800 m3		10400 m3	
				Ø400 mm	Ø400+Ø400 mm	Ø400 mm	Ø400+Ø400 mm	Ø400 mm	Ø400+Ø400 mm	Ø400 mm	Ø400+Ø400 mm
1	2015	P_{2015}	50.000	**285.769,55 TL**		351.807,41 TL		427.771,45 TL		507.180,36 TL	
2	2018	P_{2015}	53.845	**301.114,83 TL**	370.812,42 TL	365.029,85 TL	432.392,18 TL	441.562,19 TL	507.366,33 TL	521.030,96 TL	582.119,67 TL
		P_{2018}		301.148,05 TL	370.071,11 TL	367.057,43 TL	434.868,34 TL	443.098,85 TL	508.867,95 TL	522.447,90 TL	583.284,02 TL
3	2021	P_{2015}	57.985	**316.145,53 TL**	383.442,15 TL	379.231,64 TL	446.434,09 TL	454.931,41 TL	518.870,77 TL	534.711,89 TL	595.628,32 TL
		P_{2021}		324.337,93 TL	391.875,45 TL	382.162,93 TL	448.324,04 TL	457.786,42 TL	523.788,76 TL	535.948,85 TL	597.172,24 TL
4	2024	P_{2015}	62.443	**328.648,24 TL**	396.250,37 TL	390.277,27 TL	462.725,50 TL	465.882,51 TL	529.759,08 TL	546.989,03 TL	608.401,13 TL
		P_{2024}		340.132,08 TL	402.162,12 TL	400.487,63 TL	465.231,44 TL	472.892,55 TL	537.520,66 TL	551.256,83 TL	612.303,92 TL
	2027	P_{2027}		**335.488,25 TL**	396.472,93 TL	388.737,98 TL	457.494,24 TL	464.432,28 TL	529.468,10 TL	542.883,07 TL	604.840,47 TL
6	2030	P_{2027}	72.415	**392.666,96 TL**	455.459,12 TL	453.555,04 TL	509.280,07 TL	519.543,63 TL	575.869,82 TL	597.565,91 TL	650.464,38 TL
		P_{2030}		392.505,81 TL	459.523,21 TL	453.919,85 TL	524.255,47 TL	518.645,54 TL	584.030,66 TL	599.199,45 TL	657.776,59 TL
7	2033	P_{2027}	77.983	414.761,51 TL	472.187,44 TL	472.608,77 TL	539.278,33 TL	541.439,62 TL	601.082,92 TL	622.804,93 TL	676.705,32 TL
		P_{2033}		**438.879,96 TL**	509.201,34 TL	497.372,18 TL	553.314,02 TL	557.149,56 TL	616.282,60 TL	635.138,62 TL	689.720,84 TL
8	2036	P_{2033}	83.979	**462.596,20 TL**	529.959,62 TL	525.917,73 TL	590.854,63 TL	597.712,74 TL	642.188,11 TL	680.304,45 TL	717.397,69 TL
		P_{2036}		481.851,72 TL	571.034,48 TL	527.498,13 TL	591.359,38 TL	600.973,24 TL	653.252,67 TL	679.269,63 TL	716.290,60 TL
9	2039	P_{2033}	90.436	**496.965,69 TL**	553.972,24 TL	566.308,27 TL	619.502,02 TL	637.088,58 TL	683.672,18 TL	724.604,14 TL	741.797,94 TL
		P_{2039}		536.658,56 TL	577.813,52 TL	587.130,99 TL	630.663,93 TL	657.435,71 TL	695.134,85 TL	732.894,59 TL	756.499,62 TL
10	2042	P_{2033}	97.390	**503.875,34 TL**	555.487,88 TL	569.834,75 TL	610.201,27 TL	630.965,57 TL	652.734,62 TL	702.174,41 TL	722.637,12 TL
		P_{2042}		596.520,22 TL	664.126,73 TL	676.899,30 TL	703.911,24 TL	751.931,49 TL	756.960,21 TL	836.084,31 TL	830.221,79 TL
11	2045a	P_{2045a}	104.878	707.015,42 TL	764.684,80 TL	779.835,71 TL	**779.598,21 TL**	923.658,00 TL	843.074,87 TL	900.699,74 TL	921.277,82 TL
11	2045b	P_{2045b}	104.878		**640.005,88 TL**		703.040,16 TL		781.635,48 TL		851.740,90 TL
12	2048	P_{2045b}	112.943		695.393,90 TL		**771.155,73 TL**		856.616,34 TL		1.006.389,58 TL
		P_{2048}			711.493,79 TL		776.211,45 TL		872.022,73 TL		1.067.516,24 TL
13	2051	P_{2045b}	121.627		933.475,00 TL		986.327,97 TL		1.068.875,88 TL		**1.126.704,16 TL**
		P_{2051}			1.014.648,11 TL		1.087.167,28 TL		1.170.822,97 TL		1.245.312,41 TL

Tank Maximum or Minimum Level Violation
Minimum Total Annual Cost in the Study Year

Evaluation of the Table 24:

In 2015, there is no violation in all the scenarios and the cheapest price was calculated as "T2600, 2015-1,400" among the scenarios. This means that 2600 m^3 storage tank, 400 mm diameter pipe and P_{2015} pump will be used for 3 years.

In 2018, 2021, 2024 there are 16 scenarios for each year and the cheapest ones are found as "T2600, 2018-1,400", "T2600, 2021-1,400" and T2600, 2024-1,400" respectively. It means that using the same pump, same pipe and same tank is better than other alternatives in economical point of view.

In 2027, as the economic life time of the pump P_{2015} had expired, it had to be changed with P_{2027}. The cheapest scenario was observed as "T2600, 2027-1,400". It shows that using the same pipe and tank is a better idea and no need to change them with a new one.

In 2030, the pump P_{2030} was the second pump option for the system, however it is seen that larger capacity pump caused violation with the 2600 m^3 tank and 400 mm diameter pipe. Although the cheapest scenario is found as "T2600, 2030-2, 400", it is not convenient because of the existing violation. Then, the second cheapest scenario becomes the best scenario which is "T2600, 2030-1,400". The same system components can be used for 3 years more.

In 2033, There are two scenarios observed having violation in their systems which are "T2600, 2033-1,400" and "T2600,2033-2,400+400". The cheapest scenario among hydraulically convenient scenarios is "T2600, 2033-2,400". It means that, currently used pump P_{2027} should be changed with pump P_{2033}. Other components of the network can be used for the next 3 years.

In 2036, 2039 and 2042, the scenarios "T2600, 2036-1,400", "T2600, 2039-1,400" and "T2600, 2042-1,400" are the cheapest scenarios respectively in their own years. It shows that, using pump P_{2033}, 400 mm diameter pipe and 2600 m^3 storage tank is more logical from other alternative scenarios.

In 2045, as the economic life time of the pump P2033 had expired, it had to be changed with P_{2045a}. There is a violation observed in the scenarios "T2600,2045-1a, 400", "T2600,2045-1a,400+400" and "T5200,2045-1a,400". The cheapest scenario among the remaining scenarios was observed as “T5200, 2045-1a,400+400. It shows that 2600 m^3 tank and one 400 mm pipe cannot satisfy the hydraulic requirements. So another 400 mm pipe should be placed near existing pipe.

Addition of another pipe to the transmission line makes the used pump redesigned by considering two 400 mm diameter pipe condition. The pump, P_{2045b}, was designed and total annual cost of the scenarios was compared. In this case, there is no violation observed in the scenarios and the cheapest scenario was determined as “T2600,2045-1b,400+400”. When compared these two case, continuing to use the 2600 m^3 storage tank with two 400 mm diameter pipes and pump P_{2045b} is the cheapest way of operation of the system.

As the transmission of the water is satisfied by two 400 mm diameter pipes from this year, 400 mm pipe alternative was not considered in the next scenarios.

In 2048, there are 8 scenarios to compare and it is observed that 2600 m^3 storage tank is not enough to meet the hydraulic requirements of the system. When looking at the remaining scenarios, the “T5200,2045-1b,400+400” is the cheapest one. The tank volume should be upgraded to 5200 m^3 volume and P_{2045b} pump should continue to be used.

In 2051, it is seen that storage tanks with 2600 m^3, 5200 m^3 and 7800 m^3 volume are inadequate to meet the requirements of the water supply system. “T10400,2051-1,400+400” scenario is the only one alternative that meets the hydraulic requirements. So the system should be composed of 10400 m^3 storage tank, P_{2045b} pump and transmission line with 400 mm diameter two pipes.

3.15 Different Growth Rates for Population Projection

The growth rate used for population projection was taken as 2.5 in this study and rehabilitation plan of the system was determined accordingly as in section 5.13. As it is known, population may not always grow as it is predicted. To see how the system is affected from unpredicted population growth, growth rate was changed in different time periods as c=1.0 and c=3.5.

The case c=1.0;

In the case that multiplication factor was 1.0 instead of 2.5 in the time period of 2048-2051, the population grew slower than expected. This situation made the pumps pump less water because of less water demand. The daily energy consumption decreased in this case. According to calculated future populations for c=2.5 and c=1.0, rehabilitation plans can be compared as in Table 25 and Table 26.

In 2048, the tank with 2600 m3 volume cannot be used because of maximum tank level violations and the most economical scenario was found as “T5200,2048-1,400+400” in both c=2.5 and c=1.0 case. On the other hand, because of less energy consumption, total cost of the scenario was cheaper in c=1.0 case.

In 2051, Only one scenario which was “T10400,2051-1,400+400” was hydraulically convenient in c=2.5 case. However, it was seen that in c=1.0 case, 5200 m3 storage tank can be continued to use in this time period.

Table 25 Total Cost of the System with c=2.5 In Period 2048-2051.

NO	YEAR	PUMP	POPULATION	TANK VOLUME / PIPE DIAMETER							
				2600 m3		5200 m3		7800 m3		10400 m3	
				Ø400 mm	Ø400+Ø400 mm	Ø400 mm	Ø400+Ø400 mm	Ø400 mm	Ø400+Ø400 mm	Ø400 mm	Ø400+Ø400 mm
12	2048	P_{2045b}	112.943		695.393,90 TL		**771.155,73 TL**		856.616,34 TL		1.006.389,58 TL
		P_{2048}			711.493,79 TL		776.211,45 TL		872.022,73 TL		1.067.516,24 TL
13	2051	P_{2045b}	121.627		933.475,00 TL		986.327,97 TL		1.068.875,88 TL		**1.126.704,16 TL**
		P_{2051}			1.014.648,11 TL		1.087.167,28 TL		1.170.822,97 TL		1.245.312,41 TL

Table 26 Total Cost of the System with c=1.0 In Period 2048-2051.

NO	YEAR	PUMP	POPULATION	TANK VOLUME / PIPE DIAMETER							
				2600 m3		5200 m3		7800 m3		10400 m3	
				Ø400 mm	Ø400+Ø400 mm	Ø400 mm	Ø400+Ø400 mm	Ø400 mm	Ø400+Ø400 mm	Ø400 mm	Ø400+Ø400 mm
12	2048	P_{2045b}	108.056		653.922,60 TL		**734.011,87 TL**		800.687,39 TL		869.191,19 TL
		P_{2048}			666.723,25 TL		737.316,68 TL		803.569,17 TL		879.987,27 TL
13	2051	P_{2045b}	111.331		674.760,08 TL		**744.119,08 TL**		838.301,73 TL		903.157,72 TL
		P_{2051}			713.504,13 TL		765.962,90 TL		841.884,24 TL		909.748,20 TL

The case c=3.5;

In the case that multiplication factor was 3.5 instead of 2.5 in the time periods of 2018-2024 and 2036-2042, the population grew faster than expected. This situation forced the pumps pump more water because of increased water demand. The daily energy consumption increased in this case. According to calculated future populations for c=2.5 and c=3.5, rehabilitation plans can be compared as in Table 27 and Table 28.

In the period 2018-2024, as an earlier stage of the economic life of the system, there was no change on the rehabilitation plan. As the system served to more people in c=3.5 case, energy consumption and total cost increased.

Table 27 Total Cost of the System with c=2.5 In Period 2018-2024.

NO	YEAR	PUMP	POPULATION	TANK VOLUME / PIPE DIAMETER							
				2600 m3		5200 m3		7800 m3		10400 m3	
				Ø400 mm	Ø400+Ø400 mm	Ø400 mm	Ø400+Ø400 mm	Ø400 mm	Ø400+Ø400 mm	Ø400 mm	Ø400+Ø400 mm
2	2018	P_{2015}	53.845	**301.114,83 TL**	370.812,42 TL	365.029,85 TL	432.392,18 TL	441.562,19 TL	507.366,33 TL	521.030,96 TL	582.119,67 TL
		P_{2018}		301.148,05 TL	370.071,11 TL	367.057,43 TL	434.868,34 TL	443.098,85 TL	508.867,95 TL	522.447,90 TL	583.284,02 TL
3	2021	P_{2015}	57.985	**316.145,53 TL**	383.442,15 TL	379.231,64 TL	446.434,09 TL	454.931,41 TL	518.870,77 TL	534.711,89 TL	595.628,32 TL
		P_{2021}		324.337,93 TL	391.875,45 TL	382.162,93 TL	448.324,04 TL	457.786,42 TL	523.788,76 TL	535.948,85 TL	597.172,24 TL
4	2024	P_{2015}	62.443	**328.648,24 TL**	396.250,37 TL	390.277,27 TL	462.725,50 TL	465.882,51 TL	529.759,08 TL	546.989,03 TL	608.401,13 TL
		P_{2024}		340.132,08 TL	402.162,12 TL	400.487,63 TL	465.231,44 TL	472.892,55 TL	537.520,66 TL	551.256,83 TL	612.303,92 TL

Table 28 Total Cost of the System with c=3.5 In Period 2018-2024.

NO	YEAR	PUMP	POPULATION	TANK VOLUME / PIPE DIAMETER							
				2600 m3		5200 m3		7800 m3		10400 m3	
				Ø400 mm	Ø400+Ø400 mm	Ø400 mm	Ø400+Ø400 mm	Ø400 mm	Ø400+Ø400 mm	Ø400 mm	Ø400+Ø400 mm
2	2018	P_{2015}	55.436	**308.029,75 TL**	371.625,64 TL	368.309,38 TL	438.959,99 TL	447.105,08 TL	511.156,13 TL	526.595,02 TL	586.224,09 TL
		P_{2018}		308.986,06 TL	376.640,02 TL	371.129,37 TL	443.171,36 TL	446.993,03 TL	512.706,29 TL	529.656,28 TL	588.928,75 TL
3	2021	P_{2015}	61.463	**328.058,03 TL**	397.000,08 TL	389.795,10 TL	459.505,11 TL	465.117,47 TL	531.590,29 TL	546.428,03 TL	604.842,74 TL
		P_{2021}		335.678,11 TL	397.204,82 TL	396.036,94 TL	462.345,88 TL	469.140,11 TL	533.553,24 TL	548.239,13 TL	608.199,99 TL
4	2024	P_{2015}	68.145	**350.275,95 TL**	419.661,83 TL	412.782,44 TL	479.657,85 TL	486.090,73 TL	550.111,12 TL	565.637,61 TL	625.565,98 TL
		P_{2024}		355.855,55 TL	424.369,45 TL	420.096,52 TL	487.039,10 TL	492.894,92 TL	557.728,16 TL	570.816,81 TL	629.504,91 TL

The comparison of the period 2036-2042 for c=2.5 and c=3.5 case was made by Table 29 and Table 30. While the most economical and hydraulically convenient scenarios were with tank volume 2600 m3 in 2036 and 2039 years for both case, because of violations occurred at tank 2600 m3, the tank must be upgraded to 5200 m3 in 2042 in c=3.5 case. On the other hand, there was no change on pump and pipe decision.

Table 29 Total Cost of the System with c=2.5 In Period 2036-2042.

NO	YEAR	PUMP	POPULATION	TANK VOLUME / PIPE DIAMETER							
				2600 m3		5200 m3		7800 m3		10400 m3	
				Ø400 mm	Ø400+Ø400 mm	Ø400 mm	Ø400+Ø400 mm	Ø400 mm	Ø400+Ø400 mm	Ø400 mm	Ø400+Ø400 mm
8	2036	P_{2033}	83.979	**462.596,20 TL**	529.959,62 TL	525.917,73 TL	590.854,63 TL	597.712,74 TL	642.188,11 TL	680.304,45 TL	717.397,69 TL
		P_{2036}		481.851,72 TL	571.034,48 TL	527.498,13 TL	591.359,38 TL	600.973,24 TL	653.252,67 TL	679.269,63 TL	716.290,60 TL
9	2039	P_{2033}	90.436	**496.965,69 TL**	553.972,24 TL	566.308,27 TL	619.502,02 TL	637.088,58 TL	683.672,18 TL	724.604,14 TL	741.797,94 TL
		P_{2039}		536.658,56 TL	577.813,52 TL	587.130,99 TL	630.663,93 TL	657.435,71 TL	695.134,85 TL	732.894,59 TL	756.499,62 TL
10	2042	P_{2033}	97.390	**503.875,34 TL**	555.487,88 TL	569.834,75 TL	610.201,27 TL	630.965,57 TL	652.734,62 TL	702.174,41 TL	722.637,12 TL
		P_{2042}		596.520,22 TL	664.126,73 TL	676.899,30 TL	703.911,24 TL	751.931,49 TL	756.960,21 TL	836.084,31 TL	830.221,79 TL

Table 30 Total Cost of the System with c=3.5 In Period 2036-2042.

NO	YEAR	PUMP	POPULATION	TANK VOLUME / PIPE DIAMETER							
				2600 m3		5200 m3		7800 m3		10400 m3	
				Ø400 mm	Ø400+Ø400 mm	Ø400 mm	Ø400+Ø400 mm	Ø400 mm	Ø400+Ø400 mm	Ø400 mm	Ø400+Ø400 mm
8	2036	P_{2033}	86.461	**468.280,71 TL**	541.908,26 TL	531.611,73 TL	590.854,63 TL	614.844,02 TL	661.336,37 TL	689.740,43 TL	725.889,42 TL
		P_{2036}		481.511,54 TL	542.941,52 TL	565.960,74 TL	600.637,31 TL	620.308,75 TL	658.519,25 TL	695.432,19 TL	730.480,70 TL
9	2039	P_{2033}	95.861	**527.776,80 TL**	587.875,99 TL	593.306,95 TL	619.502,02 TL	666.142,21 TL	701.014,43 TL	751.178,33 TL	777.115,34 TL
		P_{2039}		538.160,17 TL	599.861,34 TL	613.136,88 TL	662.937,96 TL	691.947,55 TL	719.546,41 TL	770.434,11 TL	790.307,38 TL
10	2042	P_{2033}	106.283	585.677,32 TL	609.169,52 TL	**615.198,41 TL**	652.855,17 TL	677.867,71 TL	711.696,35 TL	752.221,02 TL	781.502,13 TL
		P_{2042}		609.865,72 TL	677.560,56 TL	686.626,55 TL	715.166,02 TL	730.351,23 TL	781.922,56 TL	804.919,88 TL	856.597,42 TL

These analyses showed that in unexpected changes at water demands can affect the rehabilitation decisions. The engineer should compare and update the predicted population growth with the real values. So the necessary update can be applied to the rehabilitation plan and more realistic decisions can be taken.

CHAPTER 4

CONCLUSION AND RECOMMENDATIONS

Basically, a municipal water supply system consists of a pumped transmission line conveying water from the source to the storage tank and then finally distributing it to the consumers located in the network; it is planned that the system serves satisfactorily respecting hydraulic conformity criteria during the lifetimes considered for each component. However, annual performance of water supply systems is not checked by water authorities carefully for each hydraulic element such as transmission line, pump and storage tank.

In this study, a methodology is offered to determine the time of rehabilitation of considered hydraulic elements based on minimum total "annual" cost and unexpected population growth cases are analyzed. Furthermore, it has been shown that the methodology developed indicates very well the moment which hydraulic element should be rehabilitated; the methodology is found to be satisfactory for cases where population growth rate is underestimated or overestimated.

The rehabilitation process should include pump scheduling and optimization of the water supply system because of the fact that energy consumption of the pumps is strongly affected by the performance of other hydraulic elements. Thus, to find the best combination of the system elements, different scenarios were created for every 3 years by considering transmission line, storage tank, pump and water demands of the related years. These scenarios are supposed to satisfy the hydraulic system requirements, which are the constraints that define minimum service quality, to make pressures at any nodes, water level in storage tank and flow rate in pipes stay in the range of acceptable interval. It was seen that some of the scenarios could not meet the hydraulic system requirements of the water supply system. The violations generally occured because of whether exceeding the maximum water level or dropping below the minimum water level of the storage tank. Operational deficiencies start to occur as a result of insufficient system elements. This situation makes the scenario unhandy for the operation of the system.

Besides satisfying the hydraulic requirements, water supply systems should also be rehabilitated by considering economy. To perform economic analyses, daily energy costs of the scenarios have been determined according to the pumping schedule of the pump station. Pumps were operated by switching on and off from time to time according to water demand of the system and unit energy prices which changes all day long as per multi tariff price policy of electricity distributer. Daily energy cost of the system is a criterion but it is not enough alone to make a decision about the time of rehabilitation of the system components because energy consumption is not only related with the pumps but it is also related with other components. At this point, a question arises: Which component should be rehabilitated? To answer this question, the initial investment costs with repair and maintenance costs of the system components have been included into the economic analysis. The annual worth of each system components were calculated considering the current interest rate and evaluated with the annual energy cost of each scenario together. The results showed that in the early stage of the analyses, water supply system did not require rehabilitation, however, after a certain time, system needed to change the current pump before the end of its lifetime, current transmission line pipe became insufficient and needed to be doubled and storage tank capacity needed to be upgraded to satisfy the water demand of the system in different time periods. All these changes have shown the necessity of rehabilitation that even they are designed to be used along their lifetimes, it is a good idea to change or upgrade the capacity of the system elements before the end of their lifetimes with regard to efficiency and economy.

The water demand of the system is one of the main factors affecting the rehabilitation of the hydraulic system elements. It changes according to the population of the region served by the system. As water burden increases on the existing system, it triggers hydraulic deficiency on the system elements after a certain level. Then, rehabilitation necessity arises. To understand the sensitivity of the rehabilitation plan, different population growth rates were assumed in different time periods; with a growth rate of 3.50, while there was no change on the rehabilitation plan in earlier stage; in the progressive periods, rehabilitation plan was required to be drawn to an earlier period. On the other hand, having 1.0 growth rate, postpone the time of rehabilitation and/or smaller capacity increment takes place instead of big capacity building.

In the case study section, some assumptions have been made to reduce the complexity and facilitate the study. Further study may be proposed to approach the problem in a different way by considering the situations stated as below:

To begin with, energy price policy was assumed to be stable along the study period. However, there is always a possibility that there may be irregular price changes according to the policy of the electricity distributer and this situation totally changes the daily energy cost of the system. This situation may haul the rehabilitation plan to a different direction.

Another point is the interest rate which was considered during cost analyses. The interest rate was considered as fix along 36 years period. However, during this period, the interest rates of the country may fluctuate according to economy policy of the government. Thus, rehabilitation plan of the water supply system may be affected from the interest rate fluctuations.

Finally, the network pipeline was not considered in scope of the study. Nevertheless, network pipes also effect the energy consumption of the pumping station because pump station feeds not only the storage tank but also the network directly. So the friction losses of the network will come into consideration. Thus, pump characteristics and daily energy costs of the scenario may need to be changed.

The rehabilitation plan of the water supply system can be affected by all these situations. Thus, to achieve a realistic and applicable rehabilitation plan, any changes in the criteria should be adapted on the current water supply system. The up-to-dateness of the the rehabilitation plan can help to the decision makers to follow a convenient way for the rehabilitation of the system.

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