QUALITATIVE EVALUATIONS ABOUT THE DISINFECTION CAPABILITIES OF A WATER DISTRIBUTION NETWORK: A MODEL STUDY

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ABSTRACT

QUALITATIVE EVALUATIONS ABOUT THE DISINFECTION CAPABILITIES OF A WATER DISTRIBUTION NETWORK: A MODEL STUDY

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"*Chlorine*" is one of the major disinfectants extensively used in distribution systems that neutralizes the disease-causing organisms. This model study evaluates the disinfection capabilities of a specific water distribution network N8.3 of Ankara water distribution system under various operating conditions. N8.3 supplies water, roughly to 40,000 people.

The network is served by a pump station and pumping schedule is critical concerning the occurrence of minimum chlorine concentrations. Continuous *"blind"* pumping by a relatively small pump is found to be less critical while optimum pump scheduling making use of two *"small"* and one *"large"* pumps targeting minimum energy costs causes the lowest concentrations of chlorine.

It is found that the genuine parameter which influences chlorine concentrations is *"travel time"* of flow from the source to the junction nodes. The network is studied in two different modes: (i) as a whole and (ii) in the form of District Metered Area's.

N8.3 is almost satisfactory based on an employed roughness parameter (C_{HW}=130), wall reaction (k_w=-0.08 m/day) and bulk coefficient of chlorine (k_b=-0.10 mg/l$^{(1-n)/day}$) while respecting minimum allowable chlorine concentration of 0.10 mg/l. Moreover, calibrated values of these model parameters may aggravate the results especially for critical junctions of this 20 year old network. Furthermore, seasonal variations should be evaluated for having a complete picture regarding the capabilities of N8.3 network.

Ultimate solutions for avoiding perennially minimum chlorine concentrations are offered as (i) forming loops regarding dead ends, (ii) additional booster injection at the pumping station P23, (iii) cancelling problematic DMA's.

Key Words: Water Distribution Networks, Water Quality Modeling, Disinfectant, Chlorine, District Metered Area

ÖZ

BİR İÇME SUYU DAĞITIM ŞEBEKESİNİN DEZENFEKTE ETME YETENEĞİ HAKKINDA NİTELİKSEL DEĞERLENDİRMELER : BİR MODEL ÇALIŞMASI

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Klor, içme suyu dağıtım şebekelerinde zararlı organizmaların etkisiz hale getirilmesinde yoğunlukla kullanılan önemli dezenfektanlar arasındadır. Bu model çalışması, Ankara ilinde yer alan N8.3 isimli içme suyu dağıtım şebekesinin çeşitli işletme şartları altında dezenfekte etme yeteneğini değerlendirmektedir. N8.3 içme suyu şebekesi yaklaşık olarak 40,000 kişiye su sağlamaktadır.

Şebekeye pompa istasyonu vasıtasıyla içme suyu temin edilmekte ve pompa programı minimum klor konsantrasyonlarının oluşumuyla bağlantılı olması açısından önemlidir. Nispeten küçük kapasiteli olan pompanın sürekli, herhangi bir öngörü yapılmadan, çalışması üzerine kurulu olan pompa programı bu açıdan daha az seviyede kritik durumda olmakla beraber, ikisi *"küçük"* ve birisi *"büyük"* kapasiteye sahip pompaları kullanan ve minimum

enerji giderini hedefleyen optimum pompa programı en düşük klor konsantrasyonlarının oluşmasına yol açmaktadır.

Klor konsantrasyonlarını etkileyen en özgün parametre suyun kaynaktan düğüm noktalarına *"erişme süresi"* olarak belirlenmiştir. Şebeke (i) bir bütün olarak ve (ii) alt bölgeler bazında olmak üzere iki farklı biçimde incelenmiştir.

N8.3 şebekesinde pürüzlülük katsayısı olarak kabul edilebilir bir değer olan (C_{HW}=130), boru çeperlerinde reaksiyon katsayısı olarak (k_w=-0.08 m/day) ve klor bozunma katsayısı olarak (k_b=-0.10 mg/l$^{(1-n)/day}$) değerleri kullanılmış olup minimum kabul edilebilir klor konsantrasyonu sınır değeri olarak da 0.10 mg/l değerine riayet edilmiştir. Buna ek olarak, modelde kullanılan bu parametrelerin kalibre edilmesi 20 yıldır işletmede olan bu şebekede kritik düğüm noktalarında elde edilen sonuçların ağırlaşmasına sebep olabilir. Ayrıca mevsimsel değişimler de N8.3 şebekesinin dezenfekte etme yeteneği hakkında bütün bir resmin oluşturulması açısından değerlendirilmelidir.

Kalıcı ve sürekli olarak gözlenen minimum klor konsantrasyonlarının önlenmesine dair nihai çözüm olarak; (i) ölü noktaların sistemden kaldırılması için boru döngülerinin oluşturulması , (ii) P23 pompa istasyonunda sisteme ilave klor takviyesi yapılması ve (iii) problemli alt bölgelerin ortadan kaldırılması teklif edilmiştir.

Anahtar Kelimeler: Su Dağıtım Şebekeleri, Su Kalite Modeli, Dezenfektan, Klor, Alt Bölge

Dedicated to people who do not have access to clean water.

According to UN records by the year 2013, 780 million people do not have access to clean water.

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LIST OF ABBREVIATIONS

ASKI	Ankara General Directorate of Water and Sewerage
AWWA	American Water Works Association
DE	Dead End Junction
DMA	District Metered Area
DBP	Disinfection Byproduct
EJ	Entrance Point Junction
EPA	United States Environmental Protection Agency
EPS	Extended Period Simulation
HAA	Haloacetic acid
JN	Junction Number
MP	Middle Point Junction
SCADA	Supervisory Control and Data Acquisition
THM	Trihalomethanes
UN	United Nations
WDN	Water Distribution Network
WHO	World Health Organization

LIST OF SYMBOLS

A_i : cross sectional area of pipe i (L^2)

C_i : concentration in pipe i (M/L^3)

C_t : concentration at time t (M/L^3)

C_0: initial concentration (at time zero)

C_{i,n_i} : concentration entering junction node from pipe i (M/L^3)

C_{OUT_j} : concentration leaving the junction node j (M/L^3)

C_k : concentration within tank or reservoir (M/L^3)

C(res) : Average concentration at the pump station (P23)

C(tank) : Average concentration at the Tank (T53)

IN_j : set of pipes entering node j

k : decay rate constant (reaction rate) (1/T)

k_b : bulk reaction coefficient (1/T)

k_w : wall reaction coefficient (L/T)

k_f : mass transfer coefficient, bulk fluid to pipe wall (L/T)

OUT_j : set of pipes leaving node j

Q_i: flow rate in pipe i (L^3/T)

Q_i : flow rate entering the junction node from pipe i (L^3/T)

Q_i : flow entering the tank or reservoir from pipe i (L^3/T)

R_H : hydraulic radius of pipeline (L)

t : time

t(res) : Travel time from pump station (P23) to junction

t(tank) : Travel time from Tank (T53) to junction

U_j : concentration source at junction node j (M/T)

V_k : volume in tank or reservoir k (L^3)

W_t: Weighted travel time

θ (C_i): reaction term ($M/L^3/T$)

$\theta(C_k)$: reaction term ($M/L^3/T$)

CHAPTER 1

INTRODUCTION

In today's world water is being supplied from large storage facilities through the urban areas via transmission lines. At first, water is transferred to treatment plants where water is processed to be consumed then, by people; finally water is supplied to a distribution network which serves the consumer taps. If the water being supplied to distribution networks satisfies drinking water standards it means water is safe enough to be consumed in the municipal water supply systems. On the other hand, water quality should be monitored on a regular basis. Although in certain areas of service or for certain time durations water quality might not satisfy the health based targets. Drinking or using such water leads to chronic illnesses and it is a major cause of death in many countries. Reduction of waterborne diseases is a public health goal in developing countries.

A wide range of substances and physical parameters can be modeled using water quality models. The common substances and organisms are reactive chemical substances (such as disinfectants), heavy metals, various toxins, dissolved oxygen and bacterial counts.

"*Chlorine*" is one of the major disinfectants extensively used in distribution systems that neutralizes the disease-causing organisms also this study takes chlorine as the neutralizing constituent. Although chlorine is invaluable in the protection of public health, over chlorinated water might also be responsible for creating a wide range of potential health risks. In addition, some byproducts as a result of the reactions between chlorine and natural organic matter may also present long term health risks. The goal for water management utilities is to keep the chlorine levels at desired levels and minimize the byproducts formed while providing the adequate health protection for the community.

1.1 The Objective of This Study

This study was carried out in a specific region of Ankara water distribution system. The study area is N8.3 which is a pressure zone that belongs to the northern supply zone of Ankara. This area is insulated from other zones with definite boundaries, therefore it is selected. There are 6 districts which are; Yayla, North Sancaktepe, South Sancaktepe, Şehit Kubilay, East Çiğdemtepe and West Çiğdemtepe. Chlorine is the disinfectant being used by Ankara General Directorate of Water and Sewerage (ASKI) for all regions of water distribution system.

WDN (Water Distribution Network) model of N8.3 is taken from the previous studies published by other researchers (Ar, 2011, Şendil 2013) who also studied in this zone of Ankara water distribution network.

In this study the network is inspected for mainly two conditions one of them is the whole distribution system operating as the pumps and tank is connected through the transmission line. In this operating condition water is supplied through the zones via transmission line and through the pipe connections between the zones as the real case. This means that there is interaction between the districts flow entering the system is distributed based on the demand patterns for each district, as there is always mixing between neighboring zones. In the second case DMA's (District Metered Areas) are studied. DMA's are sub zones which usually contain 1500 to 2000 connections (each connection is assumed to serve five people). Each DMA receive water from a single entrance to the area, while the interaction of water through neighboring zones is prevented by isolation valves.

The advantage of studying DMA's is better estimation of unaccounted water usage. Leakages thorough an unidentified pipes, pipe breaks and unmetered services can lead the model to fail, at this point a DMA based model can perform far better than a complex distribution network. However, the circulation of fresh water and as consequence chlorine concentration is less than a whole network. This leads to a sudden drop of chlorine concentrations through the serving junctions of the network. In the scope of this study both models are compared while operating the network for different configurations. The main aim of this study is to examine chlorine concentrations throughout the study area and get certain considerations about the behavior of the network in water quality .

The second chapter of this study provides information about the basic elements of a (WDN) (Water Distribution Network). While providing basic characteristics about the hydraulic elements, these elements are also examined from the water quality modeling aspects.

The third chapter covers the water quality modeling in a theoretical way. This topic is discussed widely throughout common processes and field studies concerning water quality modeling.

The fourth chapter provides information about the disinfectant chlorine. The disinfectant capability of this element is examined in the model study. Through this chapter the history, usage and chemical formation of the element is presented.

The fifth chapter is the case study part carried out in an actual WDN which is namely N8.3. The network takes places between Keçiören and Yenimahalle counties in the northern pressure zone of Ankara. The elements of the network and water quality modeling parameters are introduced. This chapter is the fundamental part of the study in which the concentration changes of chlorine through all districts are provided under several operating conditions.

The sixth chapter covers the discussion of results evaluated in chapter five while examining the variations in chlorine concentrations. Furthermore, the minimum chlorine concentrations under various operating conditions are inspected and the locations are plotted in this chapter throughout all scenarios.

The seventh chapter which is the last chapter presenting the conclusions, recommendations and suggested further studies.

CHAPTER 2

BASIC ELEMENTS OF WATER DISTRIBUTION NETWORKS

2.1 Introduction

A water distribution network's main task is to provide adequate amount of water to the consumers, within the limits of required pressure with desired quality. The water distribution network should provide also a stable hydraulic grade to provide enough pressure and water to serve people during emergency conditions such as power outage and fire demand.

2.2 Pipes

The main components of water distribution systems are the pipes. Pipes are designed, constructed with different lengths, materials and diameters in the network. All the elements of a WDN (Water Distribution Network) are connected to each other by pipes.

Ideally, low-flow dead-ends and loops should be avoided, but in practice this is not always possible. Low-flow sections of dead-ends should be as short as possible. Both dead-ends and loops in the system may cause problems by creating long residence times and sections where sediments can collect (Chambers et. al., 2004). Long residence times result in low concentrations of the disinfectants causing inadequate disinfection.

The bacteria settling on pipe walls form a layer of biofilm. A possible definition of biofilm is "a collection of micro-organisms and their extracellular products bound to solid surface". Biofilm can degrade distribution system water quality in numerous ways. They can host pathogenic organisms, deplete disinfectant residuals, accelerate corrosion, and contribute to aesthetic problems such as color or disagreeable tastes and odors. Water supplies containing high concentrations of naturally occurring organic carbon support the growth of biofilms by providing nutrients for these microbes. Thus, controlling bacterial regrowth in distribution systems points to two key strategies. These strategies are improving distribution system disinfection and minimizing bacterial nutrients in treated water supplies (AWWA, 2007).

Biofilms are modeled by the k_w coefficient which is the reaction rate at pipe walls. A higher k_w coefficient means the decay rate of the disinfectant due to the reaction rate is supreme. Generally aged pipes have higher k_w values due to the long term interaction at the pipe wall according to field studies (Li Xin et. al., 2003).

2.3 Pumps

A pump is a hydraulic machine that adds energy to the water flow by converting the mechanical energy into potential energy to overcome the friction loses and hydraulic grade differentiations within the system (Walski et al., 2008).

In WDNs pumps are scheduled to work at certain time intervals which is called pump scheduling. Pump schedule defines which pumps to use for certain periods of the day. The main aim of the pump schedule is minimizing the energy costs while providing adequate pressure and water to the network. Pump schedules usually target filling the storage tanks during low electricity price periods and switching off the pumps during high electricity price periods.

When the pumps are off the storage tank will provide water to the system and hydraulic constraints should also be satisfied in any time interval. A pump in continuous operation will fill its life time in a shorter period and higher maintenance costs are expected during operation, therefore; a pump schedule is vital for all pump operation based WDNs.

2.4 Valves

There are different types of valves in water distribution systems with different characteristics and usage conditions. Their locations and characteristics are decisive for the daily management. In this study to from DMA's isolation valves are used.

2.4.1 Isolation Valves

When a pipe breaks or if a maintenance work is needed, in order to isolate the pipe or pipe segment from the rest of the network, isolating valves are used. Generally gate valves are chosen as isolating valves. Despite of control valves, their ability to control the flow is very limited. For that purpose, the isolating pipes should be used in the fully close or open position, as partially open valves may end with broken valves in the system (Walski et al., 2008).

Furthermore, isolating valves are the most commonly used valves in a network. Their locations and working conditions directly affect the distribution systems characteristics and reliability purposes.

District Metered Areas are also formed by the help of the isolation valves. These valves are planned and positioned at certain points of the network to cut the flow interaction between neighboring areas. When isolation valves are closed DMA's receive water from a single entrance. Main reason for forming

DMA's is to detect, to fix and to control water leakages from the main water distribution network (Mac Donald and Yates, 2005).

2.5 Storage Tanks

A storage tank's main purpose is to store excess water during low demand periods in order to meet widely fluctuating demands such as fire demands and peak hour's demands.

From the water quality point of view tanks have important effects on residual concentrations. When the tank is filling, the water entering from upstream pipes mixes with the water that is already in storage. If the concentrations are different, blending occurs. The tank mixing equation mainly accounts for blending but also any reactions related with water quality also occur within the tank volume during any hydraulic step. It is generally assumed that concentrations within the tank or reservoir are completely and instantaneously mixed. (Walski et al., 2008)

2.6 Fire Hydrants

Fire Hydrants are used mainly for firefighting by local fire department which also determines the places and number of them. As they are important for firefighting their maintenance should be done properly.

In addition one of the key roles of a fire hydrant is flushing. (Figure 2.1) In a water distribution system flushing is an important tool for helping operators to control distribution system water quality. Flushing stirs up and removes sediments from mains and removes poor quality water from the system, replacing it with fresher water from the source (Walski et al., 2008)

Figure 2.1 : Fire Hydrant Flushing (Web 1)

Flushing is usually accomplished by opening one or more hydrants in a planned pattern. The usual rule of thumb for flushing is to always flush with clean water behind you, meaning that hydrants should be operated to pull the freshest water into the area being flushed. Flushing programs usually start at the source and move out through the system. Unfortunately, operators conducting the flushing program cannot see what is occurring in the mains, or measure parameters like velocity or flow rate in pipes. Water distribution models provide a way to look into the pipes and obtain an indication of how a flushing program will work (Walski et al., 2008).

If proper flushing is not conducted regularly in a network, by the time poor water quality aspects will occur. In addition sediments will form in the main pipe system causing the Hazen-Williams coefficient to increase. This situation results in the increase of the head losses in the pipes due to the high rate of pressure loss the desired pressures at the point of service might not be satisfied. An alternative way of flushing is using the drain valves in the system. When these valves are open they discharge water to the sewage system, also helping the flushing of the sewage system.

CHAPTER 3

WATER QUALITY MODELING

The procedure of hydraulic network modeling involves water quality modeling which was firstly added to network models in the middle 1980s by hydraulic network simulation developers. Disinfectant transport and decay is affected by some important facts such as, flow rate of the network, flow ways, etc. These properties are used to analyze mixing, travel times or some other characteristics of the water distribution network.

In a water quality model, basic chemical and physical processes are decay and transport mixing. To analyze a water quality model extended period simulation is performed. Because of the fact that transport, mixing and decay are time-dependent behaviors in a water quality model, extended period simulation (EPS) should be performed for useful modeling.

3.1 Transport in Pipes

Most water quality models use of one-dimensional advective-reactive transport equation in order to predict the changes in constituent concentrations. Equation is valid for transport through a pipe, formation and decay reactions. Equation 3.1 shows concentration within a pipe i as a function of distance along its length (x) and time (t). (Walski et al., 2008).

$$\frac{\partial C_i}{\partial t} = \frac{Q_i \partial C_i}{Ai \partial x} + \theta(C_i), i = 1......P \qquad (3.1)$$

C_i = concentration in pipe i (M/L^3)

Q_i= flow rate in pipe i (L^3/T)

A_i = cross sectional area of pipe i (L^2)

θ (C_i)= reaction term ($M/L^3/T$)

Equation 3.1 must be combined with two boundary condition equations (concentration at x = 0 and t = 0) to obtain a solution. For advective transport equation depends on the flow rate and the cross-sectional area of the pipe. Division of these terms (flow rates / cross-sectional area) gives the mean velocity of the fluid. Therefore, it can be said that velocity of the water transported through the pipe is directly proportional to the average flow rate. This equation includes basically two assumptions. First is that the longitudinal dispersion in pipes is negligible and the other one is that the bulk fluid is completely mixed. Furthermore, the equation can also account for the formation or decay of a substance during transport with the substitution of a suitable equation into the reaction term. Such an equation will be developed later. First, however, the nodal mixing equation is presented (Walski et al., 2008).

3.2 Mixing at Nodes

In a water quality model which has definite boundary conditions specified before, concentrations are analyzed together with the help of a nodal mixing equation. For this analyze, the pipes which are described by the advective transport equation are used. The equation 3.2 is written to compute a concentration value at a junction by performing a mass balance.

$$\left(C_{OUT_j} = \frac{\sum_{i \in IN_j} Q_i C_{i,n_i} + U_j}{\sum_{i \in OUT_j} Q_i} \right) \tag{3.2}$$

C_{OUT_j} = concentration leaving the junction node j (M/L^3)

OUT_j = set of pipes leaving node j

IN_j = set of pipes entering node j

Q_i = flow rate entering the junction node from pipe i (L^3/T)

C_{i,n_i} = concentration entering junction node from pipe i (M/L^3)

U_j = concentration source at junction node j (M/T)

This equation gives the amount of concentration at a junction which joints to a pipe in the network. So, it explains the concentration entrance to the system or removal from the network. These incoming concentrations are described averagely with this equation. Mixing equation also includes constituent mass if an extra incoming water at a junction. Figure 3.1 illustrates how the nodal mixing equation is used at a pipe junction. Concentrations enter the node with pipe flows. The incoming concentrations are mixed according to Equation (3.2), and the resulting concentration is transported through the outgoing pipes modeled as demand leaving the system. When using nodal mixing equation, it must be noted that water is in a completely mixing condition. Therefore, depending on this assumption, turbulence which causes good mixing is seen at the junction node.

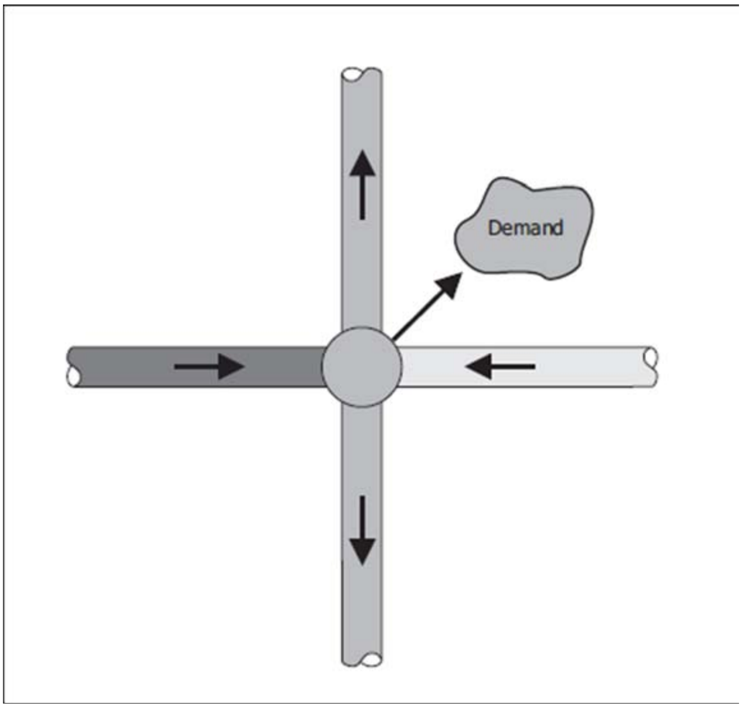

Figure 3.1: Nodal Mixing

3.3 Mixing in Tanks

In previous section, mixing at nodes were explained. However, junctions may not only be connected to pipes, they may be also connected to a reservoir or a tank. For this condition, Equation (3.3) can be used instead of nodal mixing equation. In this equation, again, a mass balance of concentrations entering or leaving the tank or reservoir can be performed (Walski et al., 2008).

$$\frac{dC_k}{dt} = \frac{Q_i}{V_k}(C_{i,np}(t) - C_k) + \theta(C_k) \qquad (3.3)$$

Where,

C_k = concentration within tank or reservoir (M/L^3)

Q_i = flow entering the tank or reservoir from pipe i (L^3/T)

V_k = volume in tank or reservoir k (L^3)

$\theta(C_k)$ = reaction term (M/L^3/T)

Equation (3.3) is used during the filling times of the tank. In a certain time period, the water filling to tank or reservoir and the water already stored in there, fully mixes. If concentrations of water in the tank/reservoir and filling water are different, concentration of mixed water depends on their concentrations. This blending and any reactions in the tank also explained with tank mixing equation. During a hydraulic step in which draining occurs, by dropping the terms equation can be simplified as below (Walski et al., 2008).

$$\frac{dC_k}{dt} = \theta(C_k) \qquad (3.4)$$

where,

C_k = concentration within tank or reservoir (M/L^3)

$\theta(C_k)$ = reaction term (M/L^3/T)

Because of the fact that dilution does not occur, the term about it is dropped. Thus, the concentration is only related to chemical. For the advective transport equation, the concentration draining from the tank becomes a boundary condition for the pipe connected to the tank. As mentioned before, it is assumed that the concentrations in the tank completely mixed in Equations 3.3 and 3.4. For water quality models, this assumption is very common and useful.

There are also different types of mixing in water quality modeling to simulate the process. For example, for contact basins or clearwells “first in first out” (FIFO) model is used to provide sufficient contact time for disinfectants are frequently represented as simple plug-flow reactors. In a FIFO model, the water which firstly enters the tank as inflow, leaves the tank firstly as outflow. Another mixing type is “last in first out” (LIFO) model. In a LIFO model, the water which lastly enters the tank as inflow, leaves the tank firstly as outflow. If severe short-circuiting is occurring within the tank, this model may be applied. For more complex tank mixing behaviors, “compartment” models can be used. These models have the ability to represent mixing processes and time delays within tanks more accurately. Many water distribution models offer a simple two-compartment model. In this type of model, water enters or exits the tank through a completely mixed inlet-outlet compartment, and if the first compartment is completely full, the overflow is exchanged with a completely mixed second main compartment. The inlet-outlet compartment can represent short-circuiting with the last flow in becoming the first out (LIFO). The main compartment can represent a stagnant or dead zone that will contain older water than the first compartment. The only parameter for this model is the fraction of the total tank volume in the first compartment. Selection of an appropriate value for this fraction is generally done by comparing model results to field measurements of a tracer or chlorine residual (Walski et al., 2008).

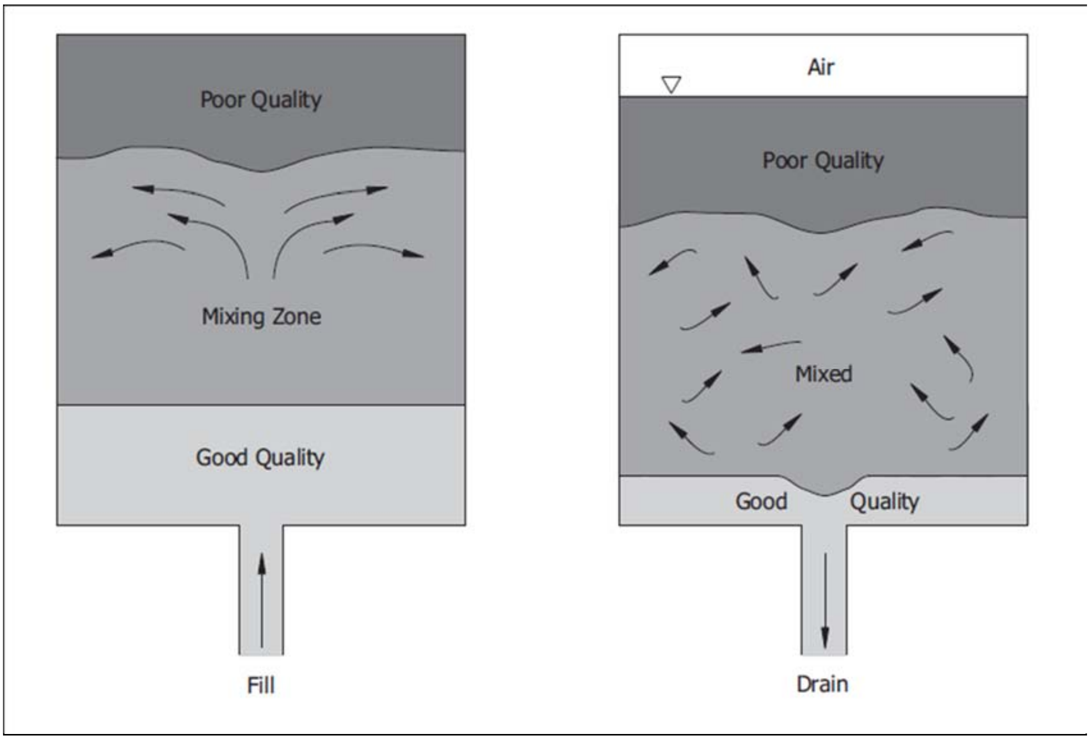

Figure 3.2 : Three-Compartment Tank Mixing Model

In Figure 3.2, a three-compartment model for a tank which has a single pipe for filling and draining is shown. In this example the tank that is layered. Procedure is that the fresh new water enters the tank from the first compartment and it mixes with the older water in the mixing compartment. Finally, it reaches to older and low quality water in the third compartment and mixes with it. The model simulates the exchange of water between different compartments, and in doing so, mimics complex tank mixing dynamics (Walski et al., 2008).

3.4 Chemical Reaction Terms

Equations 3.2, 3.3, and 3.4 compose the linked system of first-order differential equations solved by typical water quality simulation algorithms. This set of equations and the algorithms for solving them can be used to model different chemical reactions known to impact water quality in distribution systems. Chemical reaction terms are present in Equations 3.3 and 3.4. Concentrations within pipes, storage tanks, and reservoirs are a function of these reaction terms. After water leaves the treatment plant and enters the distribution system, it is subject to many complex physical and chemical processes, some of which are poorly understood, and most of which are not modeled. Three chemical processes that are frequently modeled, however, are bulk fluid reactions, reactions that occur on a surface (typically the pipe wall), and formation reactions involving a limiting reactant. First, an expression for bulk fluid reactions is presented, and then a reaction expression that incorporates both bulk and pipe wall reactions is developed (Walski et al., 2008).

3.4.1 Bulk Reactions

Bulk fluid reactions occur within the fluid volume and are a function of constituent concentrations, reaction rate and order, and concentrations of the formation products. A generalized expression for nth order bulk fluid reactions is developed in Equation (3.5)

The most commonly used reaction model is the first order decay model. This has been applied to chlorine decay, radon decay, and other decay processes. A first order decay is equivalent to an exponential decay, represented by Equation 3.5.

$$C_t = C_0 \, e^{-k \times t} \qquad (3.5)$$

where,

C_t = concentration at time t (M/L^3)

C_0= initial concentration (at time zero)

k = decay rate constant (reaction rate) (1/T)

t = time

3.4.2 Bulk and Wall Reactions

Disinfectants are the most frequently modeled constituents in water distribution systems. Upon leaving the plant and entering the distribution system, disinfectants are subject to a poorly characterized set of potential chemical reactions. Figure 3.3 illustrates the flow of water through a pipe and the types of chemical reactions with disinfectants that can occur along its length. Chlorine (the most common disinfectant) is shown reacting in the bulk fluid with natural organic matter (NOM), and at the pipe wall, where oxidation reactions with biofilms and the pipe material (a cause of corrosion) can occur (Walski et al., 2008).

Many disinfectant decay models have been developed to account for these reactions.

The first-order decay model has been shown to be sufficiently accurate for most distribution system modeling applications and is well established. Latest studies proposed a mathematical framework for combining the complex reactions occurring within distribution system pipes. This framework accounts for the physical transport of the disinfectant from the bulk fluid to the pipe wall (mass transfer effects) and the chemical reactions occurring there. (Walski et al., 2008)

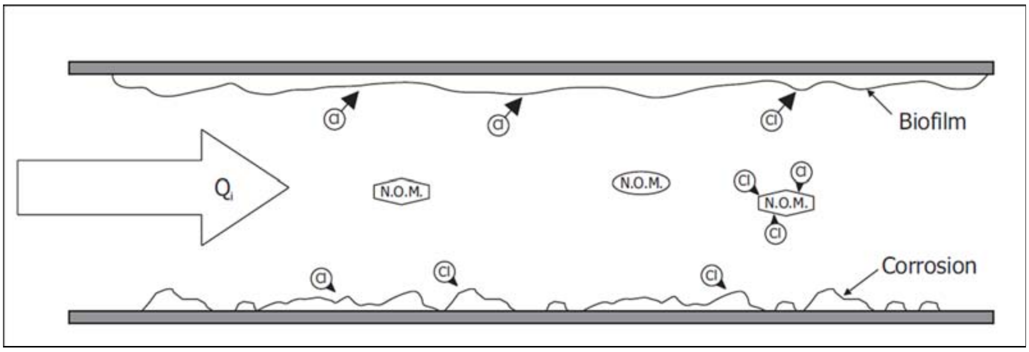

Figure 3.3: Disinfectant reactions occurring within a typical distribution system pipe (Walski et al., 2008)

$$\theta(\mathrm{C}) = \pm KC \tag{3.6}$$

where, K= overall reaction rate constant (1/T)

Equation (3.6) is a simple first-order reaction. The reaction rate coefficient K, however, is now a function of the bulk reaction coefficient and the wall reaction coefficient, as indicated in the following equation (3.7).

$$K = k_b + \frac{k_w k_f}{R_H (k_w + k_f)} \tag{3.7}$$

k_b = bulk reaction coefficient (1/T)

k_w = wall reaction coefficient (L/T)

k_f = mass transfer coefficient, bulk fluid to pipe wall (L/T)

R_H = hydraulic radius of pipeline (L)

The rate that disinfectant decays at the pipe wall depends on how quickly disinfectant is transported to the pipe wall and the speed of the reaction once it is there.

In this study, being a primary disinfectant, chlorine is used while constructing the water quality model. Reaction parameters of chlorine are the wall coefficient (kw) and the bulk coefficient (k_b). Wall coefficient is taken as -0.08 m/day and bulk coefficient is taken as -0.10 (mg/L)^(1-n)/day as recommended by Bentley (Bentley, 2009).

The mass transfer coefficient is used to determine the rate at which disinfectant is transported using the dimensionless Sherwood number, along with the molecular diffusivity coefficient (of the constituent in water) and the pipeline diameter.

$$kf = \frac{S_H d}{D} \tag{3.8}$$

S_H = Sherwood number

d= molecular diffusivity of constituent in bulk fluid (L^2/T)

D= pipeline diameter (L)

For stagnant flow conditions (Re < 1), the Sherwood number, SH, is equal to 2.0. For turbulent flow (Re > 2,300), the Sherwood number is computed using Equation 3.9.

$$S_H = 0.023\,\mathrm{Re}^{0.83}\left(\frac{v}{d}\right)^{0.333} \tag{3.9}$$

where Re= Reynolds number

v= kinematic viscosity of fluid (L^2/T)

For laminar flow conditions ($1 < Re < 2,300$), the average Sherwood number along the length of the pipe can be used.

Bulk decay coefficients can be determined experimentally. Wall decay coefficients, however, are more difficult to measure and are frequently estimated using disinfectant concentration field measurements and water quality simulation results (Walski et al., 2008).

3.5 Other Types of Water Quality Simulations

Although the water quality features of individual software packages vary, the most common types of water quality simulations, in addition to the constituent analysis already described, are source trace and water age analyses. The solution methods used in both of these simulations are actually specific applications of the method used in constituent analysis.

3.5.1 Source Trace Analysis

For the sake of reliability, or to simply provide sufficient quantities of water to customers, a utility often uses more than one water supply source. Suppose, for instance, that two treatment plants serve the same distribution system. One plant draws water from a surface source, and the other pulls from an underground aquifer. The raw water qualities from these sources are likely to differ significantly, resulting in quality differences in the finished water as well (Walski et al., 2008).

Using a source trace analysis, the areas within the distribution system influenced by a particular source can be determined, and, more important, areas where mixing of water from different sources has occurred can be identified. The significance of source mixing depends on the quality characteristics of the waters. Sometimes, mixing can reduce the aesthetic qualities of the water (for example, creating cloudiness as solids precipitate, or causing taste and odor problems to develop), and can contribute to disinfectant residual maintenance problems. Source trace analyses are also useful in tracking water quality problems related to storage tanks by tracing water from storage as it is transported through the network (Walski et al., 2008).

A source trace analysis is a useful tool for better management of these situations. Specifically, it can be used to determine the percentage of water originating from a particular source for each junction node, tank, and reservoir in the distribution system model. The procedure the software uses for this calculation is a special case of constituent analysis in which the trace originates from the source as a conservative constituent with an output concentration of 100 units. The constituent transport and mixing equations introduced in the beginning of this section are then used to simulate the transport pathways through the network and the influence of transport delays and dilution on the trace constituent concentration. The values computed by the simulation are then read directly as the percentage of water arriving from the source location (Bentley, 2009).

3.5.2 Water Age Analysis

The chemical processes that can affect distribution system water quality are a function of water chemistry and the physical characteristics of the distribution system itself (for example, pipe material and age). More generally, however, these processes occur over time, making residence time in the distribution system a critical factor influencing water quality. The cumulative residence time of water in the system, or water age, has come to be regarded as a reliable surrogate for water quality. Water age is of particular concern when quantifying the effect of storage tank turnover on water quality. It is also beneficial for evaluating the loss of disinfectant residual and the formation of disinfection by-products in distribution systems.

The chief advantage of a water age analysis when compared to a constituent analysis is that once the hydraulic model has been calibrated, no additional water quality calibration procedures are required. The water age analysis, however, will not be as precise as a constituent analysis in determining water quality; nevertheless, it is an easy way to leverage the information embedded in the calibrated hydraulic model. Consider a project in which a utility is analyzing mixing in a tank and its effect on water quality in an area of a network experiencing water quality problems. If a hydraulic model has been developed and adequately calibrated, it can immediately be used to evaluate water age. The water age analysis may indicate that excessively long residence times within the tank are contributing to water quality degradation. Using this information, a more precise analysis can be planned (such as an evaluation of tank hydraulic dynamics and mixing characteristics, or a constituent analysis to determine the impact on disinfectant residuals), and preliminary changes in design or operation can be evaluated.

The water age analysis reports the cumulative residence time for each parcel of water moving through the network. Again, the algorithm the software uses to perform the analysis is a specialized case of constituent analysis. Water entering a network from a source is considered to have an age of zero. The constituent analysis is performed assuming a zero-order reaction with a k value equal to +1 [(mg/l)/s]. Thus, constituent concentration growth is directly proportional to time, and the cumulative residence time along the transport pathways in the network is numerically summed. Using the descriptions of water quality transport and reaction dynamics provided here, and the different types of water quality-related simulations available in modern software packages, water quality in the distribution system can be accurately predicted.

Water quality modeling can be used to help improve the performance of distribution system modifications meant to reduce hydraulic residence times, and as a tool for improving the management of disinfectant residuals and other water quality related operations. Continuing advancements in technology combined with more stringent regulations on quality at the customer's tap are motivating an increasing number of utilities to begin using the powerful water quality modeling capabilities already available to them.

3.6 Sampling Process of Water Quality Models

When extending a calibrated hydraulic model to include water quality, various physical and chemical parameters must be determined. Some tests require bench scale analyses that can easily be conducted in a modestly outfitted water quality laboratory. Other measurements can be made directly in the field. The sections that follow describe the types of tests that are performed in order to support the development of a water quality model.

A calibrated, extended-period simulation hydraulic model provides a starting point for water quality modeling. Steady-state hydraulic analysis is not adequate because it does represent operational characteristics that vary temporally and does not account for the effect of storage and mixing in tanks and reservoirs, a factor known to contribute to the degradation of water quality. Transport, mixing and chemical reactions depend on the pipe flows, transport pathways, and residence times of water in the network (all are network characteristics determined by the hydraulic simulation). Therefore, a calibrated extended-period hydraulic model is a prerequisite for any water quality modeling project.

After a hydraulic model is prepared, some types of water quality modeling analyses (especially water age and source tracing) can be conducted with little additional effort whereas modeling reactive constituents requires additional information on reaction rate coefficients.

Disinfectant residuals (chlorine, chloramines) decay due to reactions in the bulk water and reactions that take place at the pipe wall. Disinfection by-products (DBP) grow over time in the distribution system, and so a formation reaction rate is required by a model (AWWA, 2012). Bulk reaction coefficients are required for all non-conservative substances, and wall reaction coefficients are required for disinfectant modeling. Boundary conditions and initial conditions are needed for all substances. Determining bulk and wall reaction coefficients involves laboratory analysis and field studies, as discussed in the following section.

3.6.1 Deciding Points of Sampling

Within the modeling context, the purpose of an intensive field survey is to collect sufficient information in order to adjust model parameters or validate model parameters by mimicking the results observed in the field. Selection of sampling sites is typically a compromise between selecting sites that provide the greatest amount of information and sites that are most amenable to sampling. Important factor about sampling is provided below:

- Points should be spread throughout the study area and should reflect a variety of situations of interest, such as transmission mains and local lines, areas directly served from the source and areas under influence of tanks.
- Sampling is usually performed around the clock; sites must be accessible at all times.
- Sampling taps must be close to the mains so that the samples reflect the water quality of the mains.

Sampling frequency is usually on the order of once per hour to once every several hours. The rate of change at a site is an important factor in choosing a sampling frequency. Thus, if the chlorine residual is expected to change gradually over the course of a day, less frequent sampling is needed than if the residual is expected to vary rapidly over time.

CHAPTER 4

CHLORINE AS A DISINFECTANT

4.1 Common Disinfectants used by Water Utilities

There are several methods being applied around the world to disinfect water to reduce or stop waterborne diseases. The common disinfectant types used for disinfection are presented in Table 4.1.

A 1999 survey in the US revealed that a large majority of smaller water treatment facilities generally use a form of chlorine as the disinfection method (AWWA, 2006).

Table 4.1 : Common Disinfection Methods (AWWA, 2006).

Disinfectant Type	Primary Application
Chloramines	Potable water
Iodine	Potable water in emergencies
Bromine	Nondrinking water uses
Chlorine dioxide	Potable water
Ozone	Potable water
Filtration / membranes	Potable water
Ultrasonic / ultrasound	Nondrinking water uses
Ultrahigh frequency	Nondrinking water uses
UV/ advanced oxidation processes	Potable water
Ionized radiation (gamma, electron beam)	Nondrinking water uses
Cations of heavy metals (silver)	Nondrinking water uses
Biocides	Nondrinking water uses

4.2 History of Chlorine

Chlorine was discovered in 1744 in a laboratory in Sweden, further later it was identified as a chemical element. The element name comes from the Greek word *"Chloros"* meaning is pale green (AWWA, 2006).

Although chlorine was on the periodic table the knowledge about the disease causing organisms were not yet discovered. Germ theory of disease was established in 1890's stating that the microorganisms are the causes of diseases. The term germ's meaning is virus, bacterium, protist, fungus or prion.

The first use of chlorine for water disinfection was in 1902 Belgium, making water biologically safe to drink. Afterwards chlorine became the disinfectant of choice, having properties of effectiveness, efficiency, economy of operation and persistence (AWWA, 2006).

Disinfection of water was always vital for treatment process and the disinfectant chlorine had a very important role in this operation.

4.3 Properties of Chlorine Chemicals

In the gaseous state chlorine has greenish – yellow color and pungent odor. The chemical symbol of chlorine is Cl and it has an atomic weight of 35.46. In nature chlorine exists only as a two atom molecule described by the symbol Cl_2 having an atomic weight of 70.92 (AWWA, 2006).

The element is a strong oxidant, reacts violently with other substances and it is not flammable. As a result of its reactivity pure chlorine does not exist naturally. It is commercially produced by the electrolysis of sodium chloride by the following chemical reaction (Wiley, 2010).

$$2NaCl + 2H2O + \text{electric current} \longrightarrow 2NaOH + Cl_2 + H_2 \quad (4.1)$$

sodium chloride → sodium hydroxide, chlorine, hydrogen

Chlorine is stored and shipped as a liquefied gas under pressure usually in cylinders, ton containers and tank cars (AWWA, 2006).

When chlorine is mixed with water it hydrolyzes to form a corrosive mixture of acids and strong oxidants shown as

$$Cl_2 + H_2O \longleftrightarrow HOCL + HCL \quad (4.2)$$

chlorine → hypochlorous acid, hydrochloric acid

The chemical reactivity of chlorine enables it to combine with many other chemicals. It reacts with most organic materials. Dry chlorine is not corrosive to metals such as carbon steel, nickel, lead or coppers but it reacts violently with other metals such as aluminum, tin, gold and titanium. Moist chlorine is corrosive to most metals with the exception of gold, silver, platinum, titanium (Wiley, 2010).

Dry liquid chlorine or gas under pressure will react with polyvinyl chloride (PVC), causing it to soften and reduce its structural integrity (Wiley, 2010).

4.4 Disinfection Mechanism

Disinfection is the treatment process used to destroy or inactivate disease-causing (pathogenic) organisms. The consequences of waterborne disease range from mild illness to death. Disinfection should not be confused with sterilization. Sterilization is the complete destruction of all living microorganisms. It has been found that treatment for turbidity removal and subsequent disinfection to control disease-causing organisms is sufficient to protect public health (AWWA, 2006).

Most pathogens are accustomed to living in the temperatures and conditions found in the bodies of humans and warm-blooded animals. In general, their ability to survive outside of this environment is limited, but some do survive long enough to cause infections if ingested in drinking water. Certain viruses and protozoans that form cysts can survive for surprisingly long periods, even under adverse conditions.

Some pathogenic organisms also tend to be somewhat resistant to certain disinfection processes, so disinfection alone cannot always be assumed to ensure safe drinking water.

Some pathogens can be inactivated by simply storing water in open tanks for extended periods of time. Some pathogens are removed by sedimentation in those tanks, and others experience natural die-off. This is not usually a practical treatment method because of the large investment required for the storage facilities and reliability of the process. In addition, the water is subject to contamination and other nuisance organisms-such as algae-while in storage (AWWA, 2006).

4.5 Distribution System Chlorination (Booster or Secondary Chlorination)

It may be necessary to add chlorine to water after it has been sent to the distribution system. This addition, performed in the distribution system, is called secondary or booster chlorination. Extended distribution systems, large finished water reservoirs, or systems that provide only free chlorine residual can easily lose some or all of the chlorine residual in the water. Growths in the distribution system may exhibit a chlorine demand and can exhaust much of the chlorine residual. This could leave the distribution system without any chlorine residual. When this happens, the utility must take corrective action. One strategy is to provide additional points of chlorination at appropriate locations in the distribution system. Continuous monitoring of the chlorine residual in the distribution system or frequent sampling at specific locations in the system will alert operating personnel to a reduction in or absence of a residual. This sampling or monitoring can also be used to determine the location where the residual has been consumed (AWWA, 2006).

Booster stations may be located at any appropriate position in the system and can be automated to operate when necessary. System operators must be aware that adding chlorine in the distribution system may result in an increase of DBPs (Disinfection byproducts). Changes in the location (or applied dosage) of chlorination booster stations may affect the monitoring site selection and the test results. Supplementing a free chlorine residual with additional free chlorine is straight forward. However, when a system uses chloramines as the residual disinfectant in the distribution system, booster chlorination can become more complicated. Several studies have been conducted to examine this situation. The results have led to the development of site-specific operational practices that optimize this procedure (AWWA, 2006).

4.6 Safe Limits of Chlorine in Potable Water

Although chlorine is invaluable in the protection of public health it has a wide range of risks concerned about health. In a study on the effects of progressively increasing chlorine doses (0, 0.001, 0.014, 0.071, 0.14, 0.26, or 0.34 mg/kg of body weight) on healthy male volunteers (10 per dose), there were physiologically significant toxicological effects in all of the study groups. It has been reported that asthma can be triggered by exposure to chlorinated water. Episodes of dermatitis have also been associated with exposure to chlorine and hypochlorite (WHO, 2003).

An increased risk of bladder cancer appeared to be associated with the consumption of chlorinated tap water in a population-based, case–control study of adults consuming chlorinated or non-chlorinated water for half of their lifetimes (WHO, 2003).

Maximum free chlorine concentration level in the water should not be higher than 0.50 mg/l (500 parts per billion (ppb)) also the minimum chlorine concentration in the distribution system cannot be less than 0.10 mg/l (Terence J., 1991). In addition, according to Republic of Turkey Ministry of Health, standards for potable Water; maximum level of free chlorine at the point of consumption should not exceed 0.50 mg/l (Republic of Turkey Ministry of Health, 2005).

Furthermore, some byproducts as a result of the reactions between chlorine and natural organic matter may present long term health risks. Byproducts formed are mainly Trihalomethanes (THM's), Haloacetic acids (HAA's). THMs and HAAs are a group of chemicals that are formed along with other disinfection byproducts when chlorine or other disinfectants used to control microbial contaminants in drinking water react with naturally occurring organic and inorganic matter in water.

One research about THM states that, drinking chlorine disinfected water has a 10 to 15 % increased risk of cancer (Hileman, 1993). Formation and levels of these byproducts in water depend on environmental conditions such as hydraulic conditions, temperature, pH levels and time. Models can capture these dynamics and be a very powerful tool for optimizing water quality in distribution systems. For water quality modelers and water distribution network designers, conflicting objective is; providing adequate microbial protection, while minimizing the formation of harmful organic byproducts.

CHAPTER 5

CASE STUDY

This study was carried out in a specific pressure zone of Ankara water distribution system namely N8.3 which belongs to the northern supply zone of Ankara. This area is isolated from other zones with definite boundaries. The isolation of N8.3 was checked during extensive field tests. (Ar, 2011, Şendil, 2013). The location of N8.3 with respect to the main water supply system of Ankara is described fully detailed by Şendil (2013).

N8.3 consists of six District Metered Areas (DMA's): Yayla District, North Sancaktepe District, South Sancaktepe District, Şehit Kubilay District East Çiğdemtepe District and West Çiğdemtepe District. These districts are located in Keçiören and Yenimahalle counties. Main reason for forming DMA's is to detect, to fix and to control water leakages from the main water distribution network (Mac Donald and Yates, 2005).

The main aim of this study is to determine the capabilities of the pressure zone in question concerning water disinfection; consequently, water quality model of N8.3 is considered. A true water quality model needs a calibrated hydraulic model. Ar (2011) studied the spatial variation of the Hazen-Williams coefficient in the DMA's already mentioned assuming nodal demands are correct; as the data collected in Ar (2011) is limited, his results are not used Hazen-Williams coefficient is taken as 130 in this study.

On the other hand, note that both the isolation of the whole pressure zone and formation of DMA's are checked carefully in the field; furthermore, almost all the pipe and valve characteristics are examined during site investigations. However, there may be still incorrect connections within the water distribution network.

In this study, being a primary disinfectant, chlorine is used while constructing the water quality model. Reaction parameters of chlorine are the wall coefficient (k_w) and the bulk coefficient (k_b). Wall coefficient (k_w) is taken as -0.08 m/day and bulk coefficient (k_b) is taken as -0.10 (mg/L) $^{(1-n)/day}$ as recommended by Bentley (Bentley, 2009).

5.1 System Characteristics and Hydraulic Elements of N8.3

Hydraulic model of a pressure zone necessitates the isolation of the whole pressure zone; furthermore, District Metered Areas (DMA) should be established; moreover system characteristics should be checked in a methodological way. DMA's are subzones which usually contain 1500 to 2000 connections (each connection is assumed to serve five people). DMA's receive water from a single entrance to the area, while the interaction of water through neighboring zones is prevented by isolation valves. DMA's provide better estimation of unaccounted water usage.

As already mentioned, in this study pipe characteristics and valve locations and valve status have been determined systematically (Şendil, 2013). Micro-calibration studies for assigning a valid Hazen-Williams coefficient were conducted by Ar (2011) and Apaydın (2013). However, in this study a Hazen-Wiliams coefficient of 130 were taken throughout all scenarios due to the limited data in the previous studies (Ar, 2011) a reliable actual Hazen-Williams coefficient was not possible to use.

The hydraulic model for N8.3 was formed and developed by the previous researchers of the network. The hydraulic model used in this study was taken from Şendil (2013). N8.3 Hydraulic Model mainly consists of an entrance point which is defined as a static hydraulic level reservoir connected to 3 pumps. A sketch for N8.3 is provided in Figure 5.1.

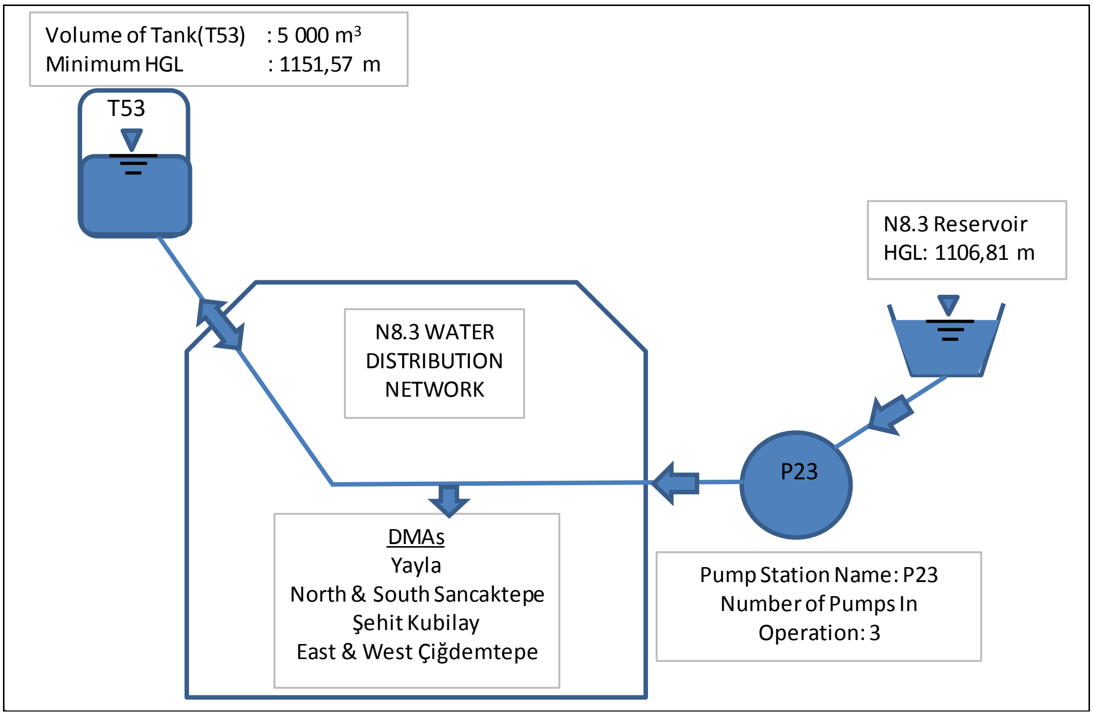

Figure 5.1: N8.3 Water Distribution Network

N8.3 Network satellite view of the area and a fully detailed map of the network with DMA's are shown in Figure 5.2 and 5.3 respectively. Measuring chambers are at the entrances of the districts; each chamber measures the flow rates of the district for one day. Measurement chamber locations are provided in Figure 5.2; each one is indicated by M.C. (Measurement Chamber).

DMA's of N8.3 district are formed by the isolation valves; these valves cut the connection between the neighboring districts. The valves are positioned around the edges of the any neighboring district, to cut the interaction of water from the neighboring district. When the isolation valves are closed the flow cannot enter the district from a neighboring pipe, also due to the locations of these valves the district only receives water from the main entrance. The locations of these valves are provided in Figure 5.3. In the hydraulic model of N8.3, Yayla District does not have any neighboring district; therefore there are no isolation valves in this area.

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Figure 5.2: N8.3 Network Satellite Preview (Google Earth)2

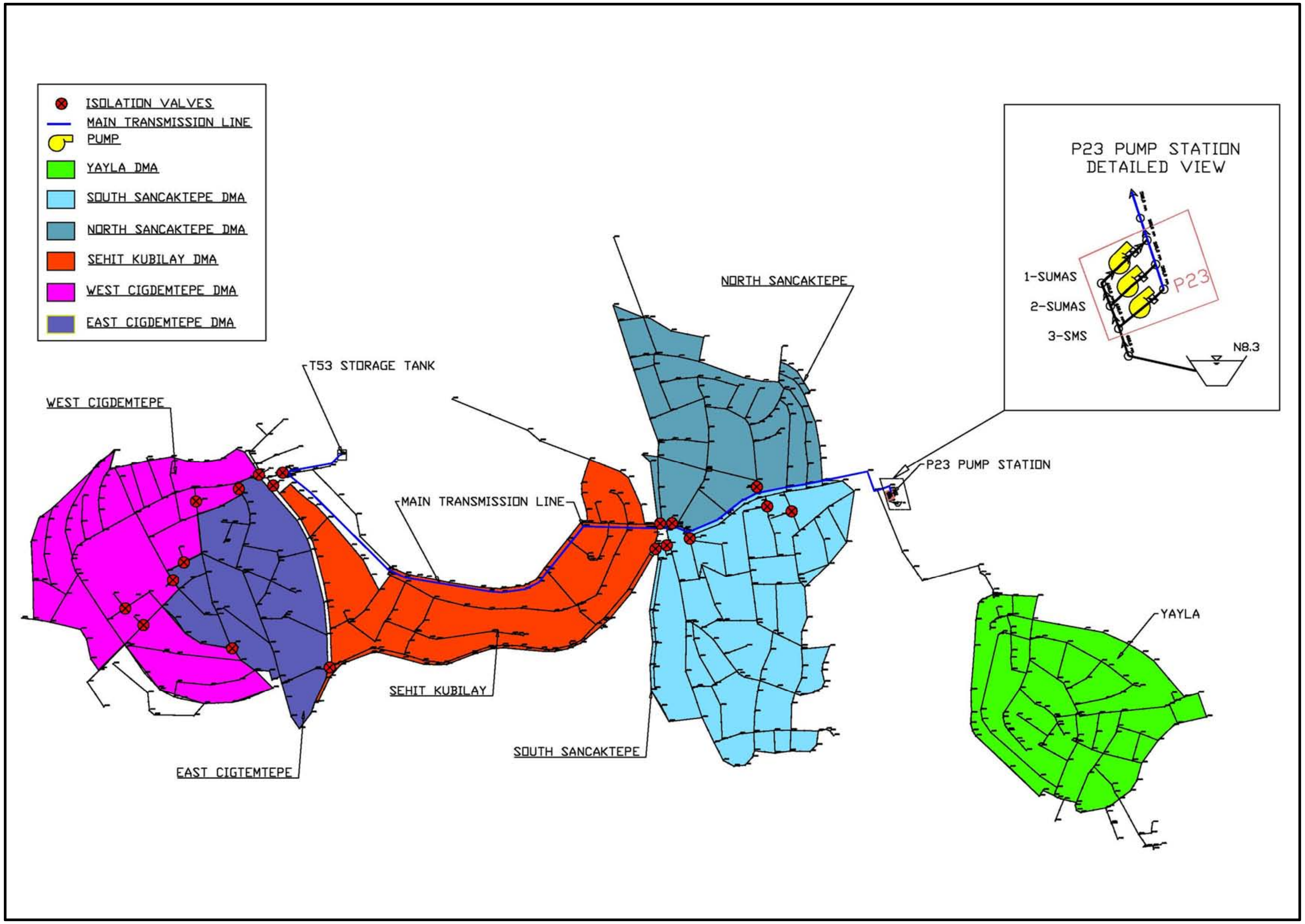


Figure 5.3: N8.3 Network and DMAs

The pumps of the network are located in pump station named P23. As already mentioned there are 3 pumps connected in parallel in the station. Pump number 1 and 2 has equal capacity, manufactured by the same company called SUMAS. Pump number 3 has a larger capacity manufactured by the company SMS (Samsun Makina Sanayi). Detailed characteristics of the pumps are presented in Table 5.1. In addition to this information a pump's fundamental characteristic which is the pump curve has to be known. The pump curves for SUMAS and SMS are presented in Figure 5.4 and 5.5 respectively. Pump 1 & 2 which are manufactured by SUMAS is called as SM (Small Pump) hence they have a lower capacity. Pump 3 which is manufactured by SMS is called as LG (Large Pump). This terminology will be used along all parts of this study.

Table 5.1: Characteristics of the Pumps in P23 Station

Pump station	P23	
Pump number	Pump 1 & 2	Pump 3
Manufacturer	SUMAS	SMS
Type	SP 125	SP 150 - 400/493
Design flow	188 m^3/hr	350 m^3/hr
Design head	45 m	45 m
Pump efficiency	74%	80%

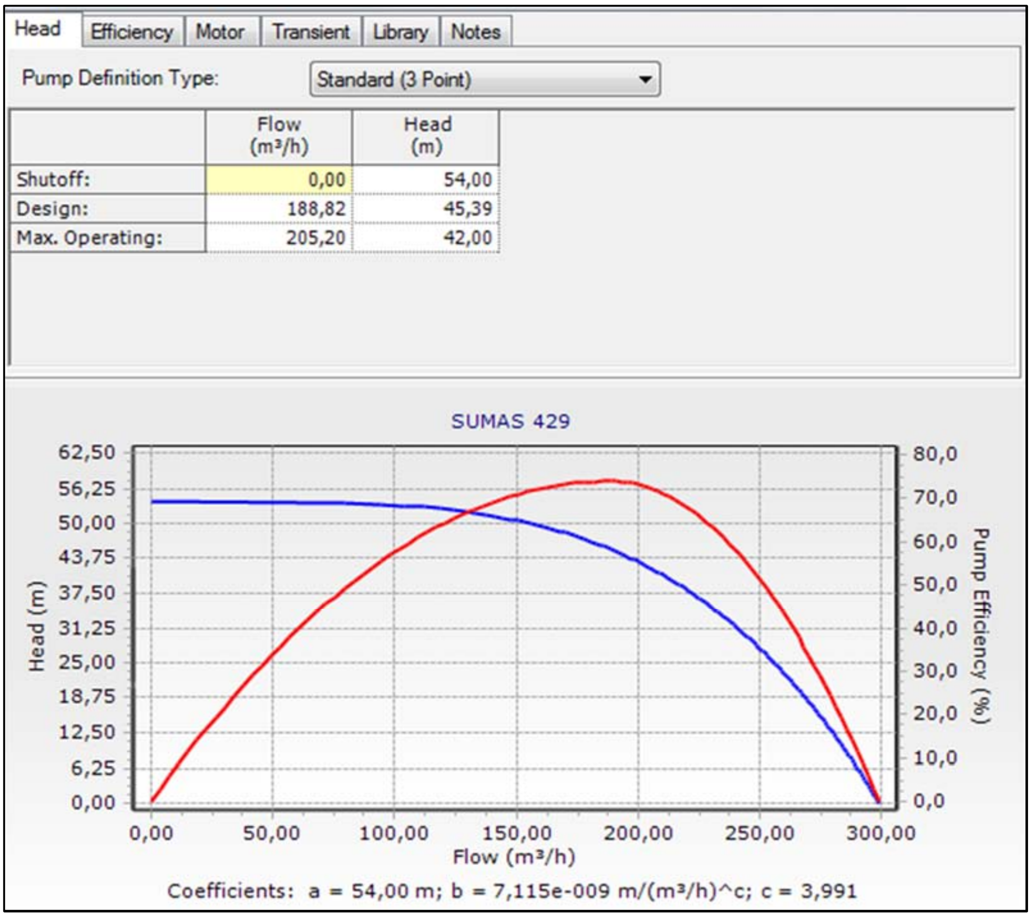


Figure 5.4: Pump Curve of SUMAS (Pump 1 and 2)

These 3 pumps are assumed to receive water from a reservoir. The reservoir is the water source of the network which is the only connection of N8.3 with the Northern Pressure Zone. The Hydraulic Grade Line (HGL) elevation of the reservoir is 1106,81 m. Actually, in the real case a reservoir does not exist in N8.3 Water Distribution Network. Dams and other storage facilities are outside the city pressure zones and these facilities are very distant to N8.3. The real case is a pipe connection point with the pump station. This point has a HGL depending on the system's pressure. Former studies (Şendil, 2013) state that, the average of the pressure readings are taken as the HGL. This point is modeled as a reservoir to simplify modeling process.

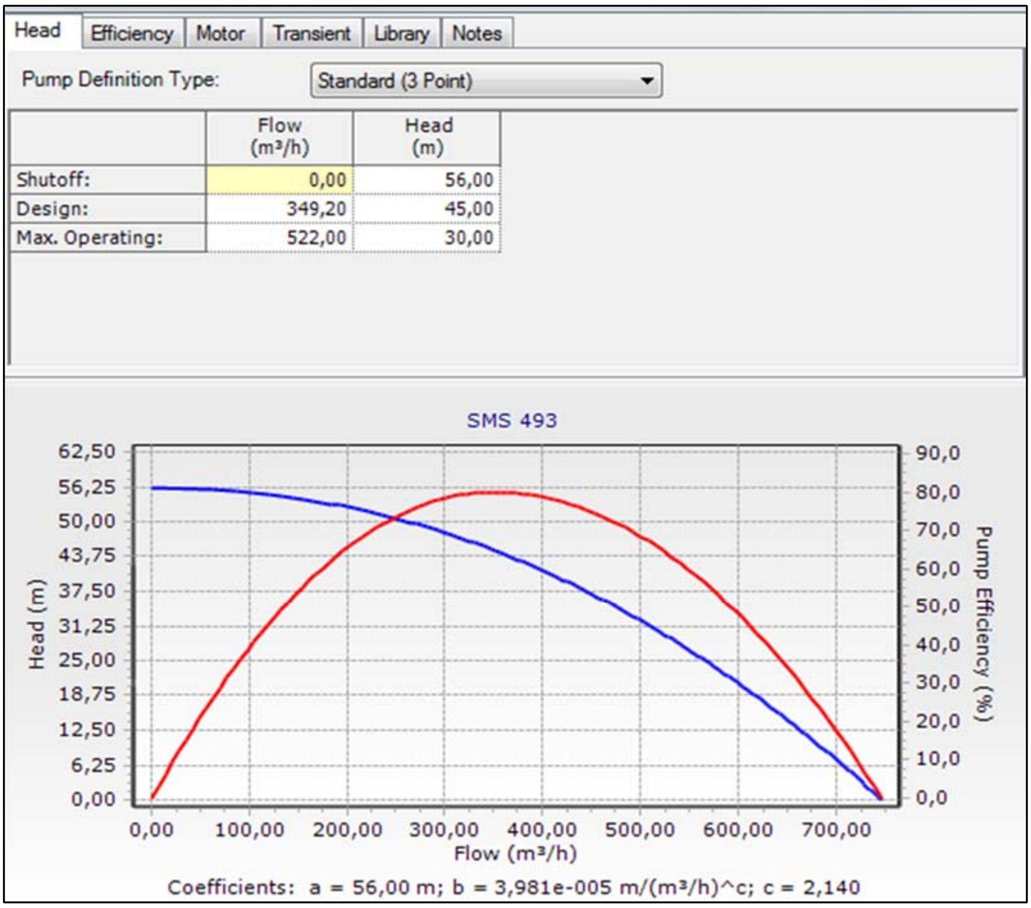


Figure 5.5: Pump Curve of SMS (Pump 3)

The storage tank T53 is located in the north east part of the network. Base elevation of the tank is 1149,82 m. Tank has an height of 5.00 m, the minimum water depth level of the tank is 1.75 m, the initial level is 2.50 m and the maximum level is 5.00 m. Detailed information about the tank is provided in Table 5.2.

Table 5.2: Tank Characteristics

Storage Tank	T53
Volume	5000 m^3
Cross-Section Type	Rectangular
Cross-Section Area	800 m^2
Height	5 m
Active Storage Volume	2600 m^3
Base Elevation	1149,82 m

The storage tank has a very important role in water quality modeling, because the concentration of the tank influences the concentration of the network. In water quality modeling of tanks, the tank is commonly assumed as completely and instantaneously mixed. This is called Fully-Mixed Water Quality Model. There are also other useful mixing models for simulating flow processes in tanks and reservoirs (Grayman et al., 1997). For contact basins or clearwells designed to provide sufficient contact time for disinfectants are frequently represented as simple plug-flow reactors using a “first in first out” (FIFO) model. In a FIFO model, the first volume of water to enter the tank as inflow is the first to leave as outflow. If severe short-circuiting is occurring within the tank, a “last in first out” (LIFO) model may be applied, in which the first volume entering the tank during filling is the last to leave while draining. More complex tank mixing behavior can be captured using more generalized “compartment” models. Compartment models have the ability to represent mixing processes and time delays within tanks more accurately (Walski et al., 2008).

In N8.3 Pressure Zone the tank T53 is assumed as Fully-Mixed Water Quality Model.

As mentioned previously reservoir, pumps and tank are the main elements of the network and these elements are connected to each other by pipes. Pipes in the network have certain characteristics like diameters, lengths and names.

The water being used by consumers is assumed to be withdrawn from the junctions; therefore adjusting and assigning demands to them is an important part of the work. The junctions of the network have certain elevations and locations defined in the system. Junctions even dead end ones have demands. Demand is a function of time for each junction and there are demand patterns defined for each different zone.

Daily demand curves were observed in the measurement chamber locations located at the entrance of each district. The measurements were made manually by using portable flow meters. These records were made for 24 hours within 3 minutes time intervals to be able to observe the overall demand pattern of the districts. Daily demand curves are provided in Figure 5.6 (a, b…f). These daily demand records were made between the dates 7.09.2011 and 22.09.2011 during week days. In the time of the records, there was not an extraordinary consumption, caused by a local event or any other case. Therefore the demands for each zone reflected an ordinary water usage in the network. Total daily demand curve of N8.3 Network is provided in Figure 5.7.

Demands at junctions are determined by developed methodology according to pipe lengths connected to each nodes. Almost in all streets distribution network pipes are available. Application of this methodology starts with determination of demand per meter pipe. So that average demand of DMA is divided by total pipe length of DMA (Şendil, 2013).

Every pipe is created by two nodes which are start and end node in the model. If these two nodes are assumed as customer connection nodes, the demand at both nodes is calculated by multiplication of half of the total length of pipe with demand per meter pipe value which was determined before. This means that demand at one customer connection point is determined according to the half-length of pipes connected to that node (Şendil, 2013). The demand at each node is calculated the equations as follows;

$$D \text{ (demand at pipe per meter)} = Dt\text{(average demand)} / \sum L \quad (5.1)$$

$$D_N \text{ (demand at a specified junction)} = (L_1/2 + L_2/2 + L_3/2 \ldots + L_n/2) \times D \quad (5.2)$$

Where;

D : Demand at pipe per meter

L : Pipe length

D_N : Demand at a specified junction

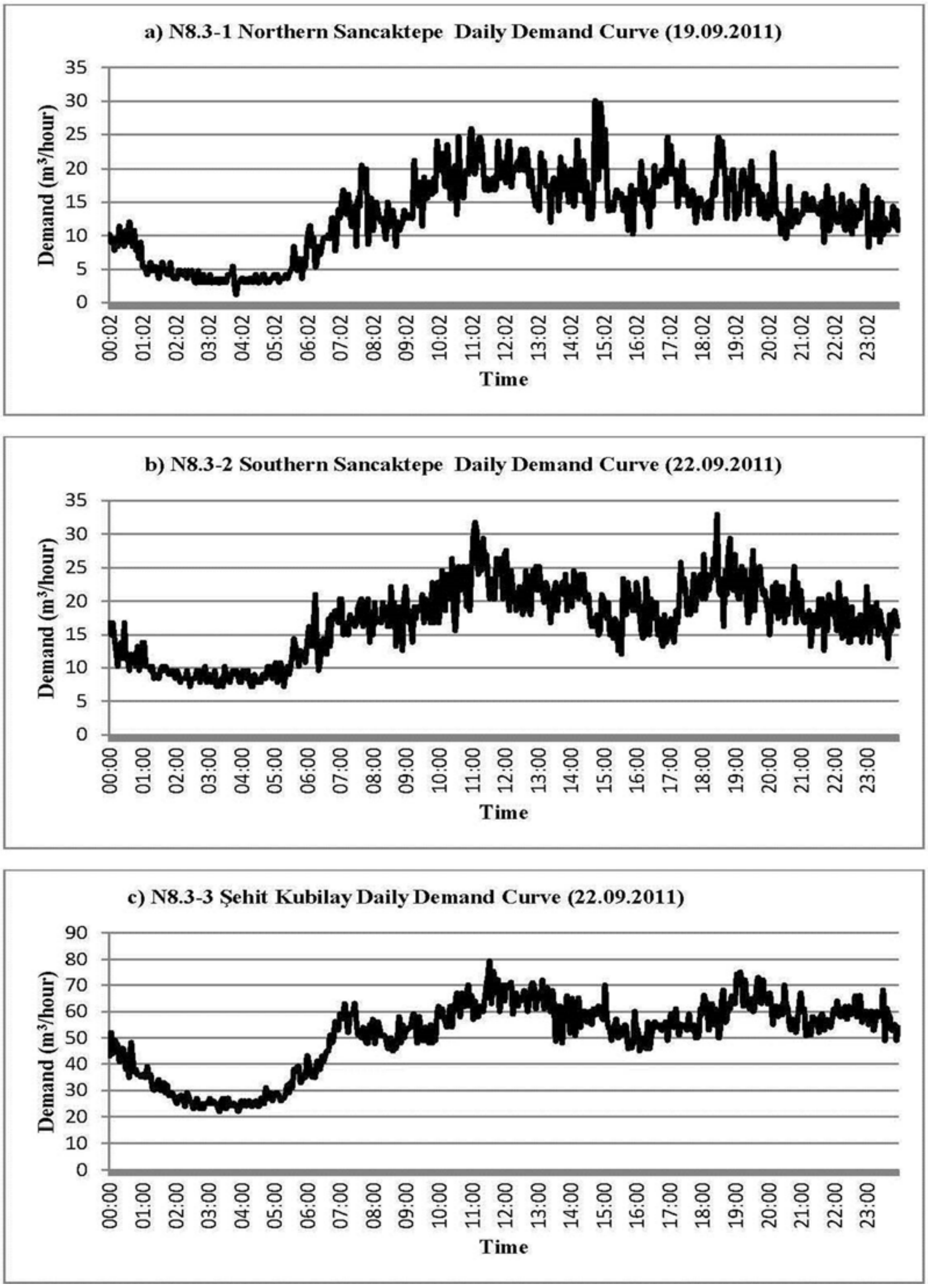
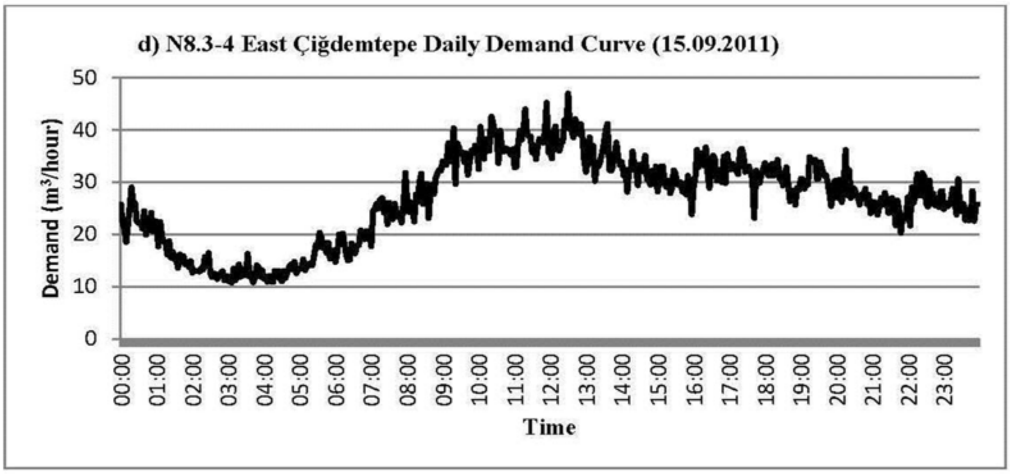
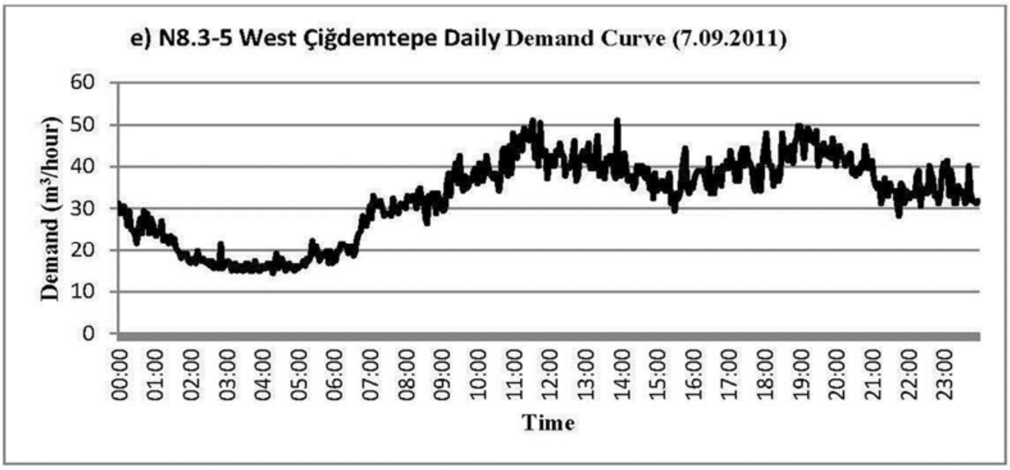


Figure 5.6 (a, b, c) : Daily Demand Curve of N8.3 Zones





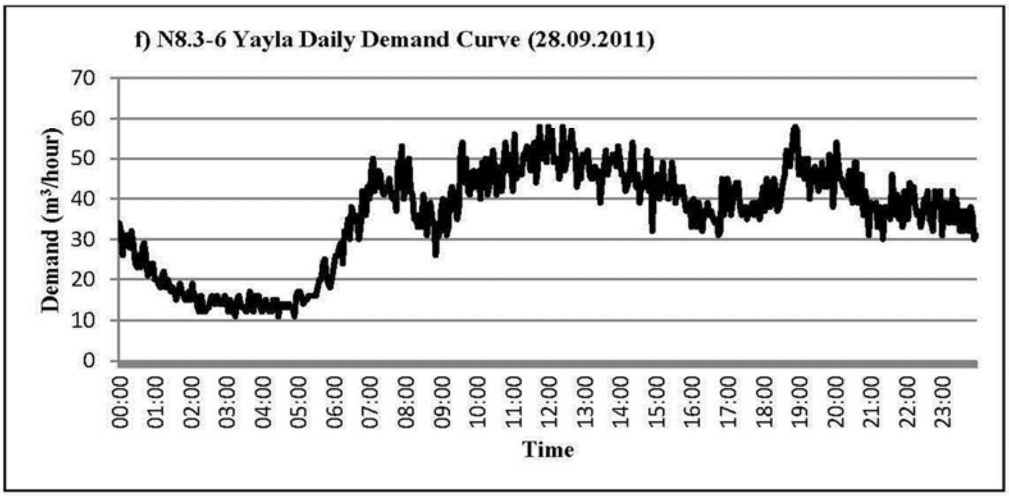


Figure 5.6 (d, e, f) : Daily Demand Curve of N8.3 Zones

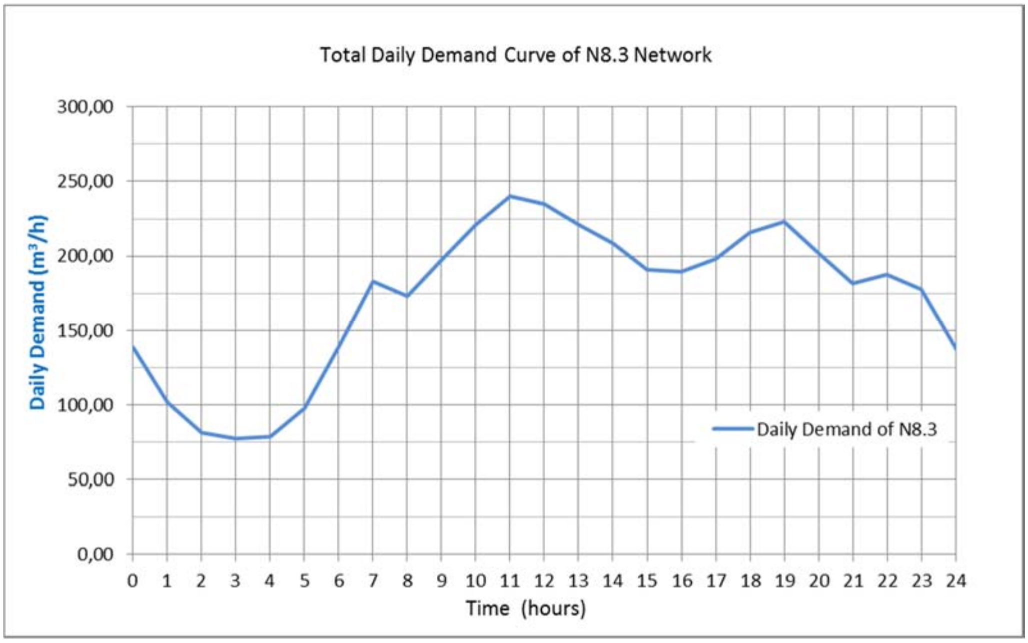


Figure 5.7 : Total Daily Demand Curve of N8.3

5.2 Water Quality Modeling of N8.3

Water quality of a network depends on the physical and chemical properties of water being supplied to consumers. In order to determine the quality properties of water first of all, a hydraulic model of the pressure zone should be constructed. A hydraulic model of a water distribution network is a mathematical representation of the real world systematic arrangement. A hydraulic model for N8.3 was set up by the previous researchers. System characteristics of this network were already presented in 5.1.

Water quality models mainly use transport, mixing and decay equations. A steady state simulation cannot solve the time dependent equations. Extended Period Simulation (EPS) is used to analyze the changes in the WDN. Extended Period Simulation (EPS) determines the quasi-dynamic behavior of a system over a period of time, computing the state of a system as a series of steady – state simulations in which hydraulic demands and boundary conditions do change with respect to time. To understand the effects of chancing water usage and fill-drain cycles of the tank EPS Study is needed. (Walski et al., 2008)

Extended Period Simulation (EPS) is conducted for water quality modeling since the properties of water and contaminants change over time according to transport, decay and mixing events. In this study chlorine which is an effective and widespread constituent is modeled.

N8.3 network operations, water usage patterns and tank fill drain cycles have a major effect in the concentration changes of residual chlorine among the network. Therefore to be able to process and model all these changes EPS study is performed.

In this study, being a primary disinfectant, chlorine is used while constructing the water quality model. Reaction parameters of chlorine are the wall coefficient (k_w) and the bulk coefficient (k_b). Wall coefficient is taken as -0.08 m/day and bulk coefficient is taken as -0.10 $(mg/l)^{(1-n)/day}$ as recommended by Bentley (Bentley, 2009).

Chlorine levels at all junctions are inspected for 16 days (384 hours) calculation time, the selection of this time depends on the stabilization of chlorine concentrations of the system. The source (pump station) concentration of 0.50 mg/l value is taken from a previous study in which the SCADA (Supervisory Control and Data Acquisition) records were used to observe the chlorine source concentrations (Bağcı, 2001). The average of the entrance chlorine concentrations were measured as 0.50 mg/l and this value was almost constant; therefore in this study entrance value is taken as 0.50 mg/l. This actual measurement data at the pump station provided a reliable initial concentration to be used in this study.

This means that the system is supplied with a concentration of 0.50 mg/l constantly along the calculation time. For every junction an initial concentration of 0.20 mg/l is assigned. Assigning an initial concentration of 0.20 mg/l for the junctions helps the system reach to the stable condition more quickly as shown in Figure 5.8. After almost 24 hours a stable graph starts to initialize and after nearly 2 weeks period of time all junctions become stable. After 384 hours of EPS study, concentration versus time graphs are formed, in these graphs chlorine concentration fluctuation at the junctions turned into a stable behavior. These graphs provided the initial and saturated concentrations of the system.

In Figure 5.9 the concentration versus time relationship for the same junction is plotted for 16 days (384 hours). Although this junction becomes stable after 24 hours other junctions and tank T53 concentration does not become stable in a short time. The tank concentration graph has a very long unstable period. Also junctions that are close to the tank have fluctuations more than 2 - 10 days depending on the tanks changing concentration. Even a certain initial concentration is assigned for the tank concentration graph starts to fluctuate for a long period. In the EPS study the tank's chlorine concentration is assumed 0.00 mg/l as the beginning concentration. After a long period of EPS the system and the tank reached to a stable period. The concentration versus time graph of the tank is provided in Figure 5.10.

Due to these reasons the case study analysis calculation time is taken as 384 hours. The last 48 hours which is between 337 – 384 hours is used in the concentrations graphs. This study represents actual daily concentrations of chlorine in the network therefore to be able to comment on the concentrations the study analysis period calculation time and the equivalent actual day time has to be known. This information is provided in Table 5.3.

Table 5.3: Case Study Analysis Period Calculation Time and Actual Day Time

Time (hours) -Last 48 hours of the Model Study											
337,00	**338,00**	**339,00**	**340,00**	**341,00**	**342,00**	**343,00**	**344,00**	**345,00**	**346,00**	**347,00**	**348,00**
01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00
349,00	**350,00**	**351,00**	**352,00**	**353,00**	**354,00**	**355,00**	**356,00**	**357,00**	**358,00**	**359,00**	**360,00**
13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	00:00
361,00	**362,00**	**363,00**	**364,00**	**365,00**	**366,00**	**367,00**	**368,00**	**369,00**	**370,00**	**371,00**	**372,00**
01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00
373,00	**374,00**	**375,00**	**376,00**	**377,00**	**378,00**	**379,00**	**380,00**	**381,00**	**382,00**	**383,00**	**384,00**
13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	00:00

(blue)	Case study calcutation time (hours)
(green)	Actual day time (hours)

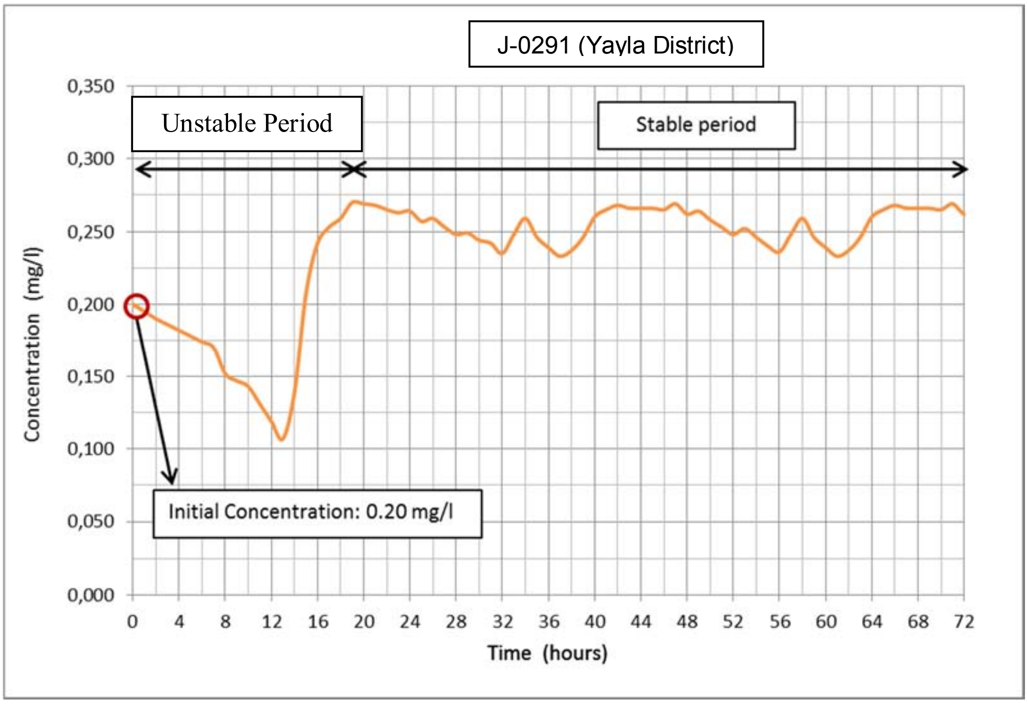


Figure 5.8: Unstable and Stable Concentration Period of J – 0291 (0-72 hours)

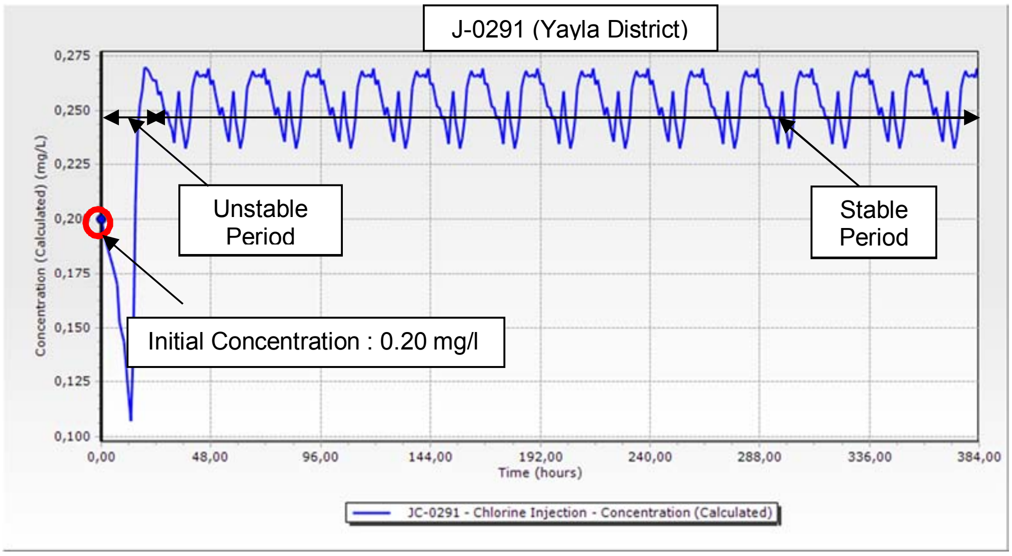


Figure 5.9: Unstable and Stable Period of J – 0291 (0- 384 hours)

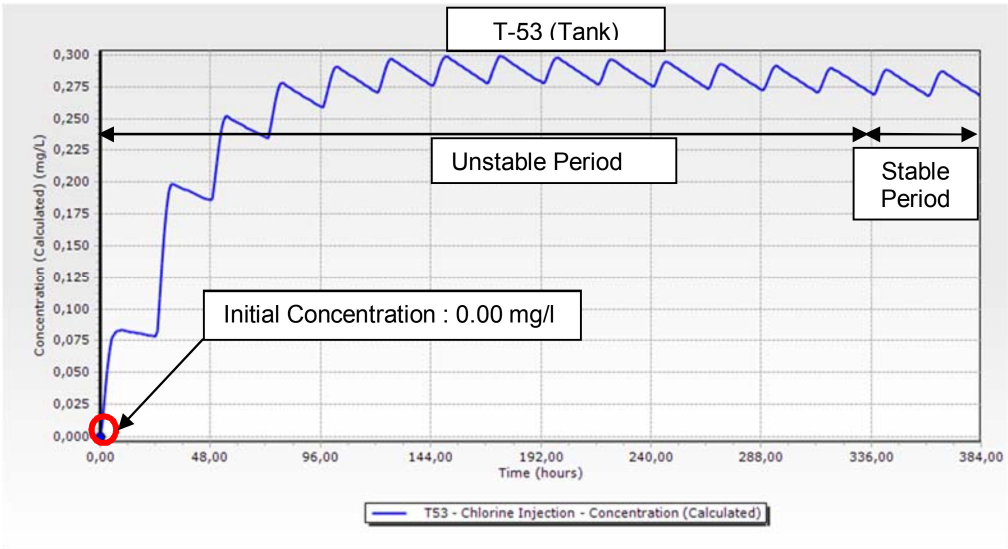


Figure 5.10: Unstable and Stable Period of the Tank (T53) (0- 384 hours)

Upon leaving the source and entering the distribution system, the disinfectant chlorine is subject to a set of potential chemical reactions. The flow of water through a pipe forms several types of chemical reactions. Chlorine reacts with natural organic matter present in water, and at the pipe wall oxidation reactions with biofilms and the pipe material (a cause of corrosion) can occur. As a result of these reactions chlorine starts to decay rapidly. There are two parameters as previously mentioned, reaction rate which is a function of the bulk reaction k_b coefficient and the wall reaction coefficient k_w. (Walski et al., 2008)

Default values of k_b and k_w is presented in Table 5.4. These values are the default values used by software WaterCAD. Compared to other studies (Piao et. al, 2010) these values represent common values calculated by other researchers.

Table 5.4: Default Values for k_b and k_w

Reaction	Coefficient
Bulk Reaction Rate (k_b)	-0.10 $(mg/L)^{(1-n)/day}$
First Order Wall Reaction Rate (k_w)	-0.08 m/day

Chlorine concentration levels vary over time and location. In general chlorine concentrations in the water distribution networks decrease as travel time increases. Travel time is expressed as a certain duration for the water to reach from the source to a specified junction or any other element of the network. This time dependent relationship will be discussed in the next chapter. In this chapter the overall change of chlorine for several scenarios is examined.

In this case study mainly 3 different scenarios are studied.

1. Single Pump Operation (Continuous for 24 hours)

1.1 Uninsulated system

1.2 Insulated system

2. Multi Pumps Operating According to Optimum Pump Schedule

2.1 Uninsulated system

2.2 Insulated system

3. ASKI Pump Operation (Operation of Pumps by Municipality)

3.1 Uninsulated system

3.2 Insulated system

Uninsulated system term is also defined as Whole Network meaning that network is operating with open isolation valves while water is transferred within districts. Insulated system refers to DMA meaning the isolation valves are closed there is no interaction of water between districts, each district receives water from a single entrance.

5.3 Single Pump Operation (Continuous for 24 hours)

In this scenario one of the three pumps 1 - SUMAS (SM) pump is operating whereas the other 2 pumps in the system are set to be closed as shown in the Figure 5.11. 1- SUMAS is in operation at all times, while the pump operating point is changing due to the fluctuations in daily demand. Initial tank level at the start of the EPS study is 2.50 m.

The flow being supplied to the network for the first 24 hours is provided in Figure 5.12a as a work schedule of pump 1-SUMAS. In addition to pump flow, tank levels for the first 24 hours are plotted in Figure 5.12a. As mentioned previously, SUMAS is the small pump (SM) which has a lower capacity compared to pump SMS. The pump operates based on the pump curve, the head and flow of the pump changes according to the daily demand.

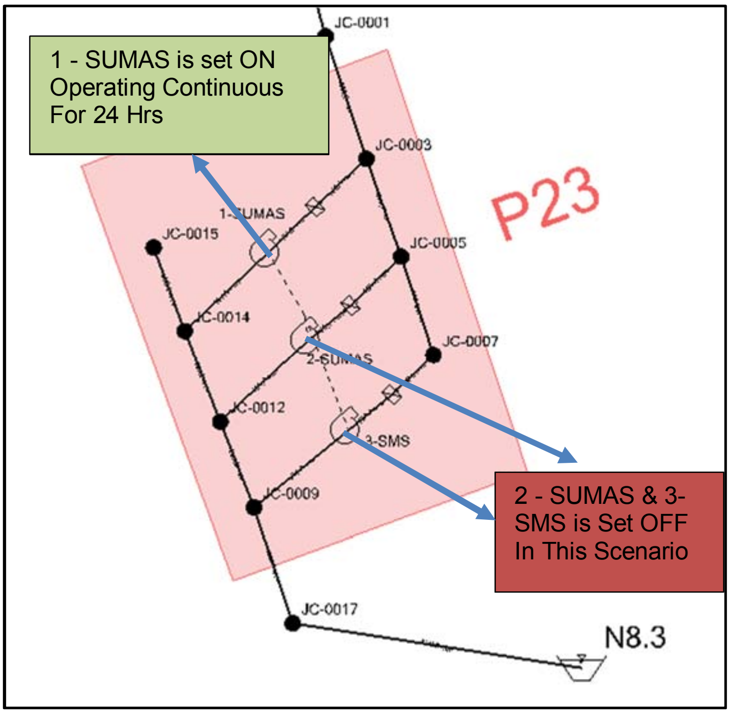


Figure 5.11: Single Pump Operation Scenario Pump Configuration (On / Off Status)

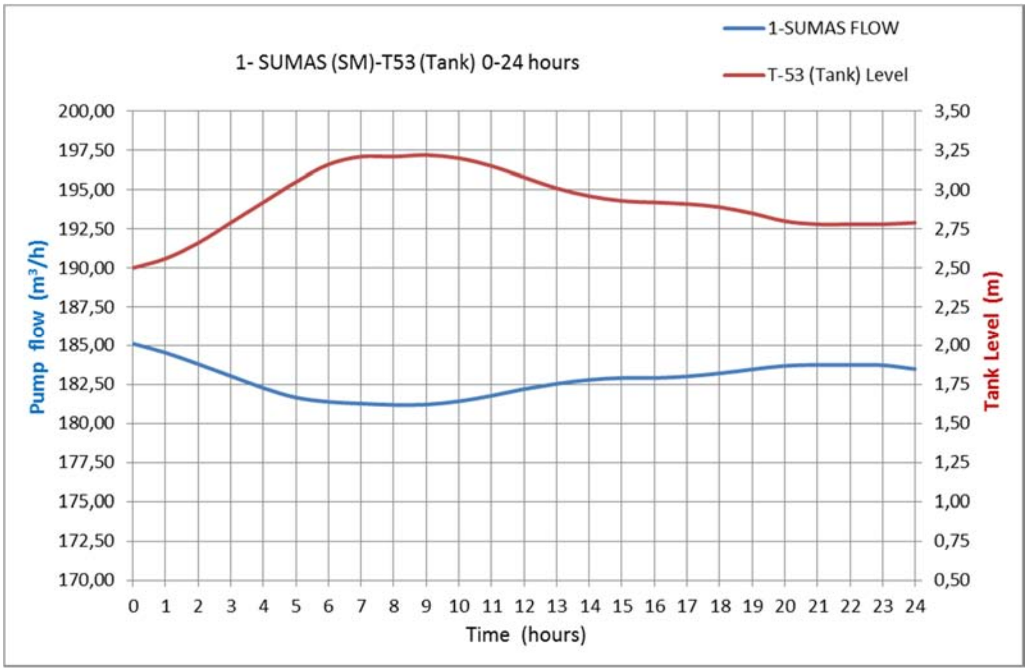


Figure 5.12 a: Pump 1-SUMAS Flow versus Time Graph and T-53 Level versus time graph for 0-24 Hours

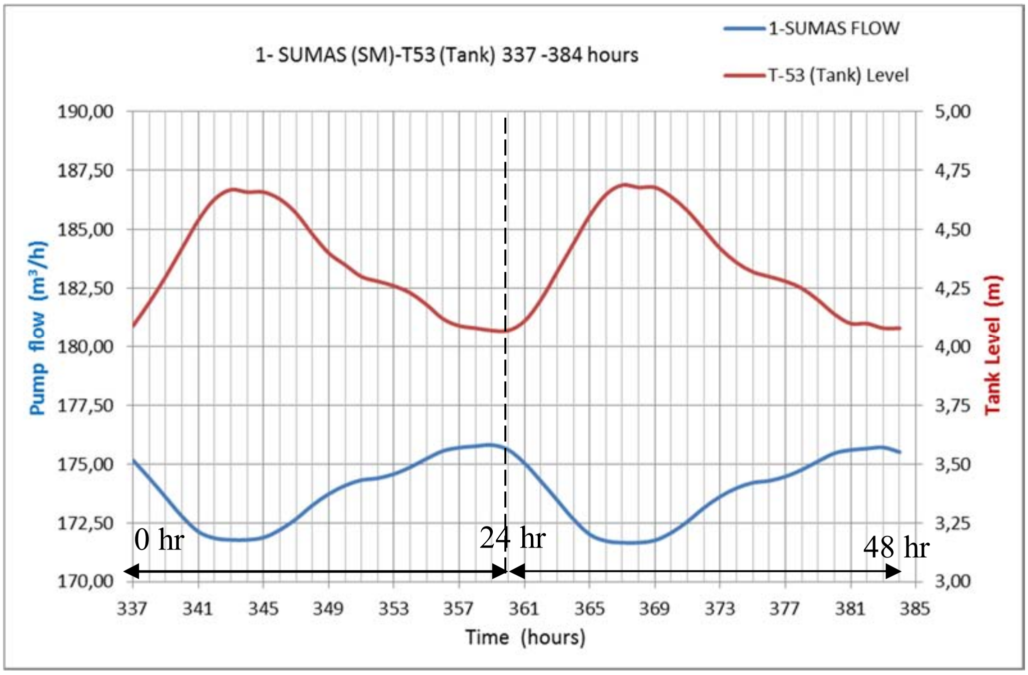


Figure 5.12 b: Pump 1-SUMAS Flow versus Time Graph and T-53 Level versus time graph for 337-385 Hours

Initial tank level at the start of the EPS study is 2.50 m, tank level fluctuates according to the daily demand and pump operation. Starting at 2.50 m the system reaches to a balance after 2 weeks (336 hours). This balanced system which is also defined as stable period is established in the last 337-384 hours. The flow being supplied to the network for the last 48 hours (337-384 hr.) is provided in Figure 5.12b; in addition to pump flow, tank levels for the last 48 hours are plotted in Figure 5.12b.

5.3.1 Uninsulated System (Whole Network Case)

Uninsulated system of N8.3 Network means all the isolation valves of the network are set open and flow passes directly through the neighboring zones. The isolation valves shown in Figure 5.3 are open in this scenario.

5.3.1.1 Yayla District

Yayla District (Figure 5.2 and 5.3) consists of 140 junctions, including dead end junctions. Yayla which is the closest district to the pump station, has only one entrance for receiving water. The area has no boundaries with other districts, which makes it completely insulated.

As a result of these conditions, it is expected that under DMA (Insulated Network) and Whole Network (Uninsulated Network) operating conditions the system will perform actually the same. This means that the chlorine concentrations will make exact matches for both conditions.

The model is set up for the chlorine parameters as mentioned above, and EPS study is performed for 384 hours. Several junctions are examined and certain ones which represent the general concentrations of Yayla District are chosen. Generally to view the overall concentrations in the district a junction at the entrance of the district, junctions at the middle points of the district and junctions at the dead end points of the district are chosen. These junctions are J-0188, J-0211, J-0343, J-0348 and J-0291 as provided in Figure 5.13.

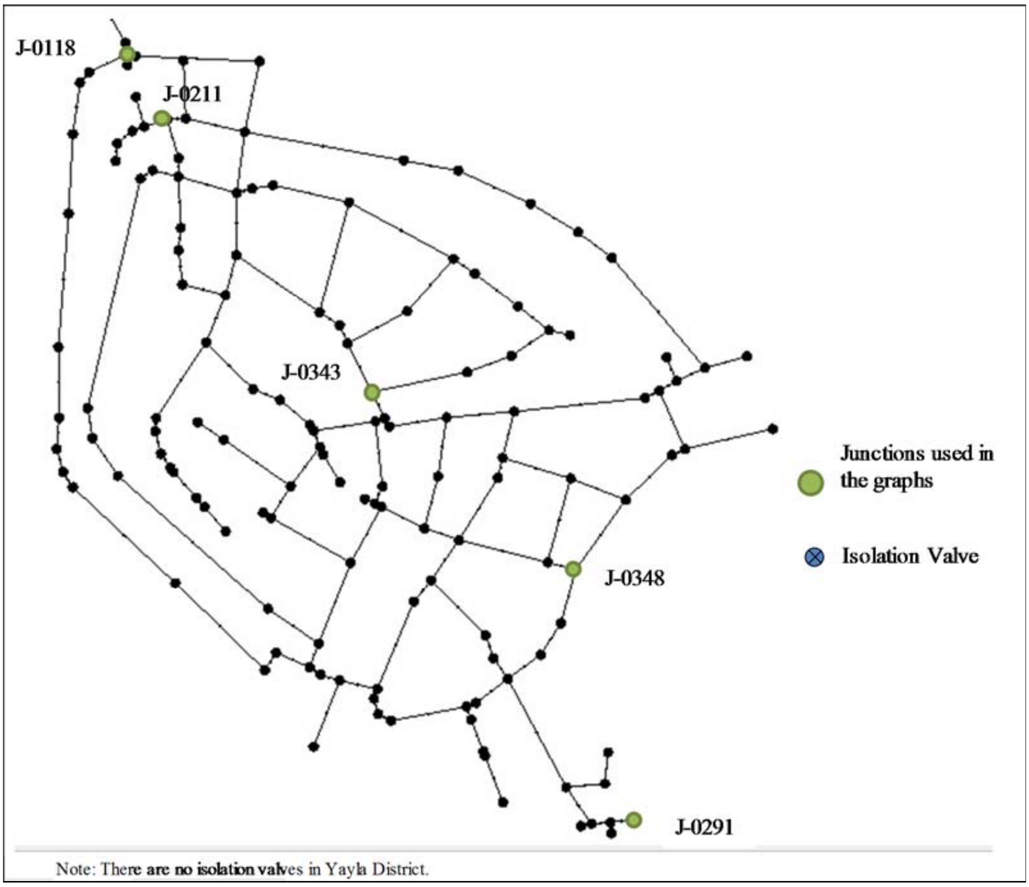


Figure 5.13: Junctions considered in Yayla District

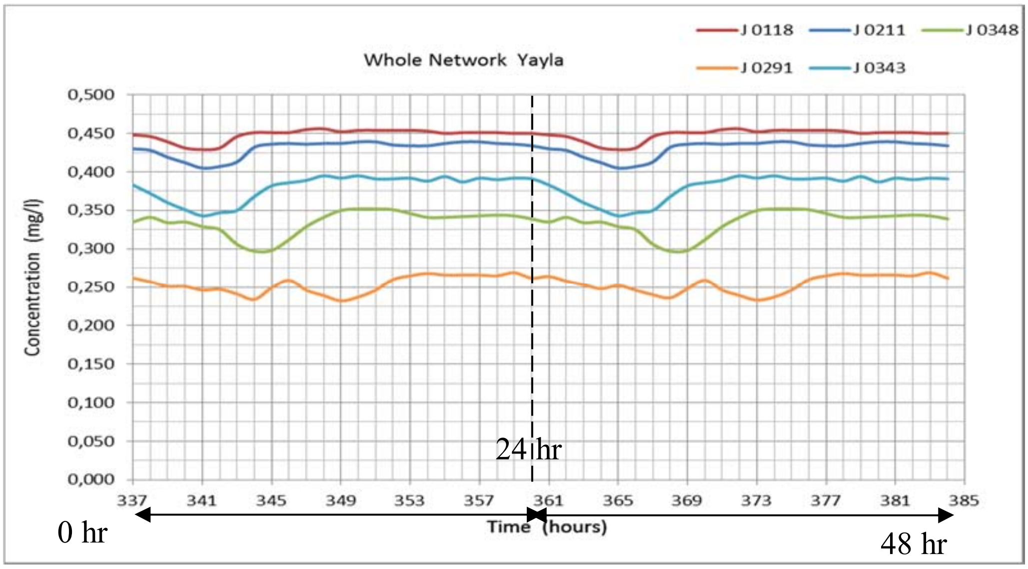


Figure 5.14: Single Pump Operation Chlorine Concentrations (Yayla Whole Network Case)

The chlorine concentrations for Yayla District are provided in Figure 5.14 between 337- 384 time intervals. This time interval refers to the last 48 hours of the system. According to these concentrations between 00:00 – 06:00 time intervals when the demands are very low, the concentrations start to decrease until 06:00 – 12:00 time intervals after this period between 12:00 – 24:00 time intervals concentrations follow almost a straight line due to the usage of water.

Examining the Figure 5.14, J-0118 which is at the entrance of the district has the highest concentration compared to other junctions in the area. J - 0211 has a lower concentration than J-0118 due to the small distance from the entrance. The middle point junction J-0343 has lower concentrations compared to the entrance junctions, this junction and the surrounding middle point junctions show the overall average concentrations of the Yayla District. J-0348 which is far away from the entrance has even 0.10 mg/l less concentration in comparison to the entrance junctions. J-0291 is the most distant junction in Yayla District and this junction is defined as the dead end junction as it does not transmit water to neighboring junctions. There are no transport and mixing events in the junction. The most important and driving parameter is the demand being withdrawn from the junction. If the demand is in increasing trend the concentration of the junction starts to increase and if the demand is decreasing trend the concentration starts to decrease. The overall concentration of J-0291 is the lowest concentration in the district as also shown in Figure 5.14. Note that distance to the source or distant junctions in the DMA's is not the only cause of the concentration changes, demand being withdrawn from the junction, flow velocity, calculated concentrations around the junction also have major effects on concentration changes. Distance to the source is expressed as a visual way of observing and understanding the concentration changes, the genuine parameter for explaining the concentration changes with respect to source is *"travel time"*.

According to drinking water regulations, maximum chlorine concentration should not exceed 0.50 mg/l and minimum chlorine concentration should not be below 0.10 mg/l. Junctions considered in Yayla District have chlorine concentrations which are in safe limits. This means chlorine concentration is enough for disinfection and does not exceed the maximum limits.

5.3.1.2. South Sancaktepe District

South Sancaktepe District (Figure 5.2 and 5.3) consists of 115 junctions, including dead end junctions. This area, mostly receives water from the transmission line passing from the north part of the area. In addition to this transmission line, it has boundaries and pipe connections with Şehit Kubilay and North Sancaktepe. As a result of these conditions, it is expected that under DMA and Whole Network (Uninsulated Network) operating conditions the system will perform differently. This means the chlorine concentrations will vary for these conditions. The model is set up for the chlorine parameters as mentioned above, and EPS study is performed for 384 hours.

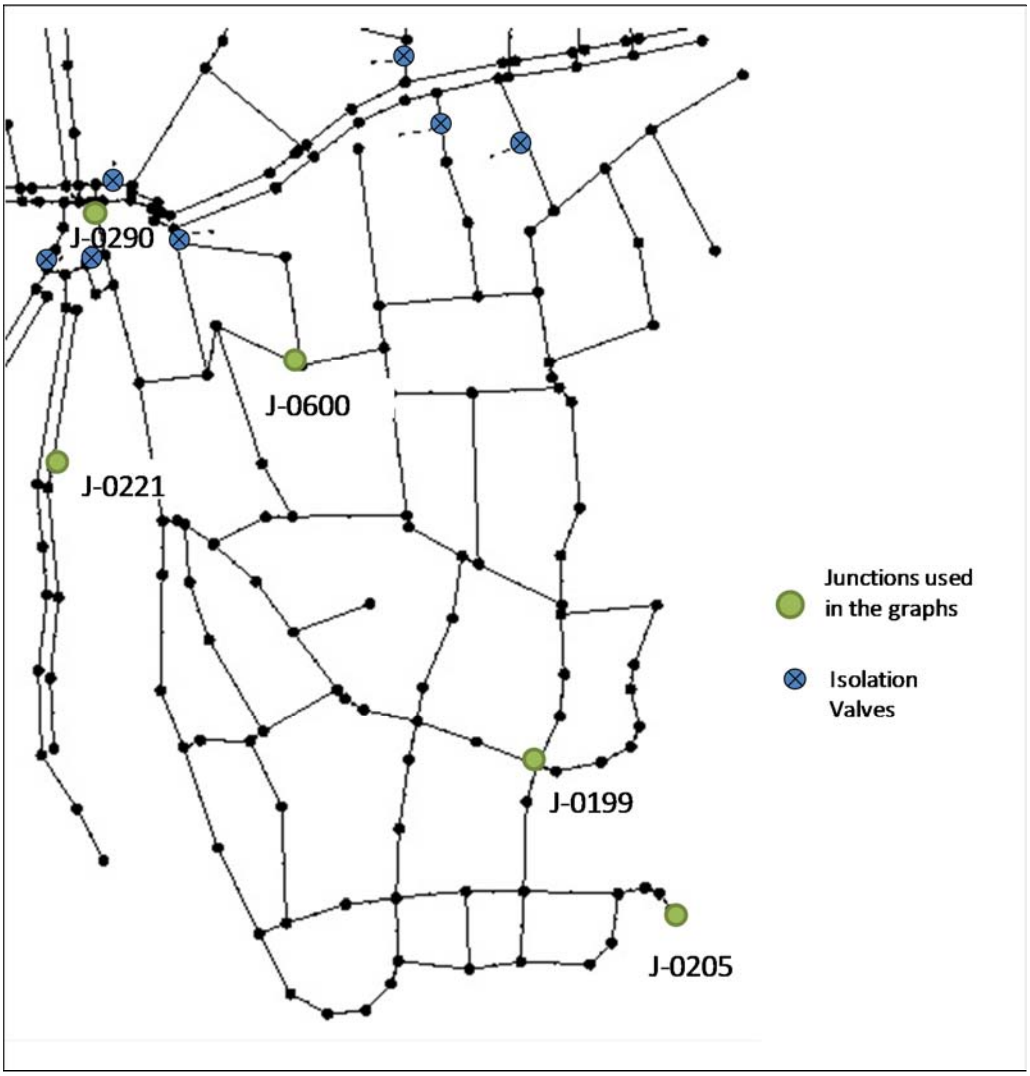


Figure 5.15: Junctions considered in South Sancaktepe District

Examining the Figure 5.16, J-0290 which is at the entrance of the district has the highest concentration compared to other junctions in the area. J - 0221 has a lower concentration than J-0290 due to the small distance from the entrance. The middle point junction J-0600 has lower concentrations compared to the entrance junctions, this junction and the surrounding middle point junctions show the overall average concentrations of the South Sancaktepe District. J-0199 which is far away from the entrance has even 0.15 mg/l less concentration in comparison to the entrance junctions. J-0205 is the most distant junction in South Sancaktepe District and this junction is defined as the dead end junction as it does not transmit water to neighboring junctions. There are no transport and mixing events in the junction. The most important and driving parameter is the demand being withdrawn from the junction. If the demand is in increasing trend the concentration of the junction starts to increase and if the demand is decreasing trend the concentration starts to decrease. The overall concentration of J-0205 is the lowest concentration in the district as also shown in Figure 5.16. Note that distance to the source or distant junctions in the DMA's is not the only cause of the concentration changes, demand being withdrawn from the junction, flow velocity, calculated concentrations around the junction also have major effects on concentration changes. Distance to the source is expressed as a visual way of observing and understanding the concentration changes, the genuine parameter for explaining the concentration changes with respect to source is *"travel time"*.

According to drinking water regulations, maximum chlorine concentration should not exceed 0.50 mg/l and minimum chlorine concentration should not be below 0.10 mg/l. Junctions considered in South Sancaktepe District have chlorine concentrations which are in safe limits. This means chlorine concentration is enough for disinfection and does not exceed the maximum limits.

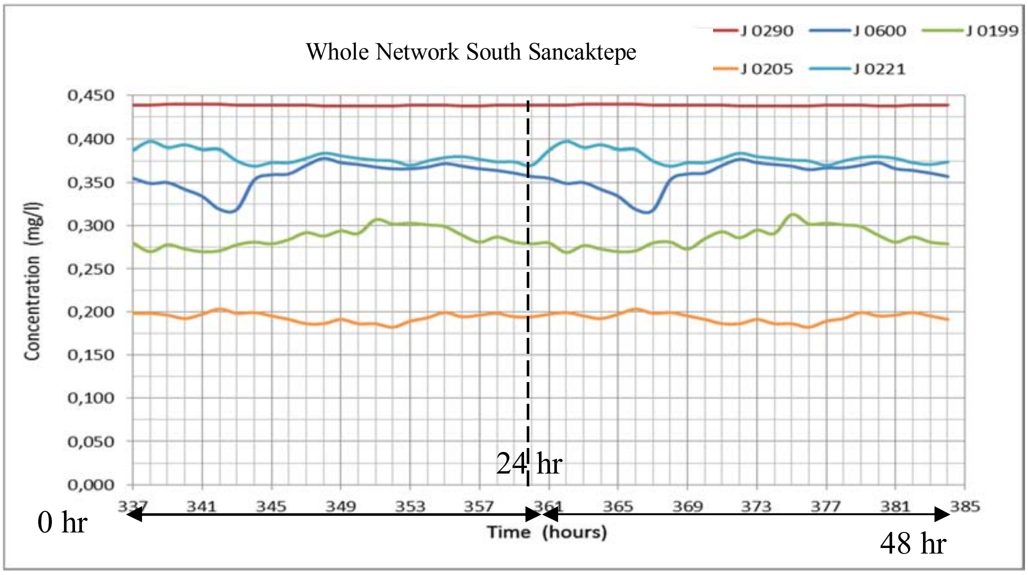


Figure 5.16: Single Pump Operation Chlorine Concentrations (South Sancaktepe Whole Network Case)

5.3.1.3. North Sancaktepe District

North Sancaktepe District (Figure 5.2 and 5.3) consisting of 92 junctions, mostly receives water from the main line passing from the south part of the area. In addition to this pipe line, it has a boundary with South Sancaktepe. As a result of these conditions, it is expected that under DMA and Whole Network (Uninsulated Network) operating conditions the system will perform differently due to the interactions between these boundaries. This means the chlorine concentrations will vary for these conditions. The model is set up for the chlorine parameters as mentioned above, and EPS study is performed for 384 hours.

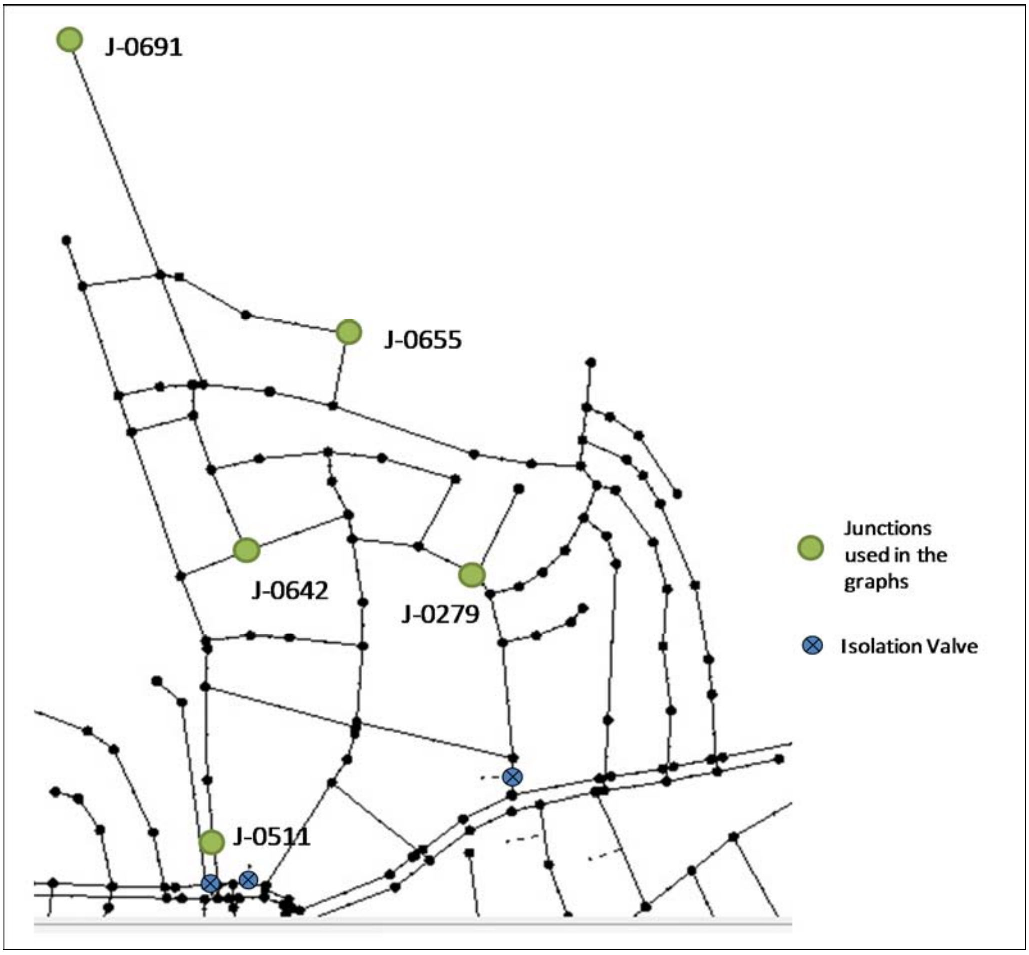


Figure 5.17: Single Pump Operation Chlorine Concentrations North Sancaktepe Uninsulated System

Examining the Figure 5.18, J-0511 which is at the entrance of the district has the highest concentration compared to other junctions in the area. J - 0279 has almost the equal concentration with J-0511. This is due to the isolation valve at the south of J – 0279. In this scenario the valve is open therefore there is a direct connection with the main transmission line. Therefore fresh water with a high concentration arrives in J-0279 almost as quickly as J-0511. The middle point junction J-0642 has lower concentrations compared to the entrance junctions.

J-0655 which is far away from the entrance has even 0.15 mg/l less concentration in comparison to the entrance junctions. J-0655 has almost equal concentrations with J-0691. J-0691 is the most distant junction in North Sancaktepe District and this junction is defined as the dead end junction as it does not transmit water to neighboring junctions. There are no transport and mixing events in the junction. The most important and driving parameter is the demand being withdrawn from the junction. If the demand is in increasing trend the concentration of the junction starts to increase and if the demand is decreasing trend the concentration starts to decrease.

The matching concentration values for J-0655 and J-0691 might be explained by the distance to the main entrance line. The distance is measured from the entrance point by summing pipe lengths. J-0655 is 740 m distant to the entrance point while J-0691 is 870 m distant. The distances are very close yet according to these distances it is expected that J-0691 will have higher concentrations. However, the concentrations provided in Figure 5.18 show that even J-0655 has lower concentrations compared to J-0691. This means the concentration difference cannot be explained by the distance.

The path that transmits water to J-0655 has loop and there are many junctions on the transport path. Concentration difference might be explained due to the several transport and decay reactions on the path to J-0655. This subject is discussed further in the discussion of results chapter. Note that distance to the source or distant junctions in the DMA's is not the only cause of the concentration changes, demand being withdrawn from the junction, flow velocity, calculated concentrations around the junction also have major effects on concentration changes. Distance to the source is expressed as a visual way of observing and understanding the concentration changes, the genuine parameter for explaining the concentration changes with respect to source is *"travel time"*.

According to drinking water regulations, maximum chlorine concentration should not exceed 0.50 mg/l and minimum chlorine concentration should not be below 0.10 mg/l. Junctions considered in North Sancaktepe District have chlorine concentrations which are in safe limits. This means chlorine concentration is enough for disinfection and does not exceed the maximum limits.

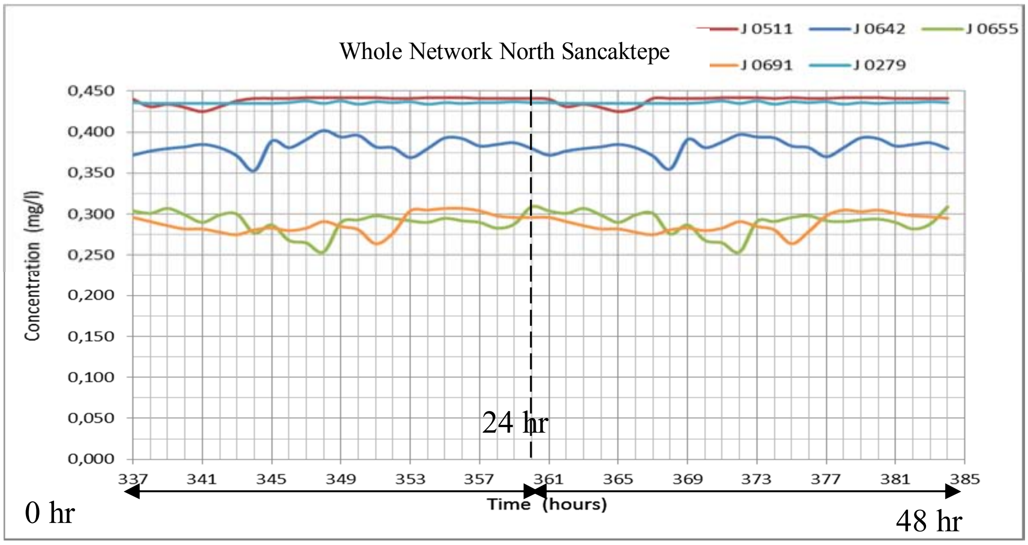


Figure 5.18: Single Pump Operation Chlorine Concentrations (North Sancaktepe Whole Network Case)

5.3.1.4. Şehit Kubilay District

Şehit Kubilay District (Figure 5.2 and 5.3) consisting of 156 junctions, mostly receives water from the main line passing from the north-east part of the area very close to J-0246. In addition to this line, it has boundaries with East Çiğdemtepe and South Sancaktepe. As a result of this the system will perform differently due to the interactions between these boundaries. This means the chlorine concentrations will vary for Insulated and Uninsulated Conditions. The model is set up for the chlorine parameters as mentioned above, and EPS study is performed for 384 hours.

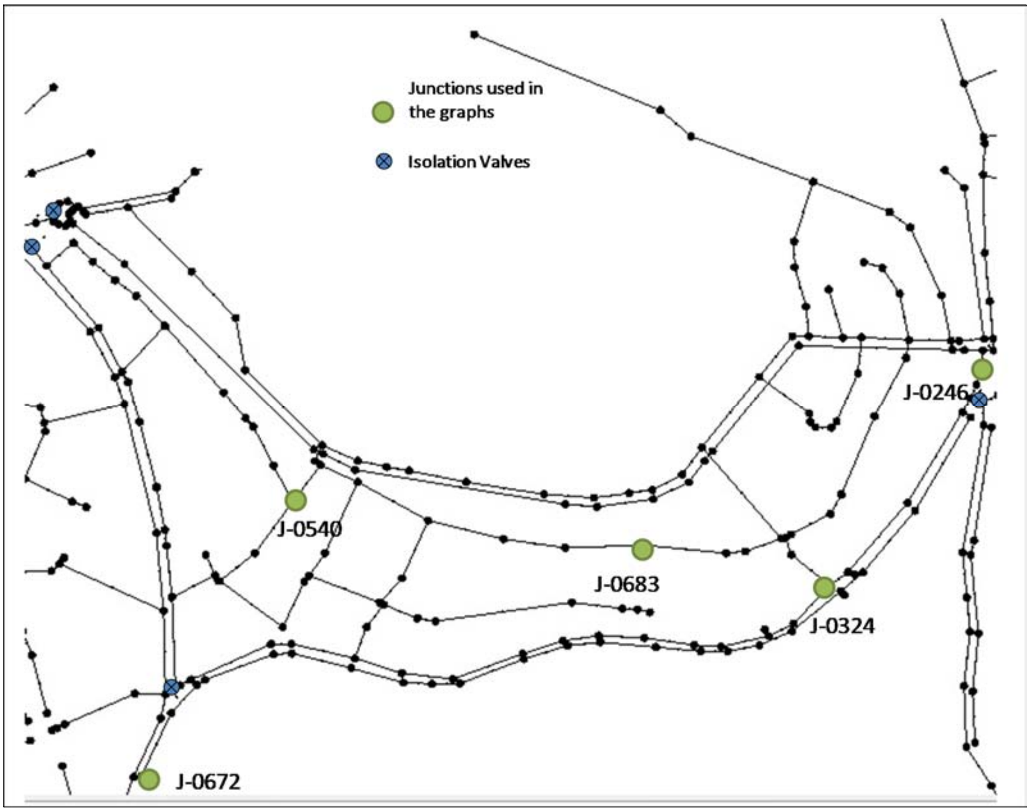


Figure 5.19: Junctions considered in Şehit Kubilay District

Examining the Figure 5.20, J-0246 which is at the entrance of the district has the highest concentration compared to other junctions in the area. J - 0324 has a lower concentration than J-0246 due to the small distance from the entrance. The middle point junction J-0683 has lower concentrations compared to the entrance junctions, this junction and the surrounding middle point junctions show the overall average concentrations of the Şehit Kubilay District. J-0540 which is far away from the entrance has even 0.10 mg/l less concentration in comparison to the entrance junctions. J-0672 is the most distant junction in Şehit Kubilay District and this junction is defined as the dead end junction as it does not transmit water to neighboring junctions. There are no transport and mixing events in the junction. The most important and driving parameter is the demand being withdrawn from the junction. If the demand is in increasing trend the concentration of the junction starts to increase and if the demand is decreasing trend the concentration starts to decrease. The overall concentration of J-0672 is the lowest concentration in the district as also shown in Figure 5.16. Note that distance to the source or distant junctions in the DMA's is not the only cause of the concentration changes, demand being withdrawn from the junction, flow velocity, calculated concentrations around the junction also have major effects on concentration changes. Distance to the source is expressed as a visual way of observing and understanding the concentration changes, the genuine parameter for explaining the concentration changes with respect to source is *"travel time"*.

According to drinking water regulations, maximum chlorine concentration should not exceed 0.50 mg/l and minimum chlorine concentration should not be below 0.10 mg/l. Junctions considered in Şehit Kubilay District have chlorine concentrations which are in safe limits. This means chlorine concentration is enough for disinfection and does not exceed the maximum limits.

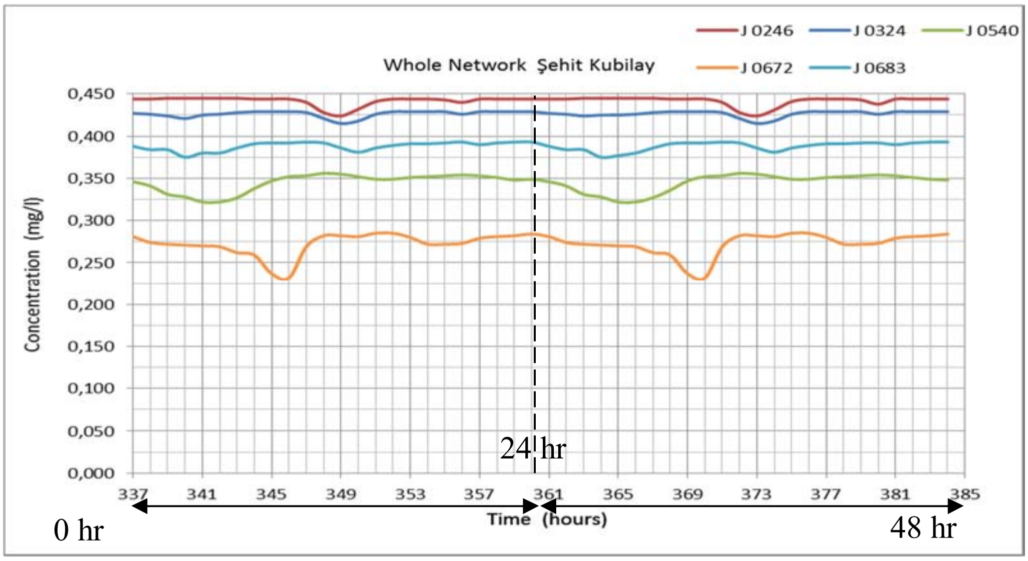


Figure 5.20: Single Pump Operation Chlorine Concentrations (Şehit Kubilay Whole Network Case)

5.3.1.5. East Çiğdemtepe District

East Çiğdemtepe District (Figure 5.2 and 5.3) consisting of 66 junctions, mostly receives water from the main line passing from the north-east part of the area. In addition to this line, it has boundaries with West Çiğdemtepe and Şehit Kubilay. As a result of this the system will perform differently due to the interactions between these boundaries. This means the chlorine concentrations will vary for these conditions.

The model is set up for the chlorine parameters as mentioned above, and EPS study is performed for 384 hours.

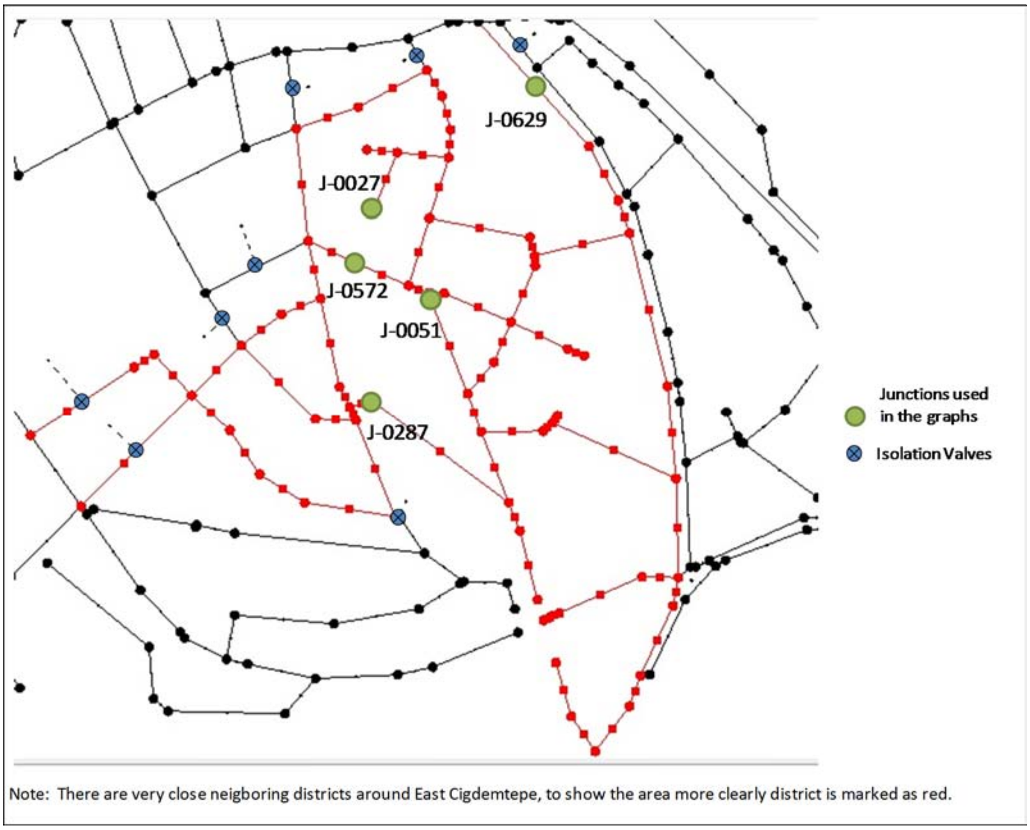


Figure 5.21: Junctions used for East Çiğdemtepe District, Concentrations for Different Scenarios

Examining the Figure 5.22a, J-0629 which is at the entrance of the district has the highest concentration compared to other junctions in the area. J-0051, J-0287 and J-0572 have almost equal concentrations and have lower concentrations compared to the entrance junctions. These junctions are also considered as middle point junctions and the concentrations calculated point out the overall average concentrations of the East Çiğdemtepe District.

J-0027 is the most distant junction in East Çiğdemtepe District and this junction is defined as the dead end junction as it does not transmit water to neighboring junctions. There are no transport and mixing events in the junction. The most important and driving parameter is the demand being withdrawn from the junction. If the demand is in increasing trend the concentration of the junction starts to increase and if the demand is decreasing trend the concentration starts to decrease. The overall concentration of J-0027 is the lowest concentration in the district as also shown in Figure 5.22a. Note that distance to the source or distant junctions in the DMA's is not the only cause of the concentration changes, demand being withdrawn from the junction, flow velocity, calculated concentrations around the junction also have major effects on concentration changes. Distance to the source is expressed as a visual way of observing and understanding the concentration changes, the genuine parameter for explaining the concentration changes with respect to source is *"travel time"*.

J-0027 is a dead and junction and its concentration graph is very different among others. Daily demand has a certain role in this graph yet also this fluctuation of J 0027 forms very slowly on the flow path of it. The fresh water that comes into J 0027 passes from J 0347, J 0373 and J 0026. Concentration graphs of these junctions are provided in Figure 5.22 b. In the figure it is seen that the different concentration formation of J 0027 forms before the arrival of water to this junction.

According to drinking water regulations, maximum chlorine concentration should not exceed 0.50 mg/l and minimum chlorine concentration should not be below 0.10 mg/l. Junctions considered in East Çiğdemtepe District have chlorine concentrations which are in safe limits. This means chlorine concentration is enough for disinfection and does not exceed the maximum limits.

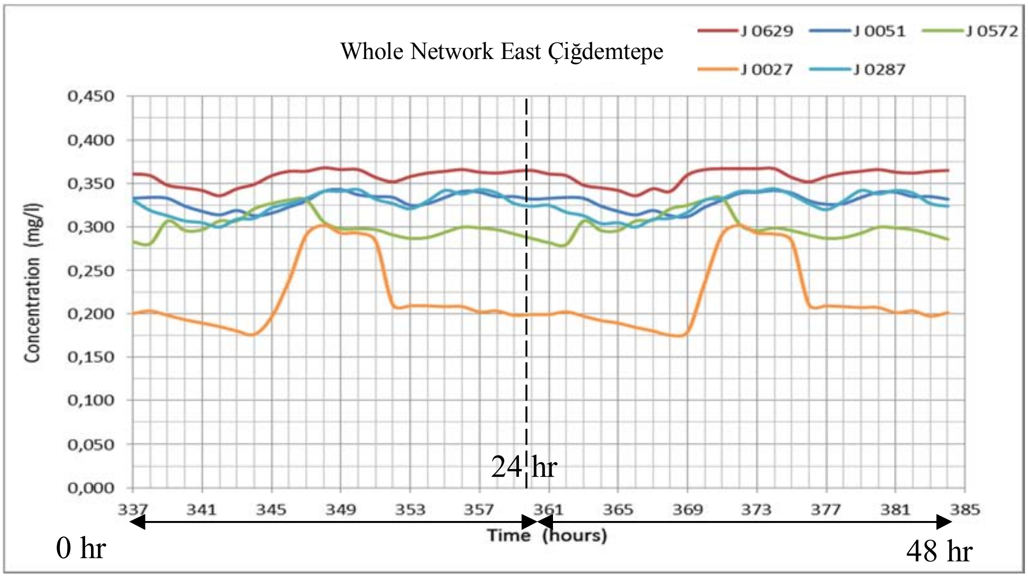


Figure 5.22a: Single Pump Operation Chlorine Concentrations (East Çiğdemtepe Whole Network Case)

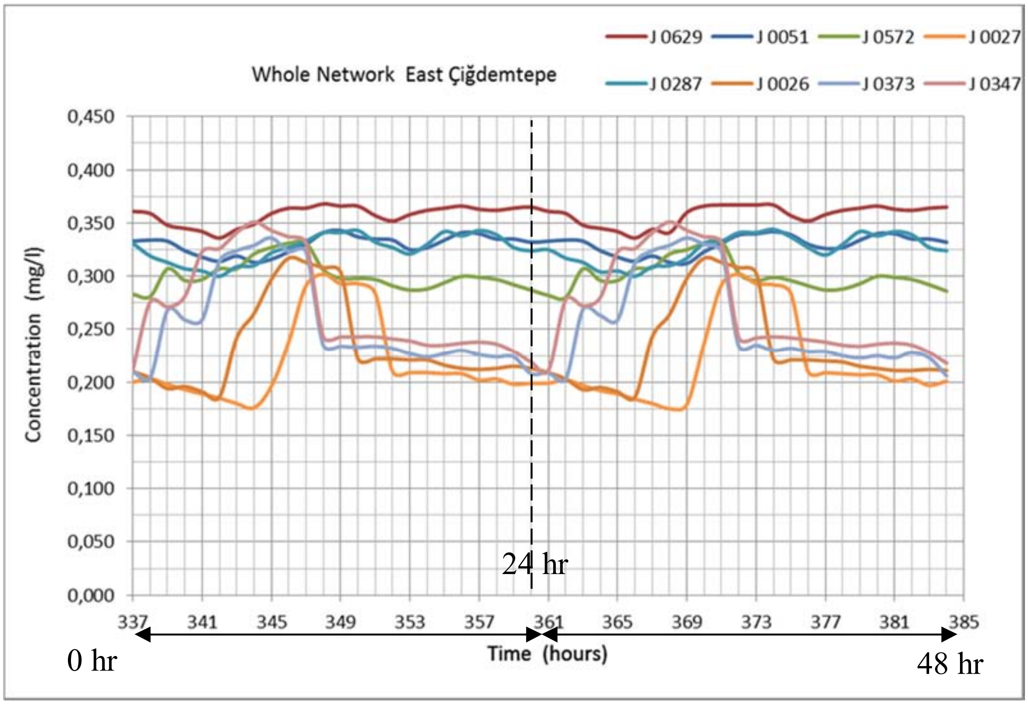


Figure 5.22b: Single Pump Operation Chlorine Concentrations (East Çiğdemtepe Whole Network Case) Junctions at the flow path of J-0027

5.3.1.6. West Çiğdemtepe District

West Çiğdemtepe District (Figure 5.2 and 5.3) consisting of 111 junctions, mostly receives water from the main line passing from the north-east part of the area. In addition to this line, it has a long boundary with East Çiğdemtepe.

As a result of this the system will perform differently due to the interactions between these boundaries. This means the chlorine concentrations will vary for these conditions. The model is set up for the chlorine parameters as mentioned above, and EPS study is performed for 384 hours.

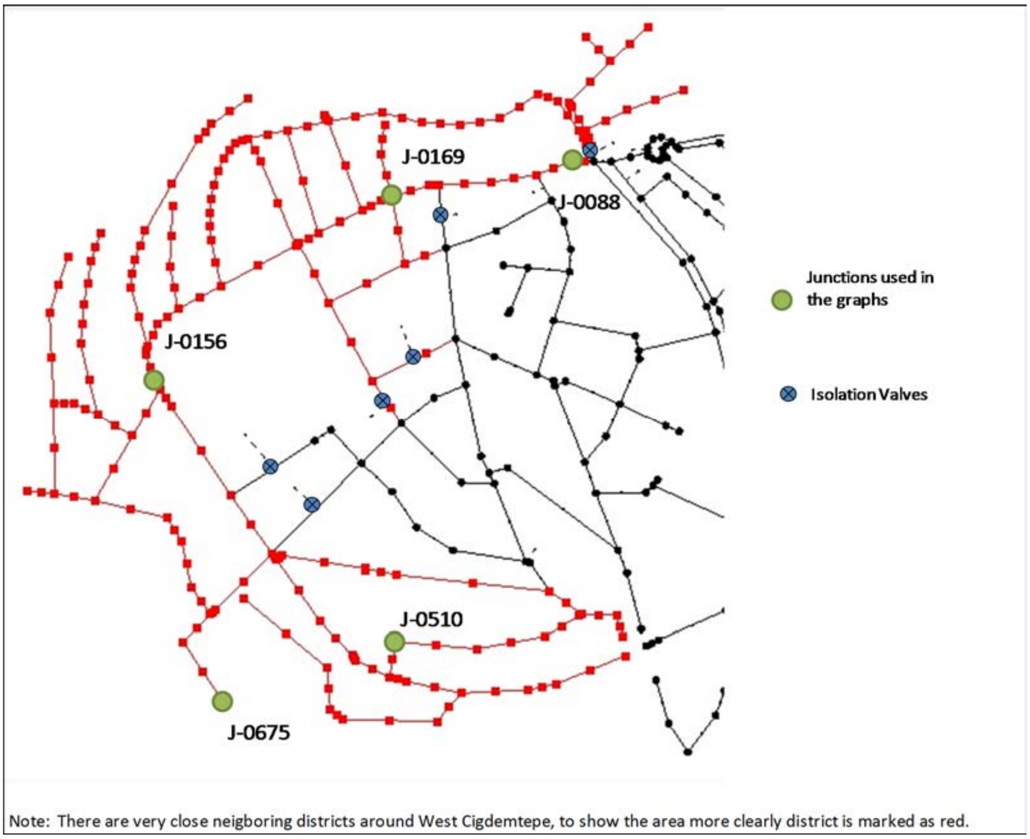


Figure 5.23: Junctions considered in West Çiğdemtepe District

Examining the Figure 5.24, J-0088 which is at the entrance of the district has the highest concentration compared to other junctions in the area. J - 0169 has a slightly lower concentration than J-0088. By reason of the short distance there is a very low concentration change.

J-0156 which is far away from the entrance has even 0.05 mg/l less concentration in comparison to the entrance junctions. There is an isolation valve very close to J-0156 therefore due to the interaction with neighboring zone East Çiğdemtepe the concentration does not decrease as much as other junctions.

J-0510 has almost equal concentrations with J-0675. J-0675 is the most distant junction in West Çiğdemtepe District and this junction is defined as the dead end junction as it does not transmit water to neighboring junctions. There are no transport and mixing events in the junction. The most important and driving parameter is the demand being withdrawn from the junction. If the demand is in increasing trend the concentration of the junction starts to increase and if the demand is decreasing trend the concentration starts to decrease as in other districts. Note that distance to the source or distant junctions in the DMA's is not the only cause of the concentration changes, demand being withdrawn from the junction, flow velocity, calculated concentrations around the junction also have major effects on concentration changes. Distance to the source is expressed as a visual way of observing and understanding the concentration changes, the genuine parameter for explaining the concentration changes with respect to source is *"travel time"*.

The matching concentration values for J-0510 and J-0675 might be explained by the isolation valve status. In this scenario the isolation valves are open therefore fresh water arrives in J-0675 more quickly. As a result of J-0675 being close to the isolation valve, its concentration does not decrease as in other dead end junctions.

According to drinking water regulations, maximum chlorine concentration should not exceed 0.50 mg/l and minimum chlorine concentration should not be below 0.10 mg/l. Junctions considered in West Çiğdemtepe District have chlorine concentrations which are in safe limits. This means chlorine concentration is enough for disinfection and does not exceed the maximum limits.

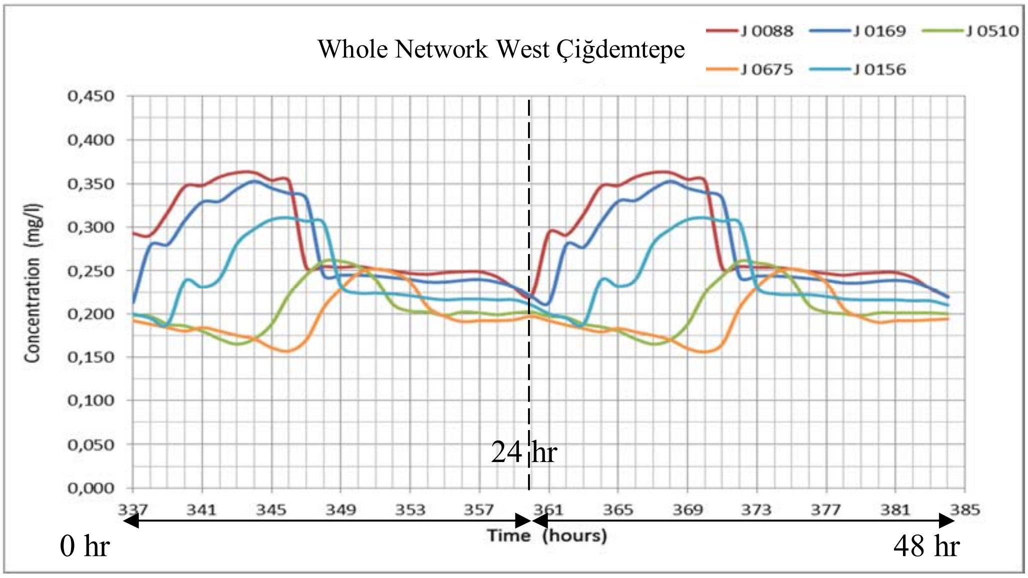


Figure 5.24: Single Pump Operation Chlorine Concentrations (West Çiğdemtepe Whole Network Case)

5.3.2 Insulated System (DMA Case)

Insulated system as previously mentioned means that all isolation valves are closed and the districts receive water from a single entrance.

5.3.2.1 Yayla District

Yayla District (Figure 5.2 and 5.3) has no boundaries with other districts which makes it completely insulated. The model is set up for the chlorine parameters as mentioned above, and EPS study is performed for 384 hours while all isolation valves in the system are closed. Several junctions are examined and certain ones which represent the general concentrations of Yayla District are chosen. These junctions are J-0188, J-0211, J-0343, J-0348 and J-0291 which are the same ones previously considered in Uninsulated case (Figure 5.13). Therefore the junction locations graph is not shown in this part.

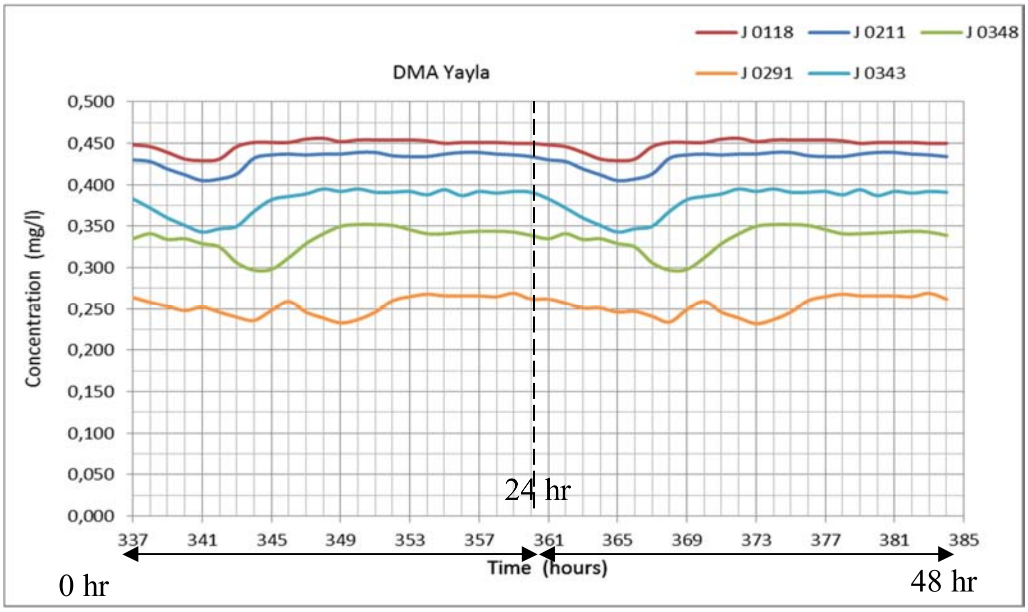


Figure 5.25: Single Pump Operation Chlorine Concentrations (Yayla DMA Case)

The concentrations for Yayla District are provided in Figure 5.14 between 337-384 time intervals. This time interval refers to the last 48 hours of the system. According to these concentrations between 00:00 – 06:00 time intervals when the demands are very low, the concentrations start to decrease until 06:00 – 12:00 time intervals after this period between 12:00 – 24:00 time intervals concentrations follow almost a straight line due to the usage of water.

Examining the Figure 5.25, J-0118 which is at the entrance of the district has the highest concentration compared to other junctions in the area. J - 0211 has a lower concentration than J-0118 due to the small distance from the entrance. The middle point junction J-0343 has lower concentrations compared to the entrance junctions, this junction and the surrounding middle point junctions show the overall average concentrations of the Yayla District. J-0348 which is far away from the entrance has even 0.10 mg/l less concentration in comparison to the entrance junctions. J-0291 is the most distant junction in Yayla District and this junction is defined as the dead end junction as it does not transmit water to neighboring junctions. There are no transport and mixing events in the junction. The most important and driving parameter is the demand being withdrawn from the junction. If the demand is in increasing trend the concentration of the junction starts to increase and if the demand is decreasing trend the concentration starts to decrease. The overall concentration of J-0291 is the lowest concentration in the district as also shown in Figure 5.25.

According to drinking water regulations, maximum chlorine concentration should not exceed 0.50 mg/l and minimum chlorine concentration should not be below 0.10 mg/l. Also for the insulated case, junctions considered in Yayla District have chlorine concentrations which are in safe limits. This means chlorine concentration is enough for disinfection and does not exceed the maximum limits.

5.3.2.2 South Sancaktepe District

South Sancaktepe (Figure 5.2 and 5.3) District consists of 115 junctions, including dead end junctions. This area, mostly receives water from the transmission line passing from the north part of the area as mentioned previously. During Insulated conditions this district receives water only from the main transmission line while the isolation valves are closed. This means the chlorine concentrations will vary under these conditions. The model is set up and run for 384 hours. Several junctions are examined and certain ones which represent the general concentrations of South Sancaktepe District are chosen. These junctions are J-0290, J-0600, J-0199, J-0205 and J-0221 which are the same ones previously considered in Uninsulated case (Figure 5.15). Therefore the junction locations graph is not shown in this part.

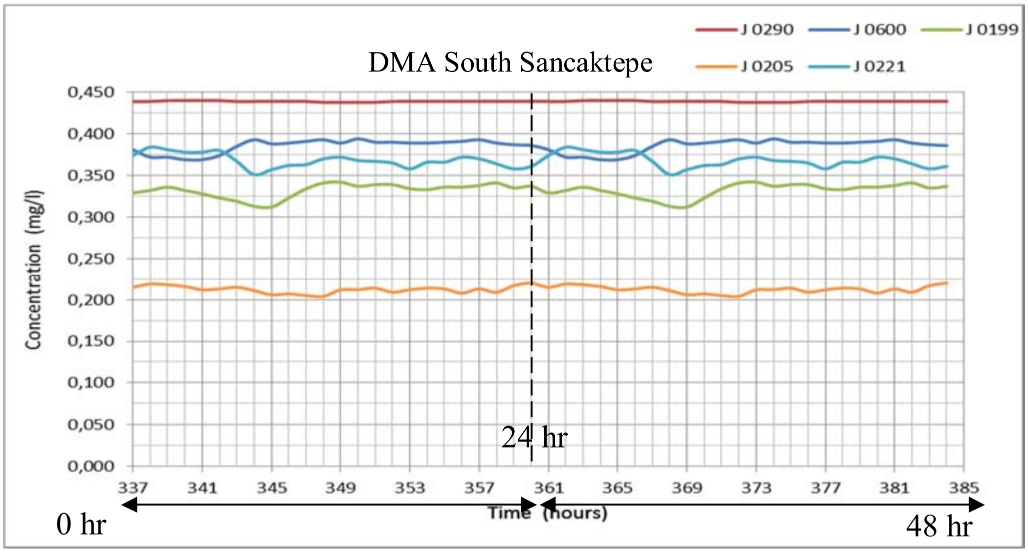


Figure 5.26: Single Pump Operation Chlorine Concentrations (South Sancaktepe DMA Case)

Examining the Figure 5.26, J-0290 which is at the entrance of the district has the highest concentration compared to other junctions in the area. J - 0221 has a lower concentration compared to the Uninsulated System. This is due to the isolation valves at the entrance of South Sancaktepe. The main line that transmits water was entering the system from several points for Uninsulated Case. While in DMA Case isolation valves are closed as a result the fresh water arrives in J- 0221 with lower and time delayed concentration. The middle point junction J-0600 has lower concentrations compared to the entrance junctions, this junction and the surrounding middle point junctions show the overall average concentrations of the South Sancaktepe District. J-0199 which is far away from the entrance has even 0.15 mg/l less concentration in comparison to the entrance junctions. J-0205 is the most distant junction in South Sancaktepe District and this junction is defined as the dead end junction as it does not transmit water to neighboring junctions. There are no transport and mixing events in the junction. The most important and driving parameter is the demand being withdrawn from the junction. If the demand is in increasing trend the concentration of the junction starts to increase and if the demand is decreasing trend the concentration starts to decrease. The overall concentration of J-0205 is the lowest concentration in the district as also shown in Figure 5.26.

Compared to uninsulated case, in this case all junctions except J 0211 have the same fluctuations of chlorine concentrations. J 0211 has a more less concentration in uninsulated case. This is probably due to the increased mixing of water from the main line coming from the open isolation valves.

According to drinking water regulations, maximum chlorine concentration should not exceed 0.50 mg/l and minimum chlorine concentration should not be below 0.10 mg/l. Also for the insulated case, junctions considered in South Sancaktepe District have chlorine concentrations which are in safe limits This means chlorine concentration is enough for disinfection and does not exceed the maximum limits.

5.3.2.3 North Sancaktepe District

North Sancaktepe District (Figure 5.2 and 5.3) consisting of 92 junctions, mostly receives water from the main line passing from the south part of the area. In addition to this pipe line, it has a boundary with South Sancaktepe. In this scenario the isolation valves are closed therefore the district only receives water from the main line. The model is set up for the chlorine parameters as mentioned above, and EPS study is performed for 384 hours.

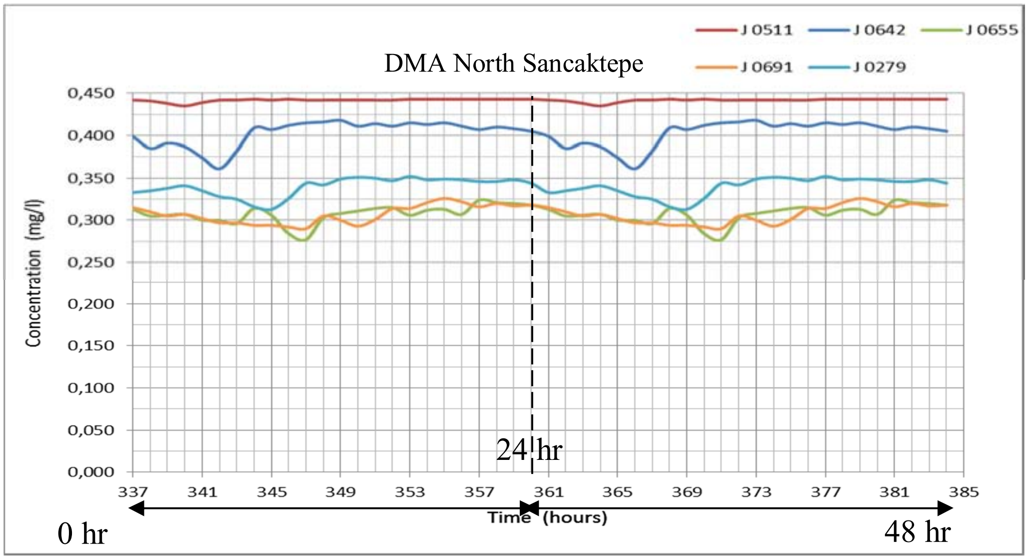


Figure 5.27: Single Pump Operation Chlorine Concentrations (North Sancaktepe DMA Case)

Examining the Figure 5.27, J-0511 which is at the entrance of the district has the highest concentration compared to other junctions in the area. During Uninsulated case J - 0279 which had the almost the equal concentration with J-0511 now has a very low concentration compared to J-0511. This is again due to the isolation valve at the south of J – 0279. In this scenario the valve is closed therefore the direct connection with the main transmission line is not existent, therefore J – 0279 cannot receive the fresh water as in this case. In this scenario the middle point junctions of North Sancaktepe J-0642 and J - 0279 has lower concentrations compared to the entrance junction.

J-0655 which is far away from the entrance has even 0.15 mg/l less concentration in comparison to the entrance junctions. As in the Uninsulated Case, also in this scenario J-0655 has almost equal concentrations with J-0691.

These values are explained by the same comments made for the Uninsulated case. The path that transmits water to J-0655 has loop and there are many junctions on the transport path. Concentration difference might be explained by the several transport and mixing reactions on the path to J-0655. This subject is discussed further in the discussion of results chapter, travel times will be presented and additional comments on this issue will be provided.

According to drinking water regulations, maximum chlorine concentration should not exceed 0.50 mg/l and minimum chlorine concentration should not be below 0.10 mg/l. Also for the insulated case, junctions considered in North Sancaktepe District have chlorine concentrations which are in safe limits This means chlorine concentration is enough for disinfection and does not exceed the maximum limits.

5.3.2.4 Şehit Kubilay District

Şehit Kubilay District (Figure 5.2 and 5.3) consisting of 156 junctions, mostly receives water from the main line passing from the north – east part of the area. In addition to this line, it has boundaries with East Çiğdemtepe and South Sancaktepe. In this scenario Şehit Kubilay District only receives water from the main line.

The model is set up for the chlorine parameters as mentioned above, and EPS study is performed for 384 hours.

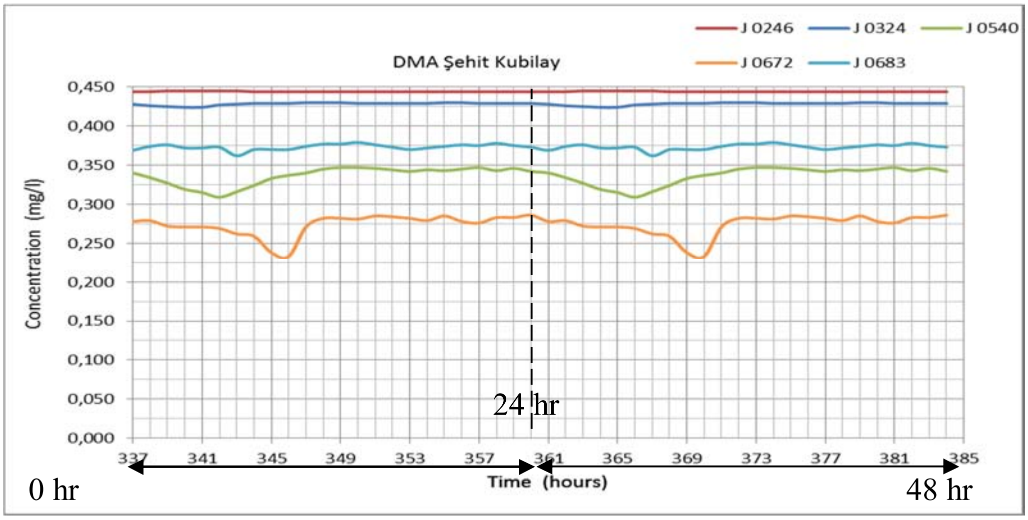


Figure 5.28: Single Pump Operation Chlorine Concentrations (Şehit Kubilay DMA Case)

Examining the Figure 5.28, J-0246 which is at the entrance of the district has the highest concentration compared to the other junctions in the area. Respectively as in the Uninsulated Case J – 0324, J-0246, J-0683 has lower concentrations compared to the entrance junction. The concentration values almost match under Uninsulated or Insulated case for Şehit Kubilay District. This means isolation valves being closed does not have any effect on the chlorine concentrations of Şehit Kubilay District.

Compared to uninsulated case chlorine concentrations behave nearly the same there are very small differences in concentrations yet the concentrations fluctuations follow almost the same pattern. There is not a certain difference between uninsulated and insulated case this is because there are no isolation valves in connection with the main line.

According to drinking water regulations, maximum chlorine concentration should not exceed 0.50 mg/l and minimum chlorine concentration should not be below 0.10 mg/l. Also for the insulated case, junctions considered in Şehit Kubilay District have chlorine concentrations which are in safe limits This means chlorine concentration is enough for disinfection and does not exceed the maximum limits.

5.3.2.5 East Çiğdemtepe District

East Çiğdemtepe District (Figure 5.2 and 5.3) consisting of 66 junctions, mostly receives water from the main line passing from the north-east part of the area. In addition to this line, it has boundaries with West Çiğdemtepe and Şehit Kubilay. In this scenario the district only receives water from the main line.

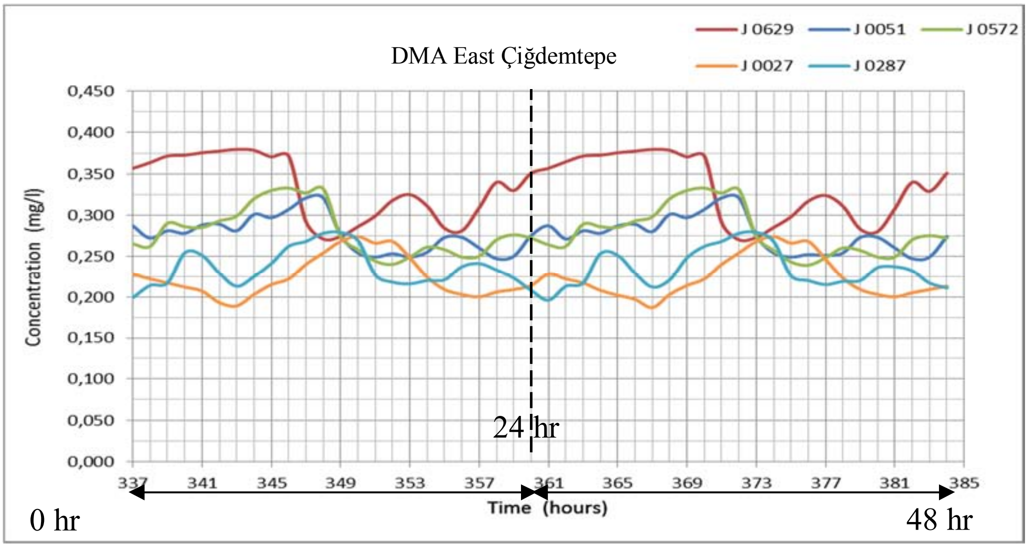


Figure 5.29: Single Pump Operation Chlorine Concentrations (East Çiğdemtepe DMA Case)

Examining the Figure 5.29, J-0629 which is at the entrance of the district has the highest concentration compared to other junctions in the area. J-0051, J-0287 and J-0572 have almost equal concentrations and have lower concentrations compared to the entrance junctions. These junctions are also considered as middle point junctions and the concentrations calculated point out the overall average concentrations of the East Çiğdemtepe District.

Also for this case, J-0027 which is the dead end junction does not transmit water to neighboring junctions. There are no transport and mixing events in the junction. The most important and driving parameter is the demand being withdrawn from the junction. If the demand is in increasing trend the concentration of the junction starts to increase and if the demand is decreasing trend the concentration starts to decrease. The overall concentration of J-0027 is the lowest concentration in the district as also shown in Figure 5.29.

According to drinking water regulations, maximum chlorine concentration should not exceed 0.50 mg/l and minimum chlorine concentration should not be below 0.10 mg/l. Also for the insulated case, junctions considered in East Çiğdemtepe District have chlorine concentrations which are in safe limits This means chlorine concentration is enough for disinfection and does not exceed the maximum limits.

5.3.2.6 West Çiğdemtepe District

West Çiğdemtepe District consisting of 111 junctions, mostly receives water from the main line passing from the north-east part of the area.

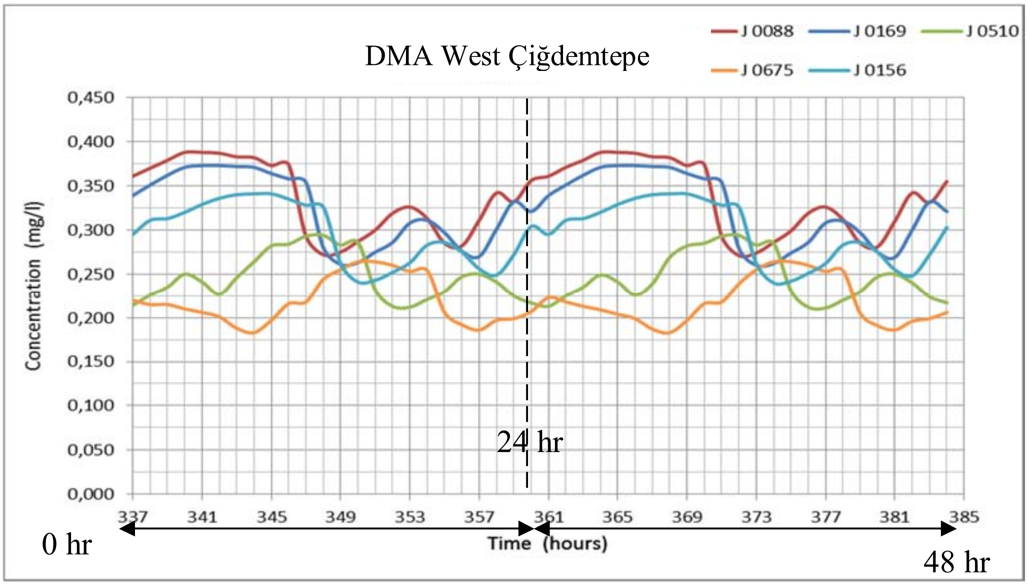


Figure 5.30: Single Pump Operation Chlorine Concentrations (West Çiğdemtepe DMA Case)

Examining the Figure 5.30, J-0088 which is at the entrance of the district has the highest concentration compared to other junctions in the area. The overall graph is as same as the Uninsulated Scenario.

According to drinking water regulations, maximum chlorine concentration should not exceed 0.50 mg/l and minimum chlorine concentration should not be below 0.10 mg/l. Also for the insulated case, junctions considered in West Çiğdemtepe District have chlorine concentrations which are in safe limits This means chlorine concentration is enough for disinfection and does not exceed the maximum limits.

5.4 Multi Pump Operation (Optimum Pump Schedule)

In this scenario all of the three pumps 1 SUMAS(SM), 2 SUMAS(SM) and 3 SMS(LM) are operating based on an optimum pump schedule as shown in Figure 5.31 and 5.32a. Optimum pump schedule is the most economical way of operating pumps for a specific distribution system, optimum schedule minimizes the energy costs of the system. Optimum pump schedule data is taken from (Şendil, 2013) in this study genetic algorithms are used to determine which pump(s) to use for certain time intervals, start, shutoff time and working period of pumps. The constraint was satisfying the hydraulic conditions while spending less energy at pumps targeting minimum energy costs. This study came up with a pump schedule, which is presented in the figure below. Initial tank level at the start of the EPS study is 2.50 m, tank level fluctuates according to the daily demand and pump operation. In this scenario chlorine concentrations are observed while the pumps start, shutoff at certain times, these operating characteristics have major effects to chlorine concentrations as discussed further on the next pages.

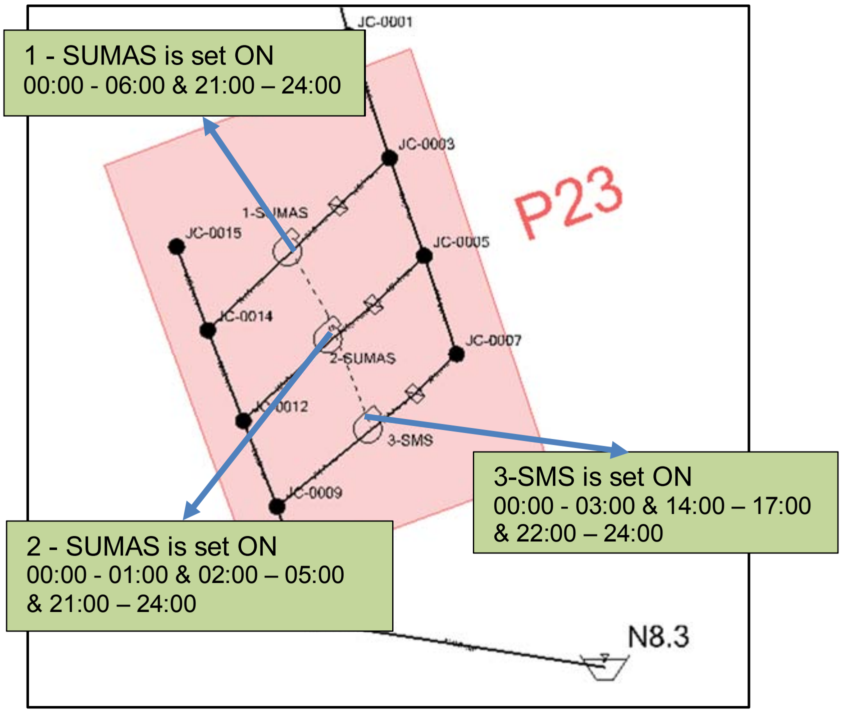


Figure 5.31: Multi Pump Operation Scenario Pump Configuration (On / Off Status)

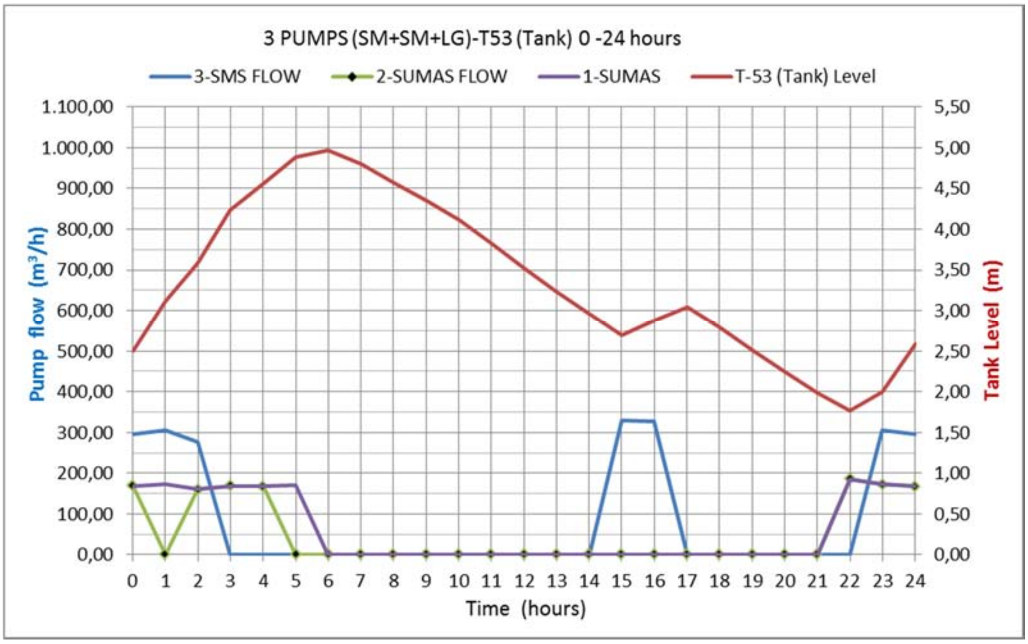


Figure 5.32 a: Flow versus Time Graph of 3 Pumps and T-53 Level versus time graphs for 24 hours (0-24 hr)

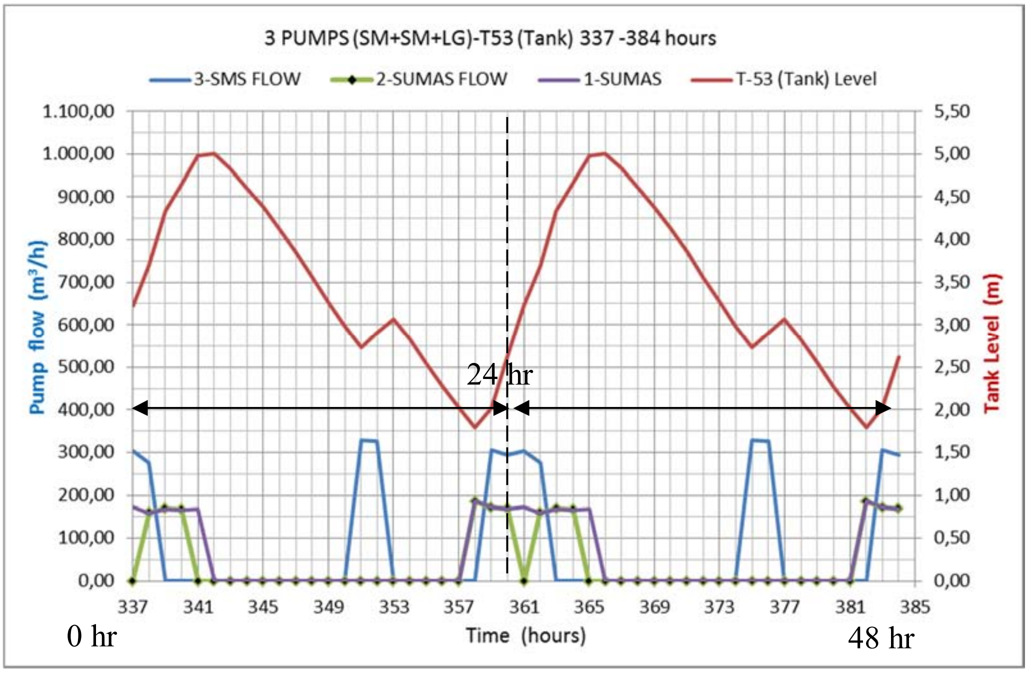


Figure 5.32 b: Flow versus Time Graph of 3 Pumps and T-53 Level versus time graph between 337-384 Hours

The flow being supplied to the network for the first 24 hours is provided in Figure 5.32a as the pump schedule of the three pumps. In addition to pump flow, tank levels for the first 24 hours are plotted in Figure 5.32a. The pumps operate based on the optimum pump schedule. Initial tank level at the start of the EPS study is 2.50 m, tank level fluctuates according to the daily demand and pump operation. Starting at 2.50 m the system reaches to a balance after 2 weeks (336 hours). This balanced system which is also defined as stable period is established in the last 337-384 hours. The flow being supplied to the network for the last 48 hours (337-384 hr.) is provided in Figure 5.32b; in addition to pump flow, tank levels for the last 48 hours are plotted in Figure 5.32b.

5.4.1 Uninsulated System (Whole Network Case)

Uninsulated system of N8.3 Network means all the isolation valves of the network are set open and flow passes directly through the neighboring zones. The isolation valves shown in Figure 5.3 are open in this Multi Pump Operation Scenario.

5.4.1.1 Yayla District

Yayla District has no boundaries with other districts which makes it completely insulated. The model is set up for the chlorine and pump parameters and EPS study is performed for 384 hours while all isolation valves in the system are open. Several junctions are examined and certain ones which represent the general concentrations of Yayla District are chosen. These junctions are J-0188, J-0211, J-0343, J-0348 and J-0291 which are the same ones previously considered in Single Pump Operation Uninsulated/Insulated case (Figure 5.13). Therefore, the junction locations are not shown again in this part.

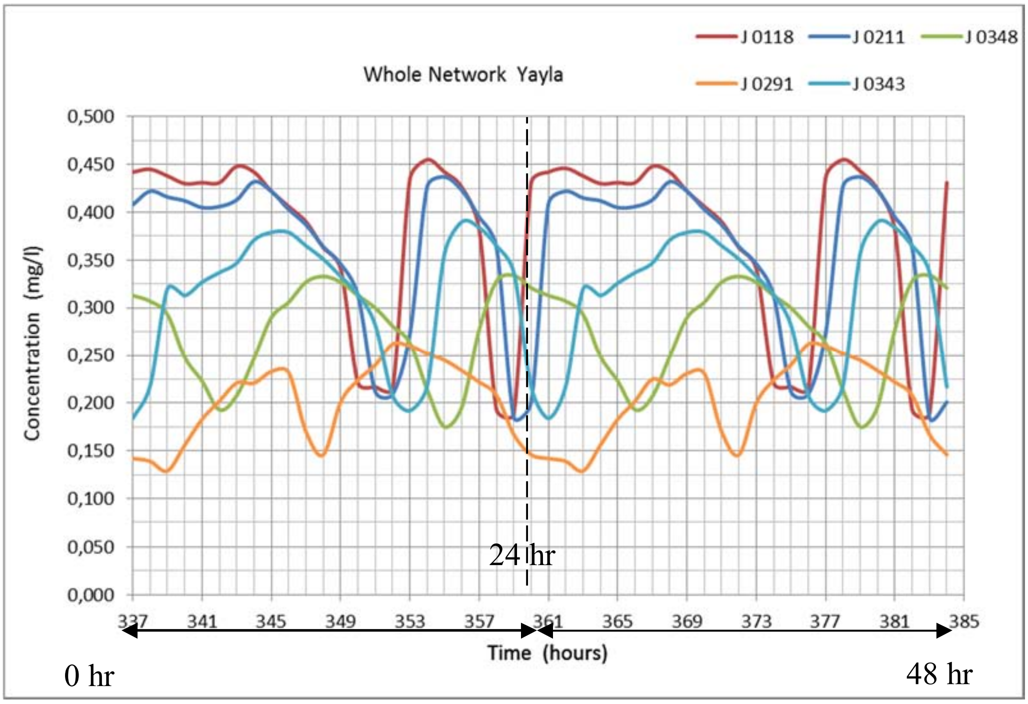


Figure 5.33: Multi Pump Operation Chlorine Concentrations (Yayla Whole Network Case)

The concentrations for Yayla District are provided in Figure 5.33 between 337-384 time intervals. This time interval refers to the last 48 hours of the system. The demands in the system are very low between 00:00 – 06:00 time intervals, yet the concentrations are in increasing trend. The increasing concentrations are caused by the pump schedule. When the pumps start to operate during the low electricity price tariff (22:00 – 06:00) the concentrations tend to increase, when the pumps shutoff during high electricity prices the concentrations start to decrease.

Examining the Figure 5.33, J-0118 which is at the entrance of the district has the highest concentration compared to other junctions in the area. J - 0211 has a lower concentration than J-0118 due to the small distance from the entrance. The middle point junction J-0343 has lower concentrations compared to the entrance junctions, this junction and the surrounding middle point junctions show the overall average concentrations of the Yayla District. J-0348 which is far away from the entrance has even 0.10 mg/l less concentration in comparison to the entrance junctions. J-0291 is the most distant junction in Yayla District and this junction is defined as the dead end junction as it does not transmit water to neighboring junctions. There are no transport and mixing events in the junction. The overall concentration of J-0291 is the lowest concentration in the district as also shown in Figure 5.33. Note that distance to the source or distant junctions in the DMA's is not the only cause of the concentration changes, demand being withdrawn from the junction, flow velocity, calculated concentrations around the junction also have major effects on concentration changes. Distance to the source is expressed as a visual way of observing and understanding the concentration changes, the genuine parameter for explaining the concentration changes with respect to source is *"travel time"*.

Examining the concentrations of the entrance point (J-0118) at Yayla District it is very clear that the concentration fluctuation is a direct reason of the pump operation. The pumps are in operation during night (22:00-06:00 hr) this operation makes the concentrations high and stable during the night period between 337 - 344 hour time intervals. The pumps shutoff at t=342 hr yet, the concentrations are still high for 2 more hours. This is due to the 2 hours shift between the pump station and Yayla District. This shift occurs as a result of the time required for the water to reach the district, the large diameter of the pipes and low velocities on the path create this shift. The pumps shutoff during 06:00–14:00 time intervals forcing the concentrations to drop at high rates. During this time interval Yayla District receives water from the tank. The concentrations drop until the pump 3-SMS (LG) starts operation again between 14:00 – 17:00 time intervals. This operation refers to 350- 353 time intervals, the effects of the pump on concentrations are seen at t=352, at this point the concentrations suddenly increase until t=354 after this point the concentrations drop again due to the shutoff of the pump. Arriving t= 357 hr.

pump operation starts again the effects on concentrations are observed at t=359 hr. and concentrations start to increase at a high rate. The shifting occurring at the entrance junction is transferred to the middle junctions as the time passes for the water to reach from the entrance to distant points. This cycle continues for all the calculation period and is valid for all the junctions except dead end ones.

Dead end junctions such as J-0291 are not affected from the pump schedule precisely but these junctions are definitely affected by the daily demand. When the daily demand is in increasing trend the concentration starts to increase as a result of the fresh water coming into the junction.

According to drinking water regulations, maximum chlorine concentration should not exceed 0.50 mg/l and minimum chlorine concentration should not be below 0.10 mg/l. Junctions considered in Yayla District have chlorine concentrations which are in safe limits This means chlorine concentration is enough for disinfection and does not exceed the maximum limits.

5.4.1.2 South Sancaktepe District

South Sancaktepe District consists of 115 junctions, including dead end junctions. This area, mostly receives water from the transmission line passing from the north part of the area as mentioned previously. The model is set up and run for 384 hours. Several junctions are examined and certain ones which represent the general concentrations of South Sancaktepe District are chosen. These junctions are J-0290, J-0600, J-0199, J-0205 and J-0221 which are the same ones previously considered in Uninsulated case (Figure 5.15). Therefore the junction locations graph is not shown again in this part.

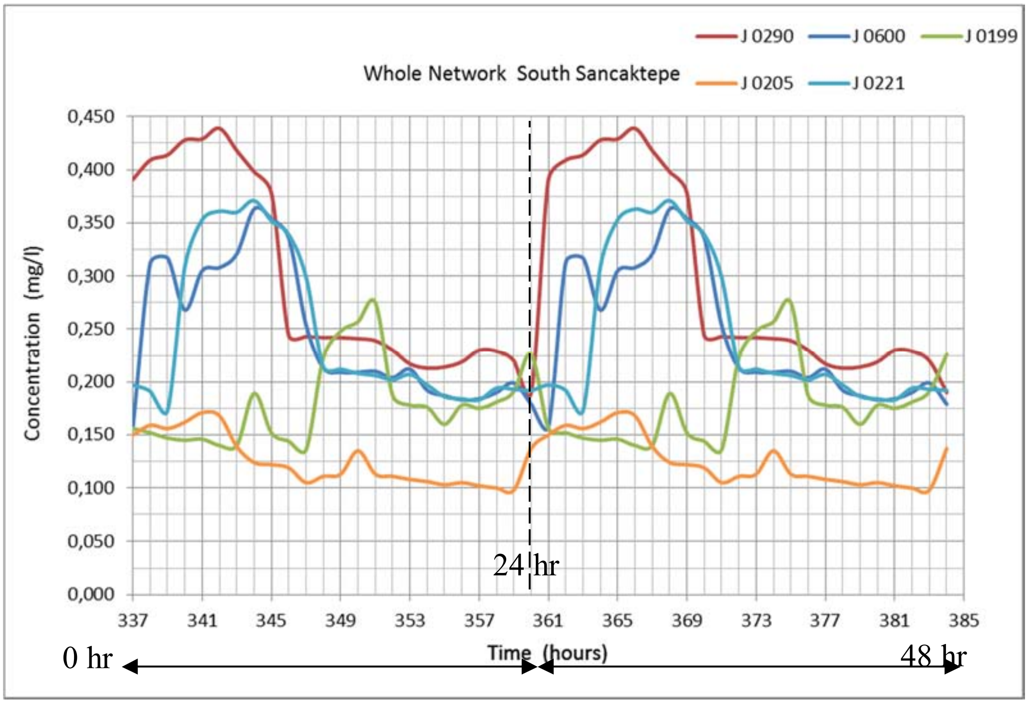


Figure 5.34: Multi Pump Operation Chlorine Concentrations (South Sancaktepe Whole Network Case)

Examining the Figure 5.34, J-0290 which is at the entrance of the district has the highest concentration compared to other junctions in the area. J - 0221 has a lower concentration than J-0290 due to the small distance from the entrance. The middle point junction J-0600 has lower concentrations compared to the entrance junctions, this junction and the surrounding middle point junctions show the overall average concentrations of the South Sancaktepe District. J-0199 which is far away from the entrance has even 0.15 mg/l less concentration in comparison to the entrance junctions. J-0205 is the most distant junction in South Sancaktepe District and this junction is defined as the dead end junction as it does not transmit water to neighboring junctions. There are no transport and mixing events in the junction. The most important and driving parameter is the pump schedule. When the pumps are in operation, the concentrations observed at the junctions starts to increase and when the pumps are shut off the concentrations start to decrease. The overall concentration of J-0205 is the lowest concentration in the district as also shown in Figure 5.34. Note that distance to the source or distant junctions in the DMA's is not the only cause of the concentration changes, demand being withdrawn from the junction, flow velocity, calculated concentrations around the junction also have major effects on concentration changes. Distance to the source is expressed as a visual way of observing and understanding the concentration changes, the genuine parameter for explaining the concentration changes with respect to source is *"travel time"*.

Examining the concentrations of the entrance point (J-0290) at South Sancaktepe District it is very clear that the concentration fluctuation is a direct reason of the pump operation. The pumps are in operation during night (22:00-06:00 hr) the observed concentrations are high during the night period between 337 - 342 hour time intervals. The pumps shutoff at t=342 hr and the concentrations start to drop at this time on a small scale yet the main concentration drop occurs at t=345 hr. This is due to the 3 hours shift between the pump station and South Sancaktepe District. This shift occurs as a result of the time required for the water to reach the district, the large diameter of the pipes and low velocities on the path create this shift.

The pumps shutoff during 06:00–14:00 time intervals forcing the concentrations to drop at high rates. 3-SMS (LG) starts operation again between 14:00 – 17:00 time intervals referring to 350 – 353 time intervals yet the concentrations are still following a smooth line. This is due to the tank's influence on the junction when the pump is off, the junction receives water from the tank until t=352 the effects of the pump on concentration cannot be observed because at t=353 pump stops. One hour of pumping between t=352 to t=353 hours cannot be observed due to the mixing of the fresh concentrations from the pump conflict in the mainline and drop down before the arrival of South Sancaktepe entrance. Arriving t= 357 hr. pump operation starts again the effects on concentrations are observed at t=359 hr. and concentrations start to increase at a high rate. The shifting occurring at the entrance junction is transferred to the middle junctions as the time passes for the water to reach from the entrance to distant points. This cycle continues for all the calculation period and is valid for all the junctions except dead end ones.

Dead end junctions such as J-0205 are not affected from the pump schedule precisely but these junctions are definitely affected by the daily demand. When the daily demand is in increasing trend the concentration starts to increase as a result of the fresh water coming into the junction.

According to drinking water regulations, maximum chlorine concentration should not exceed 0.50 mg/l and minimum chlorine concentration should not be below 0.10 mg/l. Junctions considered in South Sancaktepe District have chlorine concentrations which are in safe limits. This means chlorine concentration is enough for disinfection and does not exceed the maximum limits.

5.4.1.3 North Sancaktepe District

North Sancaktepe District consisting of 92 junctions, mostly receives water from the main line passing from the south part of the area. In addition to this pipe line, it has a boundary with South Sancaktepe. In this scenario the isolation valves are open. The model is set up for the chlorine and pump schedule. EPS study is performed for 384 hours.

Examining the Figure 5.35, J-0511 which is at the entrance of the district has the highest concentration compared to other junctions in the area. J - 0279 has almost the equal concentration with J-0511. This is due to the isolation valve at the south of J – 0279. In this scenario the valve is open therefore there is a direct connection with the main transmission line. Therefore fresh water with a high concentration arrives in J-0279 almost as quickly as J-0511. The middle point junction J-0642 has lower concentrations compared to the entrance junctions.

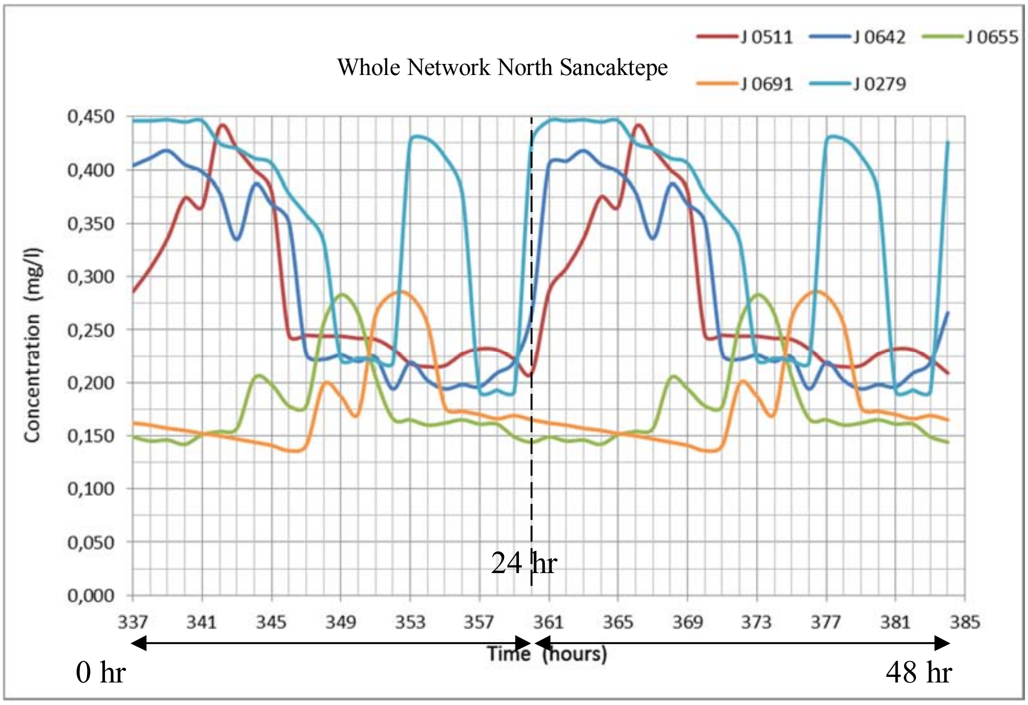


Figure 5.35: Multi Pump Operation Chlorine Concentrations (North Sancaktepe Whole Network Case)

J-0655 which is far away from the entrance has even 0.20 mg/l less concentration in comparison to the entrance junctions. J-0655 has almost equal concentrations with J-0691. J-0691 is the most distant junction in North Sancaktepe District and this junction is defined as the dead end junction as it does not transmit water to neighboring junctions. There are no transport and mixing events in the junction. The most important and driving parameter is the demand being withdrawn from the junction. If the demand is in increasing trend the concentration of the junction starts to increase and if the demand is decreasing trend the concentration starts to decrease. Note that distance to the source or distant junctions in the DMA’s is not the only cause of the concentration changes, demand being withdrawn from the junction, flow velocity, calculated concentrations around the junction also have major effects on concentration changes. Distance to the source is expressed as a visual way of observing and understanding the concentration changes, the genuine parameter for explaining the concentration changes with respect to source is *"travel time"*.

Examining the concentrations of the entrance point (J-0511) at North Sancaktepe District it is very clear that the concentration fluctuation is a direct reason of the pump operation. The pumps are in operation during night (22:00-06:00 hr) the observed concentrations are high during the night period between 337 - 342 hour time intervals. The pumps shutoff at t=342 hr and the concentrations start to drop at this time on a small scale yet the main concentration drop occurs at t=345 hr. This is due to the 3 hours shift between the pump station and North Sancaktepe District. This shift occurs as a result of the time required for the water to reach the district, the large diameter of the pipes and low velocities on the path create this shift.

The pumps shutoff during 06:00–14:00 time intervals forcing the concentrations to drop at high rates. 3-SMS (LG) starts operation again between 14:00 – 17:00 time intervals referring to 350 – 353 time intervals yet the concentrations are still following a smooth line. This is due to the tank's influence on the junction when the pump is off, the junction receives water from the tank until t=352 the effects of the pump on concentration cannot be observed because at t=353 pump stops. One hour of pumping between t=352 to t=353 hours cannot be observed due to the mixing of the fresh concentrations from the pump conflict in the mainline and drop down before the arrival of North Sancaktepe entrance. Although most junctions fit in to this scenario, J – 0279 makes an exemption between 14:00 – 17:00 time intervals (350 – 353 hr) during pump operation. The concentrations suddenly increase and rapidly drop down as showing the effects of the pump operation, this is due to the isolation valve at the south of J – 0279. In this scenario the valve is open therefore there is a direct connection with the main transmission line. Actually J-0279 shows the direct effects of the pump operation in any time interval.

Arriving t= 357 hr. pump operation starts again the effects on concentrations are observed at t=359 hr. and concentrations start to increase at a high rate. The shifting occurring at the entrance junction is transferred to the middle junctions as the time passes for the water to reach from the entrance to distant points. This cycle continues for all the calculation period and is valid for all the junctions except dead end ones.

According to drinking water regulations, maximum chlorine concentration should not exceed 0.50 mg/l and minimum chlorine concentration should not be below 0.10 mg/l. Junctions considered in North Sancaktepe District have chlorine concentrations which are in safe limits. This means chlorine concentration is enough for disinfection and does not exceed the maximum limits.

5.4.1.4 Şehit Kubilay District

Şehit Kubilay District consisting of 156 junctions, mostly receives water from the main line passing from the north-east part of the area. In addition to this line, it has boundaries with East Çiğdemtepe and South Sancaktepe. As a result of this the system will perform differently due to the interactions between these boundaries. This means the chlorine concentrations will vary for these conditions. The model is set up for the chlorine parameters and pump schedule as mentioned above, and EPS study is performed for 384 hours.

Examining the Figure 5.36, J-0246 which is at the entrance of the district has the highest concentration compared to other junctions in the area. J - 0324 has a lower concentration than J-0246 due to the small distance from the entrance. The middle point junction J-0683 has lower concentrations compared to the entrance junctions, this junction and the surrounding middle point junctions show the overall average concentrations of the Şehit Kubilay District. J-0540 which is far away from the entrance has even 0.10 mg/l less concentration in comparison to the entrance junctions. J-0672 is the most distant junction in Şehit Kubilay District and this junction is defined as the dead end junction as it does not transmit water to neighboring junctions. The concentration of J-0672 is the lowest concentration in the district as also shown in Figure 5.36. Note that distance to the source or distant junctions in the DMA's is not the only cause of the concentration changes, demand being withdrawn from the junction, flow velocity, calculated concentrations around the junction also have major effects on concentration changes. Distance to the source is expressed as a visual way of observing and understanding the concentration changes, the genuine parameter for explaining the concentration changes with respect to source is *"travel time"*.

Examining the overall concentrations of the district, although the peak occurring times shift due to the pump run and shut off times of the pumps, it is observed that in Multi Pumps operation Scenario there is not a certain change compared to Single Pump Operation.

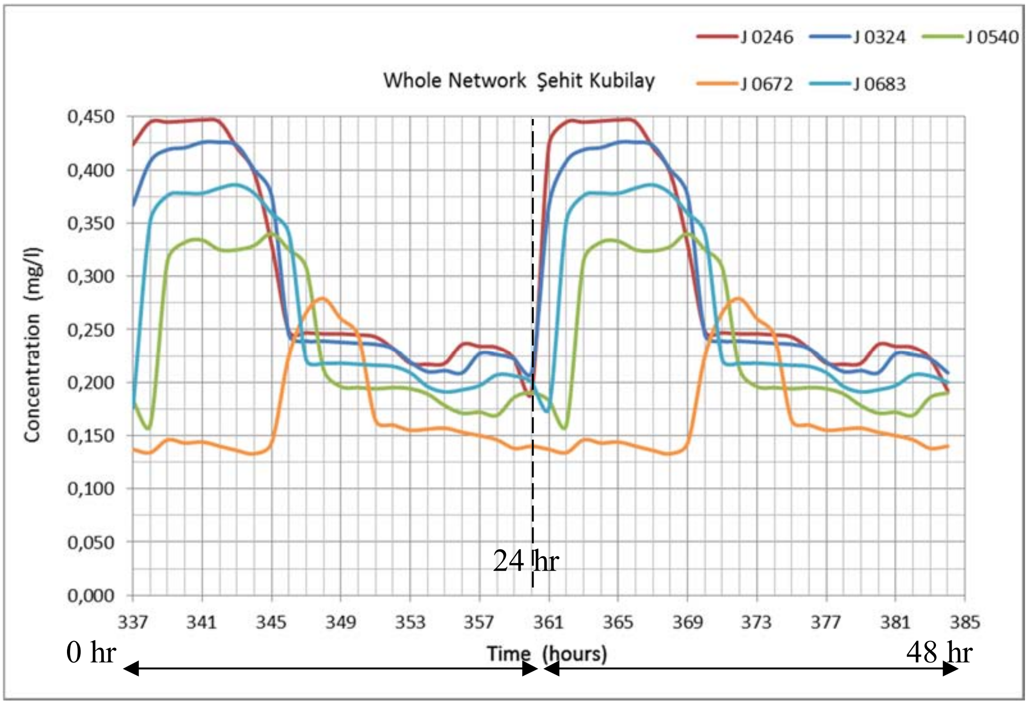


Figure 5.36: Multi Pump Operation Chlorine Concentrations (Şehit Kubilay Whole Network Case)

Examining the concentrations of the entrance point (J-0246) at Şehit Kubilay District it is very clear that the concentration fluctuation is a direct reason of the pump operation. The pumps are in operation during night (22:00-06:00 hr) the observed concentrations are high during the night period between 337 - 342 hour time intervals. The pumps shutoff at t=342 hr and the concentrations start to drop at this time on a small scale yet the main concentration drop occurs at t=345 hr. This is due to the 3 hours shift between the pump station and Şehit Kubilay District. This shift occurs as a result of the time required for the water to reach the district, the large diameter of the pipes and low velocities on the path create this shift.

The pumps shutoff during 06:00–14:00 time intervals is expected to force the concentrations to drop at high rates. 3-SMS (LG) starts operation again between 14:00 – 17:00 time intervals referring to 350 – 353 time intervals yet the concentrations are still following a smooth line. This is due to the tank's influence on the junction when the pump is off, the junction receives water from the tank until t=352 the effects of the pump on concentration cannot be observed because at t=353 pump stops. One hour of pumping between t=352 to t=353 hours cannot be observed due to the mixing of the fresh concentrations from the pump conflict in the mainline and drop down before the arrival of Şehit Kubilay entrance. Arriving t= 357 hr. pump operation starts again the effects on concentrations are observed at t=360 hr. and concentrations start to increase at a high rate. The shifting occurring at the entrance junction is transferred to the middle junctions as the time passes for the water to reach from the entrance to distant points. This cycle continues for all the calculation period and is valid for all the junctions except dead end ones.

Dead end junctions such as J-0672 are not affected from the pump schedule precisely but these junctions are definitely affected by the daily demand. When the daily demand is in increasing trend the concentration starts to increase as a result of the fresh water coming into the junction.

According to drinking water regulations, maximum chlorine concentration should not exceed 0.50 mg/l and minimum chlorine concentration should not be below 0.10 mg/l. Junctions considered in Şehit Kubilay District have chlorine concentrations which are in safe limits. This means chlorine concentration is enough for disinfection and does not exceed the maximum limits.

5.4.1.5 East Çiğdemtepe District

East Çiğdemtepe District consisting of 66 junctions, mostly receives water from the main line passing from the north-east part of the area. In addition to this line, it has boundaries with West Çiğdemtepe and Şehit Kubilay. As a result of this the system will perform differently due to the interactions between these boundaries. The model is set up for the chlorine parameters and pump schedule before EPS study is performed for 384 hours.

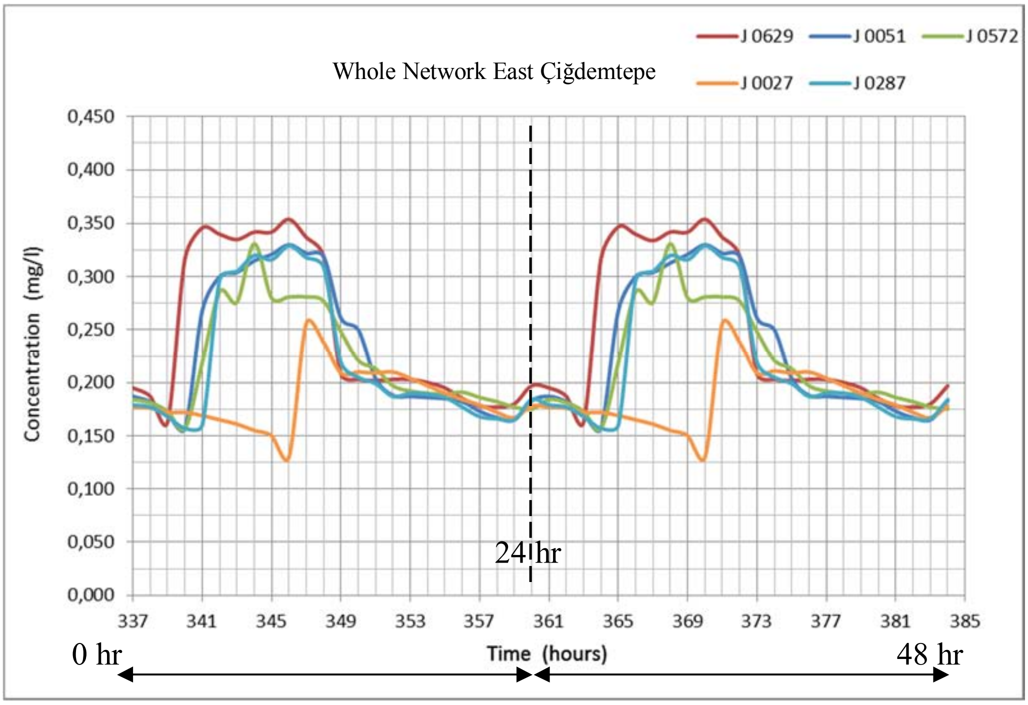


Figure 5.37: Multi Pump Operation Chlorine Concentrations (East Çiğdemtepe Whole Network Case)

Examining the Figure 5.37, J-0629 which is at the entrance of the district has the highest concentration compared to other junctions in the area. J-0051, J-0287 and J-0572 have almost equal concentrations and have lower concentrations compared to the entrance junctions. These junctions are also considered as middle point junctions and the concentrations calculated point out the overall average concentrations of the East Çiğdemtepe District.

J-0027 is the most distant junction in East Çiğdemtepe District and this junction is defined as the dead end junction as it does not transmit water to neighboring junctions. There are no transport and mixing events in the junction. The most important and driving parameter is the demand being withdrawn from the junction. If the demand is in increasing trend the concentration of the junction starts to increase and if the demand is decreasing trend the concentration starts to decrease. The overall concentration of J-0027 is the lowest concentration in the district as also shown in Figure 5.37 . Note that distance to the source or distant junctions in the DMA's is not the only cause of the concentration changes, demand being withdrawn from the junction, flow velocity, calculated concentrations around the junction also have major effects on concentration changes. Distance to the source is expressed as a visual way of observing and understanding the concentration changes, the genuine parameter for explaining the concentration changes with respect to source is *"travel time"*.

Examining the concentrations of the entrance point (J-0629) at East Çiğdemtepe District it is very clear that the concentration fluctuation is a direct reason of the pump operation. The pumps are in operation during night (22:00-06:00 hr) the observed concentrations are high during the night period between 341 - 346 hour time intervals. The pumps shutoff at t=342 hr and the concentrations start to drop down at this time on a small scale yet the main concentration drop occurs at t=348 hr. This is due to the 6 hours shift between the pump station an East Çiğdemtepe District. This shift occurs as a result of the time required for the water to reach the district, the large diameter of the pipes and low velocities on the path create this shift.

The pump shutoff during 06:00–14:00 time intervals is expected to force the concentrations to drop at high rates. 3-SMS (LG) starts operation again between 14:00 – 17:00 time intervals referring to 350 – 353 time intervals yet the concentrations are still following a smooth line. This is due to the tank's influence on the junction when the pump is off, the junction receives water from the tank until t=352 the effects of the pump on concentration cannot be observed because at t=353 pump stops. One hour of pumping between t=352 to t=353 hours cannot be observed due to the mixing of the fresh concentrations from the pump conflict in the mainline and drop down before the arrival of East Çiğdemtepe entrance. Arriving t= 357 hr. pump operation starts again the effects on concentrations are observed at t=363 hr. and concentrations start to increase at a high rate. The shifting occurring at the entrance junction is transferred to the middle junctions as the time passes for the water to reach from the entrance to distant points. This cycle continues for all the calculation period and is valid for all the junctions except dead end ones.

Dead end junctions such as J-0027 are not affected from the pump schedule precisely but these junctions are definitely affected by the daily demand. When the daily demand is in increasing trend the concentration starts to increase as a result of the fresh water coming into the junction.

According to drinking water regulations, maximum chlorine concentration should not exceed 0.50 mg/l and minimum chlorine concentration should not be below 0.10 mg/l. Junctions considered in East Çiğdemtepe District have chlorine concentrations which are in safe limits. This means chlorine concentration is enough for disinfection and does not exceed the maximum limits.

5.4.1.6 West Çiğdemtepe District

West Çiğdemtepe District consisting of 111 junctions, mostly receives water from the main line passing from the north-east part of the area. In addition to this line, it has a boundary with East Çiğdemtepe. As a result of this the system will perform differently due to the interactions between these boundaries. This means the chlorine concentrations will vary for these conditions. The model is set up for the chlorine parameters as mentioned above, and EPS study is performed for 384 hours.

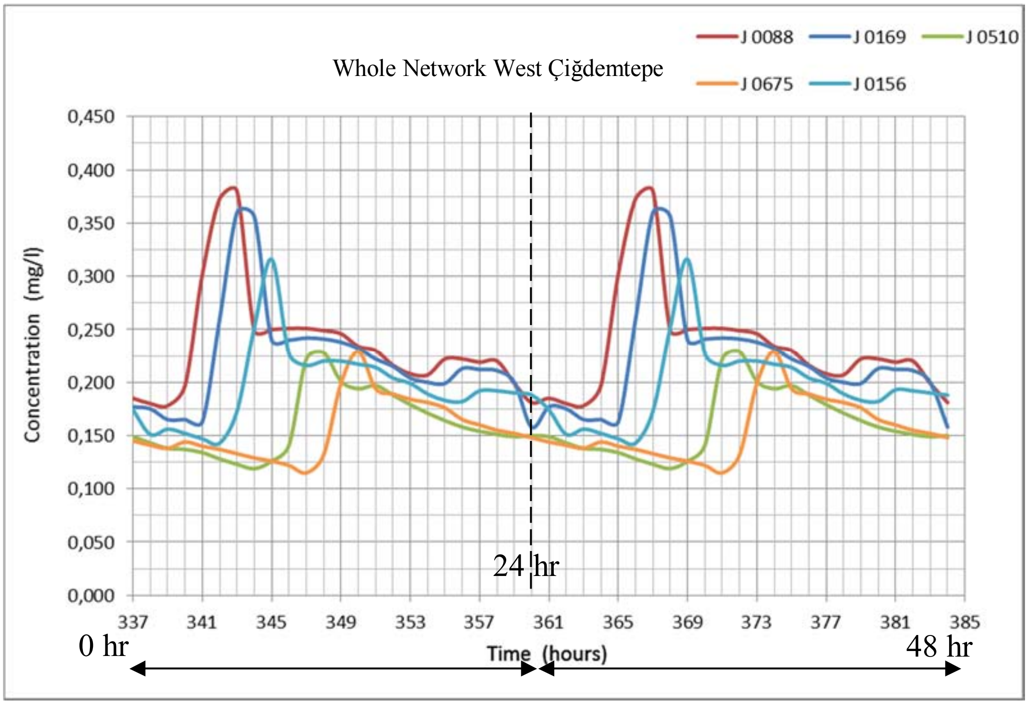


Figure 5.38: Multi Pump Operation Chlorine Concentrations (West Çiğdemtepe Whole Network Case)

Examining the Figure 5.24, J-0088 which is at the entrance of the district has the highest concentration compared to other junctions in the area. J - 0169 has a slightly lower concentration than J-088. By reason of the short distance there is a very low concentration change.

J-0156 which is far away from the entrance has even 0.25 mg/l less concentration in comparison to the entrance junctions. There is an isolation valve very close to J-0156 therefore due to the interaction with neighboring zone East Çiğdemtepe the concentration does not decrease as much as other junctions.

J-0510 has almost equal concentrations with J-0675. J-0675 is the most distant junction in West Çiğdemtepe District and this junction is defined as the dead end junction as it does not transmit water to neighboring junctions. There are no transport and mixing events in the junction. The most important and driving parameter is the demand being withdrawn from the junction. If the demand is in increasing trend the concentration of the junction starts to increase and if the demand is decreasing trend the concentration starts to decrease.

The matching concentration values for J-0510 and J-0675 might be explained by the isolation valve status. In this scenario the isolation valves are open therefore fresh water arrives in J-0675 more quickly. As a result of J-0675 being close to the isolation valve, its concentration does not decrease as in other dead end junctions. Note that distance to the source or distant junctions in the DMA's is not the only cause of the concentration changes, demand being withdrawn from the junction, flow velocity, calculated concentrations around the junction also have major effects on concentration changes. Distance to the source is expressed as a visual way of observing and understanding the concentration changes, the genuine parameter for explaining the concentration changes with respect to source is *"travel time"*.

Examining the concentrations of the entrance point (J-0088) at West Çiğdemtepe District it is very clear that the concentration fluctuation is a direct reason of the pump operation. The pumps are in operation during night (22:00-06:00 hr) and the observed concentrations are high before the noon period between 342 - 343 hour time intervals. The pumps shutoff at t=342 hr and the concentrations start to drop down at t=343 hr. This is due to the influence of the tank starts at t=343 hr J-0088 receives its water from the tank hours shift between the pump station and West Çiğdemtepe District.

The pump shutoff during 06:00–14:00 time intervals is expected to force the concentrations to drop at high rates. 3-SMS (LG) starts operation again between 14:00 – 17:00 time intervals referring to 350 – 353 time intervals yet the concentrations are still following a smooth line. This is due to the tank's influence on the junction when the pump is off, the junction receives water from the tank until t=352 the effects of the pump on concentration cannot be observed because at t=353 pump stops. One hour of pumping between t=352 to t=353 hours cannot be observed due to the mixing of the fresh concentrations from the pump conflict in the mainline and drop down before the arrival of West Çiğdemtepe entrance. Arriving t= 357 hr. pump operation starts again the effects on concentrations are observed at t=363 hr. and concentrations start to increase at a high rate. The shifting occurring at the entrance junction is transferred to the middle junctions as the time passes for the water to reach from the entrance to distant points. This cycle continues for all the calculation period and is valid for all the junctions except dead end ones.

Dead end junctions such as J-0675 are not affected from the pump schedule precisely but these junctions are definitely affected by the daily demand. When the daily demand is in increasing trend the concentration starts to increase as a result of the fresh water coming into the junction.

According to drinking water regulations, maximum chlorine concentration should not exceed 0.50 mg/l and minimum chlorine concentration should not be below 0.10 mg/l. Junctions considered in West Çiğdemtepe District have chlorine concentrations which are in safe limits. This means chlorine concentration is enough for disinfection and does not exceed the maximum limits.

5.4.2 Insulated System (DMA Case)

Insulated system as previously mentioned means that all isolation valves are closed and the districts receive water from a single entrance.

5.4.2.1 Yayla District

Yayla District has no boundaries with other districts which makes it completely insulated. The model is set up for the chlorine parameters as mentioned above, and EPS study is performed for 384 hours. Several junctions are examined and certain ones which represent the general concentrations of Yayla District are chosen. These junctions were shown in the previous Uninsulated System case. These junctions are named as J-0188, J-0211, J-0343, J-0348 and J-0291 as provided in Figure 5.13.

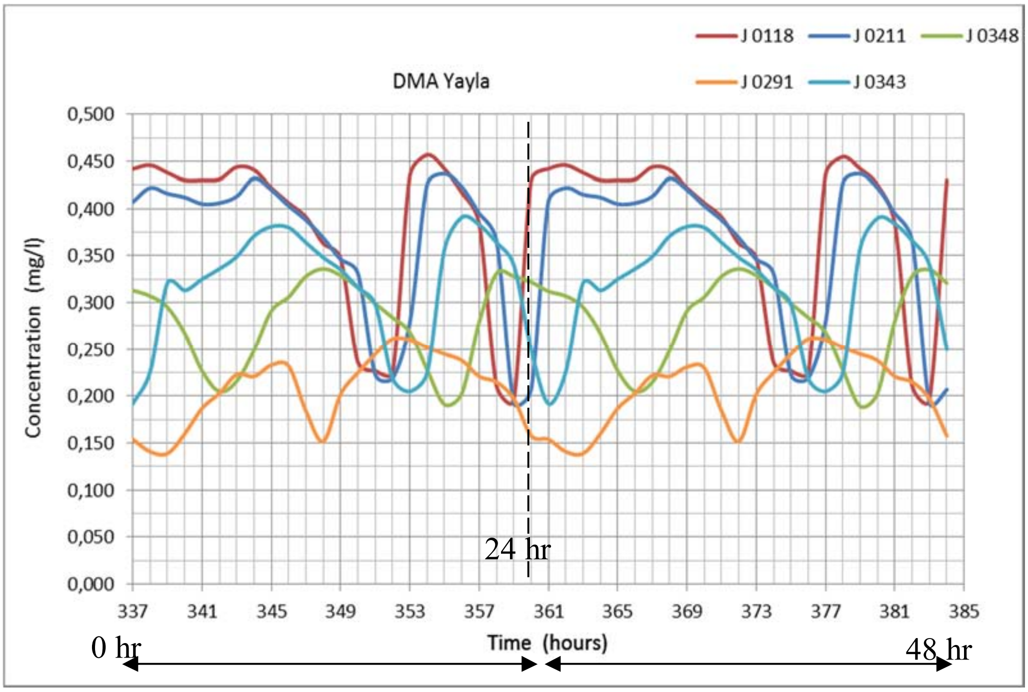


Figure 5.39: Multi Pump Operation Chlorine Concentrations (Yayla DMA Case)

The concentrations for Yayla District are provided in Figure 5.39 between 337-384 time intervals. This time interval refers to the last 48 hours of the system. Also for DMA case the concentration graphs match each other exactly.

Examining the Figure 5.39, J-0118 which is at the entrance of the district has the highest concentration compared to other junctions in the area. J - 0211 has a lower concentration than J-0118 due to the small distance from the entrance. The middle point junction J-0343 has lower concentrations compared to the entrance junctions, this junction and the surrounding middle point junctions show the overall average concentrations of the Yayla District. J-0348 which is far away from the entrance has even 0.10 mg/l less concentration in comparison to the entrance junctions. J-0291 is the most distant junction in Yayla District and this junction is defined as the dead end junction as it does not transmit water to neighboring junctions. There are no transport and mixing events in the junction. The overall concentration of J-0291 is the lowest concentration in the district as also shown in Figure 5.39. The multi pump operation causes the concentrations to make sudden peaks sudden drops according to the pump shut off times.

Examining the concentrations of the entrance point (J-0118) at Yayla District the same situation for Uninsulated case is still valid. The concentration fluctuation is a direct reason of the pump operation. The pumps are in operation during night (22:00-06:00 hr) this operation makes the concentrations high and stable during the night period between 337 - 344 hour time intervals. The pumps shutoff at t=342 hr yet, the concentrations are still high for 2 more hours. This is due to the 2 hours shift between the pump station and Yayla District. This shift occurs as a result of the time required for the water to reach the district, the large diameter of the pipes and low velocities on the path create this shift. The pumps shutoff during 06:00–14:00 time intervals forcing the concentrations to drop at high rates. During this time interval Yayla District receives water from the tank. The concentrations drop until the pump 3-SMS (LG) starts operation again between 14:00 – 17:00 time intervals. This operation refers to 350- 353 time intervals, the effects of the pump on concentrations are seen at t=352, at this point the concentrations suddenly increase until t=354 after this point the concentrations drop again due to the shutoff of the pump. Arriving t= 357 hr. pump operation starts again the effects on concentrations are observed at t=359 hr. and concentrations start to increase at a high rate. The shifting occurring at the entrance junction is transferred to the middle junctions as the time passes for the water to reach from the entrance to distant points. This cycle continues for all the calculation period and is valid for all the junctions except dead end ones.

Dead end junctions such as J-0291 are not affected from the pump schedule precisely but these junctions are definitely affected by the daily demand. When the daily demand is in increasing trend the concentration starts to increase as a result of the fresh water coming into the junction.

According to drinking water regulations, maximum chlorine concentration should not exceed 0.50 mg/l and minimum chlorine concentration should not be below 0.10 mg/l. Also for Insulated case, junctions considered in Yayla District have chlorine concentrations which are in safe limits. This means chlorine concentration is enough for disinfection and does not exceed the maximum limits.

5.4.2.2 South Sancaktepe District

South Sancaktepe District consists of 115 junctions, including dead end junctions. This area, mostly receives water from the transmission line passing from the north part of the area. In Uninsulated case this district only receives water from the main transmission line. This means the chlorine concentrations are expected vary for these conditions. The model is set up for the chlorine parameters and physical conditions.

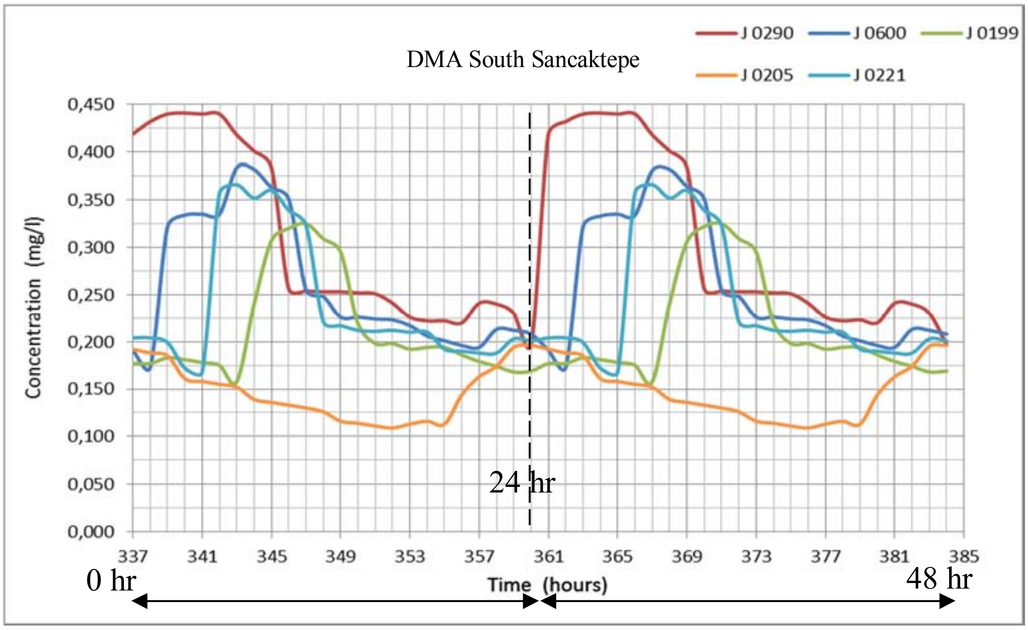


Figure 5.40: Multi Pump Operation Chlorine Concentrations (South Sancaktepe DMA Case)

Examining the Figure 5.40, J-0290 which is at the entrance of the district has the highest concentration compared to other junctions in the area. J - 0221 has a lower concentration than J-0290 due to the small distance from the entrance. The middle point junction J-0600 has lower concentrations compared to the entrance junctions, this junction and the surrounding middle point junctions show the overall average concentrations of the South Sancaktepe District. J-0199 which is far away from the entrance has even 0.15 mg/l less concentration in comparison to the entrance junctions. J-0205 is the most distant junction in South Sancaktepe District and this junction is defined as the dead end junction as it does not transmit water to neighboring junctions. There are no transport and mixing events in the junction. The most important and driving parameter is the pump schedule. When the pumps are in operation, the concentrations observed at the junctions starts to increase and when the pumps are shut off the concentrations start to decrease. The overall concentration of J-0205 is the lowest concentration in the district as also shown in Figure 5.40. There is not a significant difference compared to Uninsulated case, the graphs fluctuation shape is nearly the same with very small vibrations of concentration.

Examining the concentrations of the entrance point (J-0290) at South Sancaktepe District the situation which is valid for Uninsulated case is still valid. The concentration fluctuation is a direct reason of the pump operation. The pumps are in operation during night (22:00-06:00 hr) the observed concentrations are high during the night period between 337 - 342 hour time intervals. The pumps shutoff at t=342 hr and the concentrations start to drop at this time on a small scale yet the main concentration drop occurs at t=345 hr. This is due to the 3 hours shift between the pump station and South Sancaktepe District. This shift occurs as a result of the time required for the water to reach the district, the large diameter of the pipes and low velocities on the path create this shift.

The pumps shutoff during 06:00–14:00 time intervals forcing the concentrations to drop at high rates. 3-SMS (LG) starts operation again between 14:00 – 17:00 time intervals referring to 350 – 353 time intervals yet the concentrations are still following a smooth line. This is due to the tank's influence on the junction when the pump is off, the junction receives water from the tank until t=352 the effects of the pump on concentration cannot be observed because at t=353 pump stops. One hour of pumping between t=352 to t=353 hours cannot be observed due to the mixing of the fresh concentrations from the pump conflict in the mainline and drop down before the arrival of South Sancaktepe entrance. Arriving t= 357 hr. pump operation starts again the effects on concentrations are observed at t=359 hr. and concentrations start to increase at a high rate. The shifting occurring at the entrance junction is transferred to the middle junctions as the time passes for the water to reach from the entrance to distant points. This cycle continues for all the calculation period and is valid for all the junctions except dead end ones.

Dead end junctions such as J-0205 are not affected from the pump schedule precisely but these junctions are definitely affected by the daily demand. When the daily demand is in increasing trend the concentration starts to increase as a result of the fresh water coming into the junction.

Compared to uninsulated case, in this case all junctions except J 0199 have the same fluctuations of chlorine concentrations. J 0199 follows a slightly more straight line compared to insulated case. This is probably due to the entrance of fresh water from the main line due to open isolation valves. Mixing of water decreases the sudden increase and drops in chlorine concentrations. In insulated case these valves are closed therefore concentrations fluctuate as a result of the pump operation.

According to drinking water regulations, maximum chlorine concentration should not exceed 0.50 mg/l and minimum chlorine concentration should not be below 0.10 mg/l. Also for insulated case, junctions considered in South Sancaktepe District have chlorine concentrations which are in safe limits. This means chlorine concentration is enough for disinfection and does not exceed the maximum limits.

5.4.2.3 North Sancaktepe District

North Sancaktepe District consisting of 92 junctions, mostly receives water from the main line passing from the south part of the area. In addition to this pipe line, it has a boundary with South Sancaktepe. In this scenario the isolation valves are closed therefore the district only receives water from the main line. This means the chlorine concentrations are expected vary for these conditions. The model is set up for the isolation parameters as mentioned above, and EPS study is performed for 384 hours.

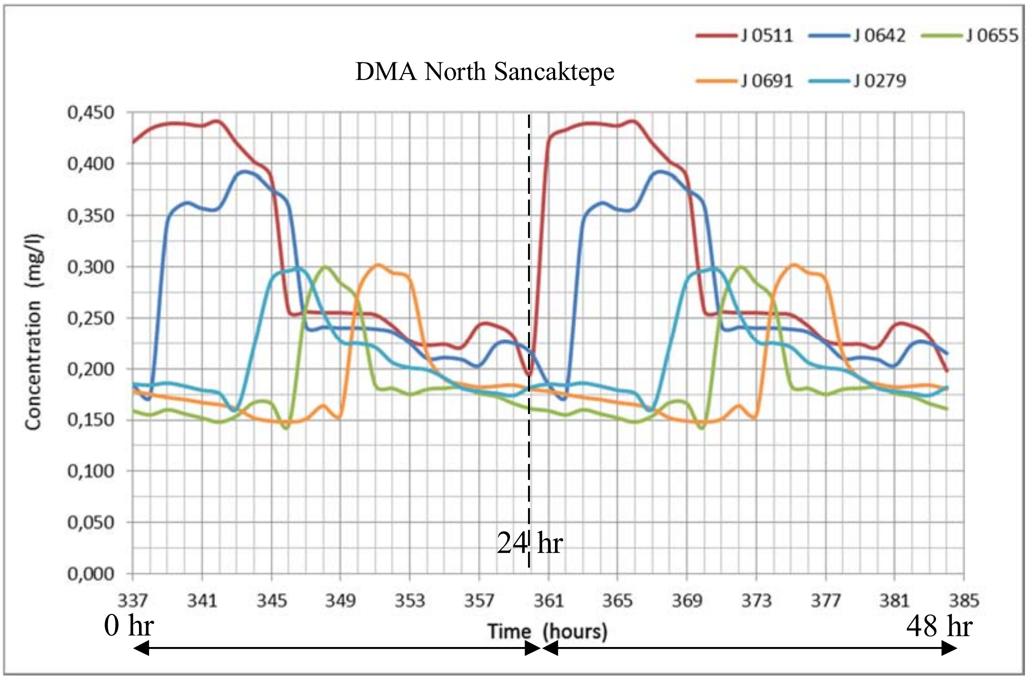


Figure 5.41: Multi Pump Operation Chlorine Concentrations (North Sancaktepe DMA Case)

Examining the Figure 5.41, J-0511 which is at the entrance of the district has the highest concentration compared to other junctions in the area. During Uninsulated case J - 0279 which had the almost the equal concentration with J-0511 now has a very low concentration compared to J-0511. This is again due to the isolation valve at the south of J – 0279. In this scenario the valve is closed therefore the direct connection with the main transmission line is not existent, therefore J – 0279 cannot receive the fresh water as in this case. In this scenario the middle point junctions of North Sancaktepe J-0642 and J - 0279 has lower concentrations compared to the entrance junction.

J-0655 which is far away from the entrance has even 0.15 mg/l less concentration in comparison to the entrance junctions. As in the Uninsulated Case, also in this scenario J-0655 has almost equal concentrations with J-0691.

These values are explained by the same comments made for the Uninsulated case. The path that transmits water to J-0655 has loop and there are many junctions on the transport path. Concentration difference might be explained by the several transport and decay reactions on the path to J-0655. This subject is discussed further in the discussion of results chapter, travel times will be presented and additional comments on this issue will be provided.

Examining the concentrations of the entrance point (J-0511) at North Sancaktepe District the same situation for Uninsulated case is also valid. The concentration fluctuation is a direct reason of the pump operation. The pumps are in operation during night (22:00-06:00 hr) the observed concentrations are high during the night period between 337 - 342 hour time intervals. The pumps shutoff at t=342 hr and the concentrations start to drop at this time on a small scale yet the main concentration drop occurs at t=345 hr. This is due to the 3 hours shift between the pump station and North Sancaktepe District. This shift occurs as a result of the time required for the water to reach the district, the large diameter of the pipes and low velocities on the path create this shift.

The pumps shutoff during 06:00–14:00 time intervals forcing the concentrations to drop at high rates. 3-SMS (LG) starts operation again between 14:00 – 17:00 time intervals referring to 350 – 353 time intervals yet the concentrations are still following a smooth line. This is due to the tank's influence on the junction when the pump is off, the junction receives water from the tank until t=352 the effects of the pump on concentration cannot be observed because at t=353 pump stops. One hour of pumping between t=352 to t=353 hours cannot be observed due to the mixing of the fresh concentrations from the pump conflict in the mainline and drop down before the arrival of North Sancaktepe entrance. Although most junctions fit in to this scenario, J – 0279 had made an exemption between 14:00 – 17:00 time intervals (350 – 353 hr) during Uninsulated case. In uninsulated case the concentrations suddenly increase and rapidly drop down as showing the effects of the pump operation, this was due to the isolation valve at the south of J – 0279. In this scenario the valve is closed therefore there is no longer a direct connection with the main transmission line. J-0279 and surrounding junctions cannot show the direct effects of the pump operation in Insulated case.

Arriving t= 357 hr. pump operation starts again the effects on concentrations are observed at t=359 hr. and concentrations start to increase at a high rate. The shifting occurring at the entrance junction is transferred to the middle junctions as the time passes for the water to reach from the entrance to distant points. This cycle continues for all the calculation period and is valid for all the junctions except dead end ones.

Compared to uninsulated case chlorine concentrations behave nearly the same except J-0279. This junction receives water from the main line in uninsulated case causing its concentrations to increase just as an entrance junction. In insulated case the valve is closed therefore this junction's behavior turns back to similar fluctuation behavior as observed in other junctions.

According to drinking water regulations, maximum chlorine concentration should not exceed 0.50 mg/l and minimum chlorine concentration should not be below 0.10 mg/l. Also for Insulated case, junctions considered in North Sancaktepe District have chlorine concentrations which are in safe limits. This means chlorine concentration is enough for disinfection and does not exceed the maximum limits.

5.4.2.4 Şehit Kubilay District

Şehit Kubilay District consisting of 156 junctions, mostly receives water from the main line passing from the north-east part of the area. In addition to this line, it has boundaries with East Çiğdemtepe and South Sancaktepe. In this scenario Şehit Kubilay District only receives water from the main line. The model is set up for the parameters as mentioned above, and EPS study is performed for 384 hours.

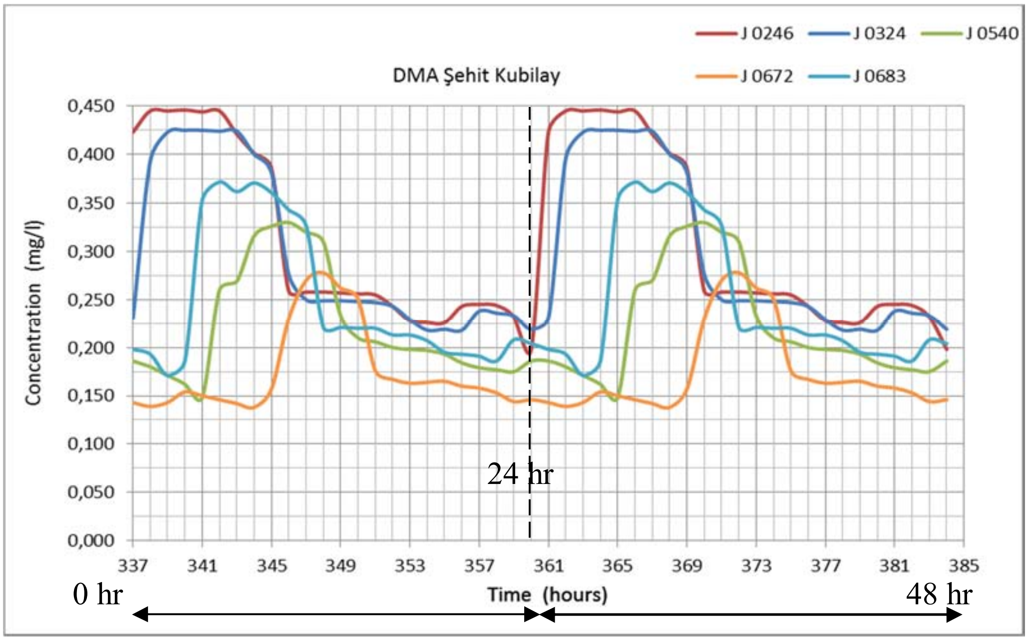


Figure 5.42: Multi Pump Operation Chlorine Concentrations (Şehit Kubilay DMA Case)

Examining the Figure 5.42, J-0246 which is at the entrance of the district has the highest concentration compared to other junctions in the area. J - 0324 has a lower concentration than J-0246 due to the small distance from the entrance. The middle point junction J-0683 has lower concentrations compared to the entrance junctions, this junction and the surrounding middle point junctions show the overall average concentrations of the Şehit Kubilay District. J-0540 which is far away from the entrance has even 0.10 mg/l less concentration in comparison to the entrance junctions. J-0672 is the most distant junction in Şehit Kubilay District and this junction is defined as the dead end junction as it does not transmit water to neighboring junctions. The concentration of J-0672 is the lowest concentration in the district as also shown in Figure 5.42. Examining the overall concentrations of the district, although the peak occurring times shift due to the pump run and shut off times of the pumps, it is observed that in Multi Pumps operation Scenario there is not a certain change compared to Single Pump Operation. The graphs for Uninsulated case make exact matches also for insulated case.

Examining the concentrations of the entrance point (J-0246) at Şehit Kubilay District it is very clear that the concentration fluctuation is a direct reason of the pump operation. The pumps are in operation during night (22:00-06:00 hr) the observed concentrations are high during the night period between 337 - 342 hour time intervals. The pumps shutoff at t=342 hr and the concentrations start to drop at this time on a small scale yet the main concentration drop occurs at t=345 hr. This is due to the 3 hours shift between the pump station and Şehit Kubilay District. This shift occurs as a result of the time required for the water to reach the district, the large diameter of the pipes and low velocities on the path create this shift.

The pumps shutoff during 06:00–14:00 time intervals is expected to force the concentrations to drop at high rates. 3-SMS (LG) starts operation again between 14:00 – 17:00 time intervals referring to 350 – 353 time intervals yet the concentrations are still following a smooth line. This is due to the tank's influence on the junction when the pump is off, the junction receives water from the tank until t=352 the effects of the pump on concentration cannot be observed because at t=353 pump stops. One hour of pumping between t=352 to t=353 hours cannot be observed due to the mixing of the fresh concentrations from the pump conflict in the mainline and drop down before the arrival of Şehit Kubilay entrance. Arriving t= 357 hr. pump operation starts again the effects on concentrations are observed at t=360 hr. and concentrations start to increase at a high rate. The shifting occurring at the entrance junction is transferred to the middle junctions as the time passes for the water to reach from the entrance to distant points. This cycle continues for all the calculation period and is valid for all the junctions except dead end ones.

Compared to uninsulated case chlorine concentrations behave nearly the same there are very small differences in concentrations yet the concentrations fluctuations follow almost the same pattern. There is not a certain difference between uninsulated and insulated case this is because there are no isolation valves in connection with the main line.

Dead end junctions such as J-0672 are not affected from the pump schedule precisely but these junctions are definitely affected by the daily demand. When the daily demand is in increasing trend the concentration starts to increase as a result of the fresh water coming into the junction.

According to drinking water regulations, maximum chlorine concentration should not exceed 0.50 mg/l and minimum chlorine concentration should not be below 0.10 mg/l. Also for Insulated case, junctions considered in Şehit Kubilay District have chlorine concentrations which are in safe limits. This means chlorine concentration is enough for disinfection and does not exceed the maximum limits.

5.4.2.5 East Çiğdemtepe District

East Çiğdemtepe District consisting of 66 junctions, mostly receives water from the main line passing from the north-east part of the area. In addition to this line, it has boundaries with West Çiğdemtepe and Şehit Kubilay. In this scenario the district only receives water from the main line. The model is set up for the isolation valves being closed and EPS study is performed for 384 hours.

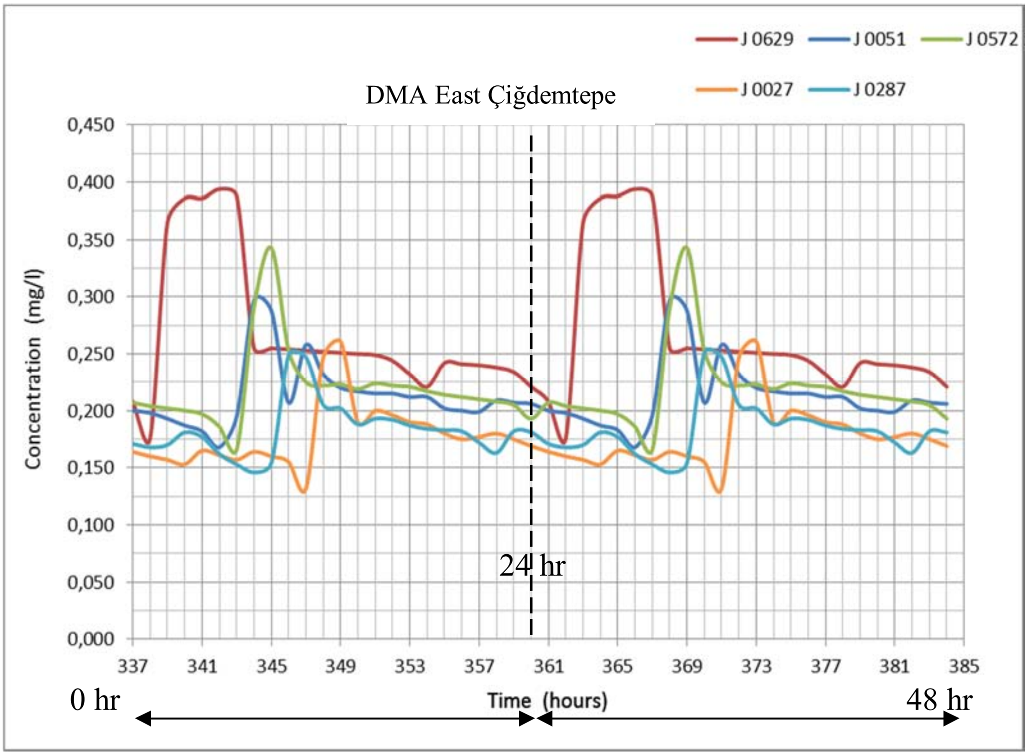


Figure 5.43: Multi Pump Operation Chlorine Concentrations (East Çiğdemtepe DMA Case)

Examining the Figure 5.37, J-0629 which is at the entrance of the district has the highest concentration compared to other junctions in the area. J-0051, J-0287 and J-0572 have almost equal concentrations and have lower concentrations compared to the entrance junctions. These junctions are also considered as middle point junctions and the concentrations calculated point out the overall average concentrations of the East Çiğdemtepe District.

J-0027 is the most distant junction in East Çiğdemtepe District and this junction is defined as the dead end junction as it does not transmit water to neighboring junctions. There are no transport and mixing events in the junction. The most important and driving parameter is the demand being withdrawn from the junction. If the demand is in increasing trend the concentration of the junction starts to increase and if the demand is decreasing trend the concentration starts to decrease. The overall concentration of J-0027 is the lowest concentration in the district as also shown in Figure 5.37 .

Examining the concentrations of the entrance point (J-0629) at East Çiğdemtepe District it is very clear that the concentration fluctuation is a direct reason of the pump operation. The pumps are in operation during night (22:00-06:00 hr) the observed concentrations are high during the night period between 341 - 346 hour time intervals. The pumps shutoff at t=342 hr and the concentrations start to drop down at this time on a small scale yet the main concentration drop occurs at t=348 hr. This is due to the 6 hours shift between the pump station an East Çiğdemtepe District. This shift occurs as a result of the time required for the water to reach the district, the large diameter of the pipes and low velocities on the path create this shift.

The pump shutoff during 06:00–14:00 time intervals is expected to force the concentrations to drop at high rates. 3-SMS (LG) starts operation again between 14:00 – 17:00 time intervals referring to 350 – 353 time intervals yet the concentrations are still following a smooth line. This is due to the tank's influence on the junction when the pump is off, the junction receives water from the tank until t=352 the effects of the pump on concentration cannot be observed because at t=353 pump stops. One hour of pumping between t=352 to t=353 hours cannot be observed due to the mixing of the fresh concentrations from the pump conflict in the mainline and drop down before the arrival of East Çiğdemtepe entrance. Arriving t= 357 hr. pump operation starts again the effects on concentrations are observed at t=363 hr. and concentrations start to increase at a high rate. The shifting occurring at the entrance junction is transferred to the middle junctions as the time passes for the water to reach from the entrance to distant points. This cycle continues for all the calculation period and is valid for all the junctions except dead end ones.

Dead end junctions such as J-0027 are not affected from the pump schedule precisely but these junctions are definitely affected by the daily demand. When the daily demand is in increasing trend the concentration starts to increase as a result of the fresh water coming into the junction.

Compared to uninsulated case chlorine concentrations behave nearly the same except the concentration values. The concentrations observed for middle point junctions are greater in insulated case. This issue is due to the less mixing of fresh water entering the system due to the closed isolation valves.

According to drinking water regulations, maximum chlorine concentration should not exceed 0.50 mg/l and minimum chlorine concentration should not be below 0.10 mg/l. Also for Insulated case, junctions considered in East Çiğdemtepe District have chlorine concentrations which are in safe limits. This means chlorine concentration is enough for disinfection and does not exceed the maximum limits.

5.4.2.6 West Çiğdemtepe District

West Çiğdemtepe District consisting of 111 junctions, mostly receives water from the main line passing from the north-east part of the area. In addition to this line, it has a long boundary with East Çiğdemtepe. In this scenario the district only receives water from the main line.

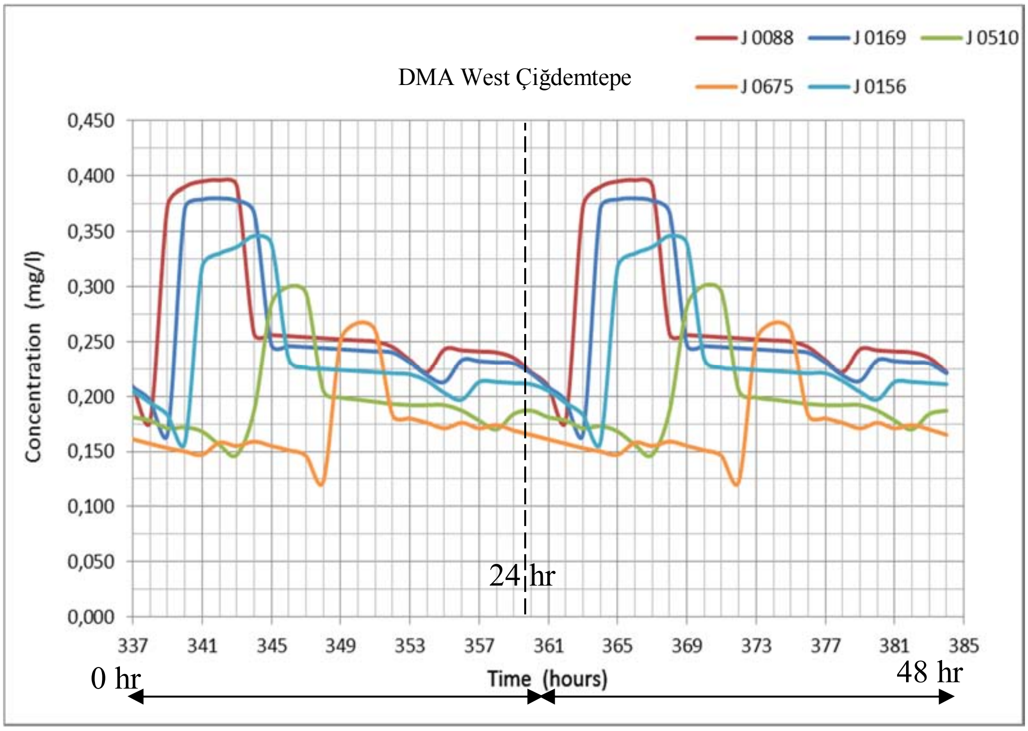


Figure 5.44: Multi Pump Operation Chlorine Concentrations (West Çiğdemtepe DMA Case)

Examining the Figure 5.44, J-0088 which is at the entrance of the district has the highest concentration compared to other junctions in the area. J - 0169 has a slightly lower concentration than J-088. By reason of the short distance there is a very low concentration change.

J-0156 which is far away from the entrance has even 0.25 mg/l less concentration in comparison to the entrance junctions. There is an isolation valve very close to J-0156 therefore due to the interaction with neighboring zone East Çiğdemtepe the concentration does not decrease as much as other junctions.

J-0510 has almost equal concentrations with J-0675. J-0675 is the most distant junction in West Çiğdemtepe District and this junction is defined as the dead end junction as it does not transmit water to neighboring junctions. There are no transport and mixing events in the junction. The most important and driving parameter is the demand being withdrawn from the junction. If the demand is in increasing trend the concentration of the junction starts to increase and if the demand is decreasing trend the concentration starts to decrease.

The matching concentration values for J-0510 and J-0675 might be explained by the isolation valve status. In this scenario the isolation valves are open therefore fresh water arrives in J-0675 more quickly. As a result of J-0675 being close to the isolation valve, its concentration does not decrease as in other dead end junctions.

Examining the concentrations of the entrance point (J-0088) at West Çiğdemtepe District it is very clear that the concentration fluctuation is a direct reason of the pump operation. The pumps are in operation during night (22:00-06:00 hr) and the observed concentrations are high before the noon period between 342 - 343 hour time intervals. The pumps shutoff at t=342 hr and the concentrations start to drop down at t=343 hr. This is due to the influence of the tank starts at t=343 hr J-0088 receives its water from the tank hours shift between the pump station an West Çiğdemtepe District.

The pump shutoff during 06:00–14:00 time intervals is expected to force the concentrations to drop at high rates. 3-SMS (LG) starts operation again between 14:00 – 17:00 time intervals referring to 350 – 353 time intervals yet the concentrations are still following a smooth line. This is due to the tank's influence on the junction when the pump is off, the junction receives water from the tank until t=352 the effects of the pump on concentration cannot be observed because at t=353 pump stops. One hour of pumping between t=352 to t=353 hours cannot be observed due to the mixing of the fresh concentrations from the pump conflict in the mainline and drop down before the arrival of West Çiğdemtepe entrance. Arriving t= 357 hr. pump operation starts again the effects on concentrations are observed at t=363 hr. and concentrations start to increase at a high rate. The shifting occurring at the entrance junction is transferred to the middle junctions as the time passes for the water to reach from the entrance to distant points. This cycle continues for all the calculation period and is valid for all the junctions except dead end ones.

Dead end junctions such as J-0675 are not affected from the pump schedule precisely but these junctions are definitely affected by the daily demand. When the daily demand is in increasing trend the concentration starts to increase as a result of the fresh water coming into the junction.

Compared to uninsulated case chlorine concentrations behave nearly the same there are very small differences in concentrations yet the concentrations fluctuations does not follow the same pattern. In DMA case concentrations reach to peak point and remain constant for a certain duration. While in uninsulated case concentrations drop very sudden. This issue is related with the isolation valve located very close to the entrance junction when this valve is open fresh water concentration is dispersed into this area lowering the concentrations in the overall system.

According to drinking water regulations, maximum chlorine concentration should not exceed 0.50 mg/l and minimum chlorine concentration should not be below 0.10 mg/l. Also for Insulated case, junctions considered in West Çiğdemtepe District have chlorine concentrations which are in safe limits. This means chlorine concentration is enough for disinfection and does not exceed the maximum limits.

5.5 ASKI Pump Operation (Current Operation Of Pumps By Municipality)

In this scenario 2 pumps 1 SUMAS (SM) and 3 SMS (LM) are operating based on a schedule as shown in Figure 5.45. Ankara General Directorate of Water and Sewerage (ASKI) starts pumps when the tank is nearly empty and stops the operation when tank is full, while trying to operate pumps between 22:00 – 6:00 hours when the electricity prices are low. Actually, there is not a certain schedule for ASKI, this schedule is predicted and designed as much as the real case. The initial level of the tank is taken as 2.50 m.

In this scenario chlorine concentrations are observed while the pumps start, shutoff at certain times, these operating characteristics have major effects to chlorine concentrations as discussed further on the next pages. This scenario also refers to the current chlorine concentration and water quality aspects of N8.3 network.

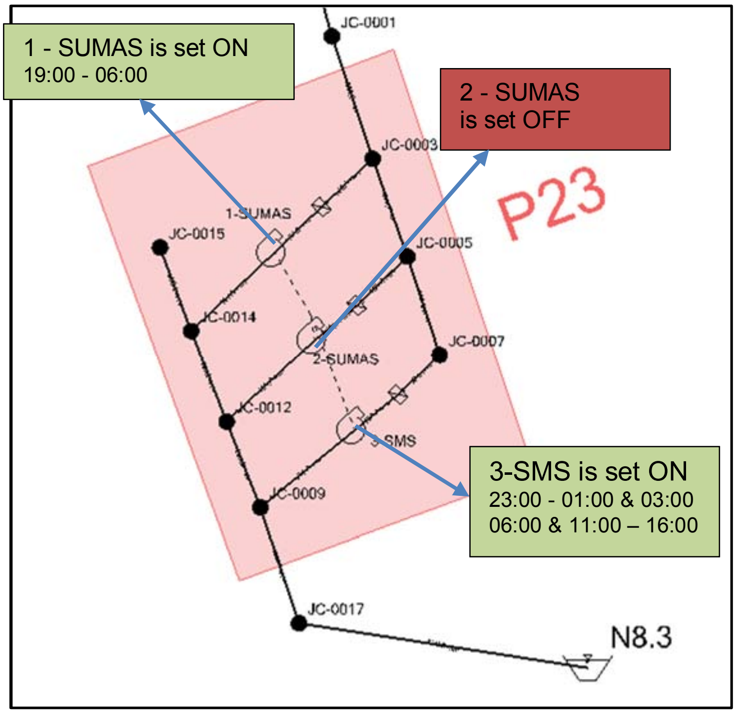


Figure 5.45: ASKI Pump Operation Scenario Pump Configuration (On / Off Status)

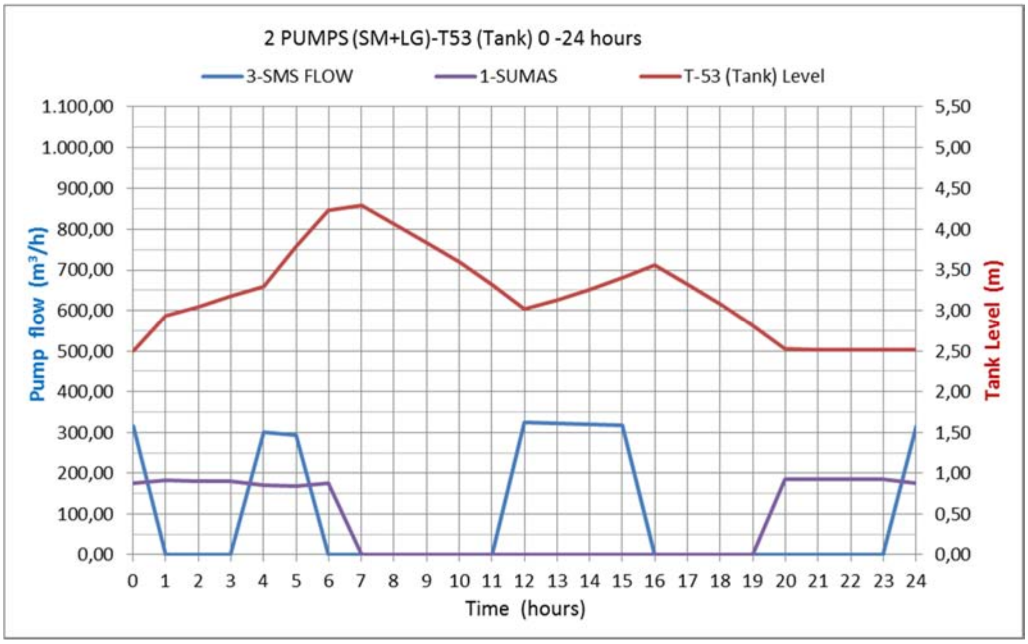


Figure 5.46a: Flow versus time graph of 1 – SUMAS & 3 – SMS pumps for 24 hours

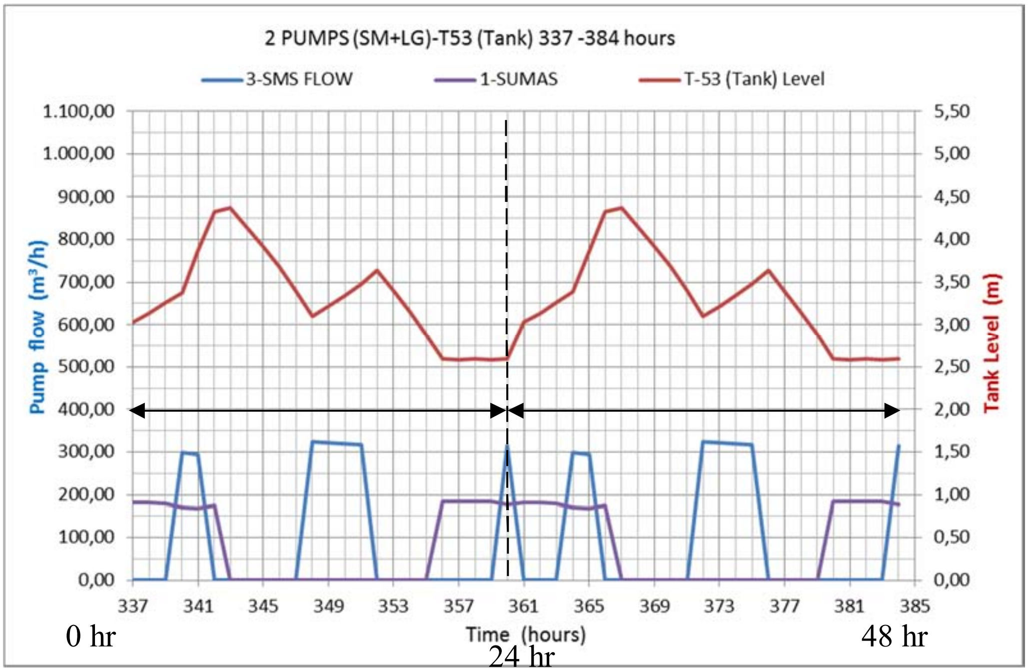


Figure 5.46b: Flow versus time graph of 1 – SUMAS & 3 – SMS pumps between 337-384 hours

The flow being supplied to the network for the first 24 hours is provided in Figure 5.46a as a work schedule of the two pumps. In addition to pump flow, tank levels for the first 24 hours are plotted in Figure 5.46a. The pumps operate based on the ASKI pump schedule.

Initial tank level at the start of the EPS study is 2.50 m, tank level fluctuates according to the daily demand and pump operation. Starting at 2.50 m the system reaches to a balance after 2 weeks (336 hours). This balanced system which is also defined as stable period is established in the last 337-384 hours. The flow being supplied to the network for the last 48 hours (337-384 hr.) is provided in Figure 5.46b; in addition to pump flow, tank levels for the last 48 hours are plotted in Figure 5.46b.

5.5.1 Uninsulated System (Whole Network Case)

Uninsulated system of N8.3 Network means all the isolation valves of the network are set open and flow passes directly through the neighboring zones. The isolation valves shown in Figure 5.3 are open in this scenario.

5.5.1.1 Yayla District

Yayla District (Figure 5.2 and 5.3) consists of 140 junctions, including dead end junctions. Yayla which is the closest district to the pump station, has only one entrance for receiving water. The area has no boundaries with other districts, which makes it completely insulated.

As a result of these conditions, it is expected that under DMA (Insulated Network) and Whole Network (Uninsulated Network) operating conditions the system will perform the actually the same. This means that the chlorine concentrations will make exact matches for also ASKI pump operation scenario.

The model is set up for the chlorine parameters and pump schedule as mentioned above then EPS study is performed for 384 hours.

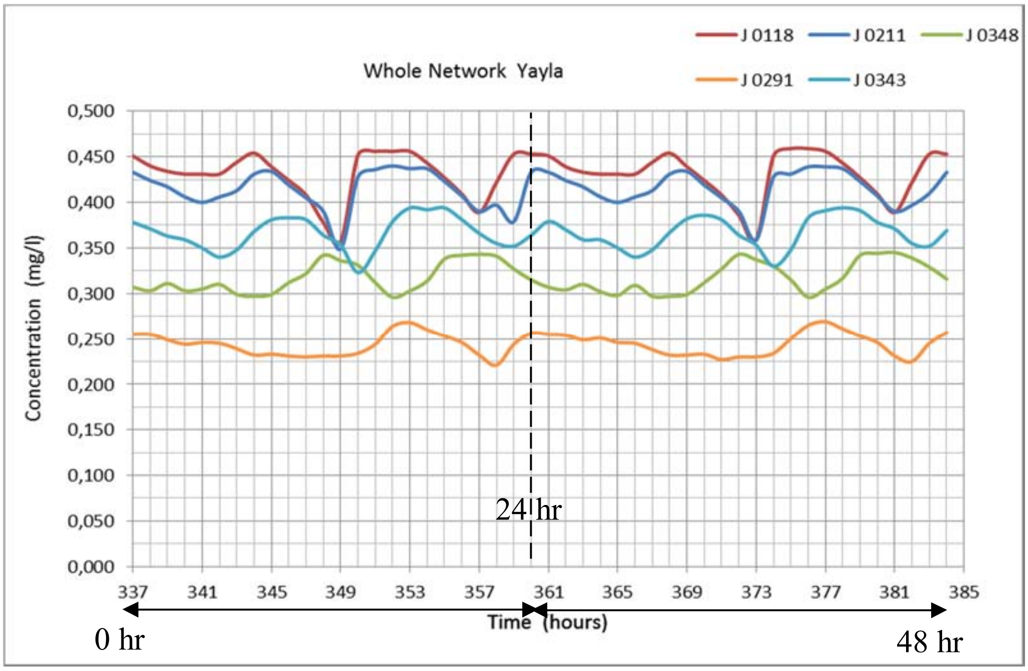


Figure 5.47: ASKI Pump Operation Chlorine Concentrations (Yayla Whole Network Case)

Examining the Figure 5.47, J-0118 which is at the entrance of the district has the highest concentration compared to other junctions in the area. J - 0211 has a lower concentration than J-0348 due to the small distance from the entrance. The middle point junction J-0343 has lower concentrations compared to the entrance junctions, this junction and the surrounding middle point junctions show the overall average concentrations of the Yayla District. J-0291 is the most distant junction in Yayla District and this junction is defined as the dead end junction as it does not transmit water to neighboring junctions. The concentration of J-0291 is the lowest concentration in the district as also shown in Figure 5.47. Note that distance to the source or distant junctions in the DMA's is not the only cause of the concentration changes, demand being withdrawn from the junction, flow velocity, calculated concentrations around the junction also have major effects on concentration changes. Distance to the source is expressed as a visual way of observing and understanding the concentration changes, the genuine parameter for explaining the concentration changes with respect to source is *"travel time"*.

Examining the overall concentrations of the district, although the peak occurring times shift due to the pump run and shut off times of the pumps, it is observed that in ASKI Pump operation Scenario there is no change in the ordering of the junctions according to concentrations from maximum to minimum.

Examining the concentrations of the entrance point (J-0118) at Yayla District it is very clear that the concentration fluctuation is a direct reason of the pump operation. The pumps are in operation during the evening and night (19:00-07:00 hr) the observed concentrations are high during the night period between 337 - 344 hour time intervals. The pumps shutoff at t=343 hr and the concentrations start to drop at t=344 hr.

The pumps shutoff during 07:00–11:00 time intervals is expected to force the concentrations to drop at high rates. 3-SMS (LG) starts operation again between 11:00 – 16:00 time intervals referring to 347 – 352 time intervals yet the concentrations are decreasing until t=349 hr. This is due to the tank's influence on the junction when the pump is off, the junction receives water from the tank until t=349 the effects of the pump on concentration can be observed after t=349. Arriving t= 355 hr. pump operation starts again the effects on concentrations are observed at t=357 hr. after a 2 hours shift due to the influence of the tank. The shifting occurring at the entrance junction is transferred to the middle junctions as the time passes for the water to reach from the entrance to distant points. This cycle continues for all the calculation period and is valid for all the junctions except dead end ones.

Dead end junctions such as J-0156 are not affected from the pump schedule precisely but these junctions are definitely affected by the daily demand. When the daily demand is in increasing trend the concentration starts to increase as a result of the fresh water coming into the junction.

According to drinking water regulations, maximum chlorine concentration should not exceed 0.50 mg/l and minimum chlorine concentration should not be below 0.10 mg/l. Junctions considered in Yayla District have chlorine concentrations which are in safe limits. This means chlorine concentration is enough for disinfection and does not exceed the maximum limits.

5.5.1.2 South Sancaktepe District

South Sancaktepe District (Figure 5.2 and 5.3) consists of 115 junctions, including dead end junctions. This area, mostly receives water from the transmission line passing from the north part of the area. In addition to this transmission line, it has boundaries and pipe connections with Şehit Kubilay and North Sancaktepe as mentioned before. As a result of these conditions, it is expected that under DMA and Whole Network (Uninsulated Network) operating conditions the system will perform different. This means the chlorine concentrations will vary for these conditions. EPS study is performed for 384 hours.

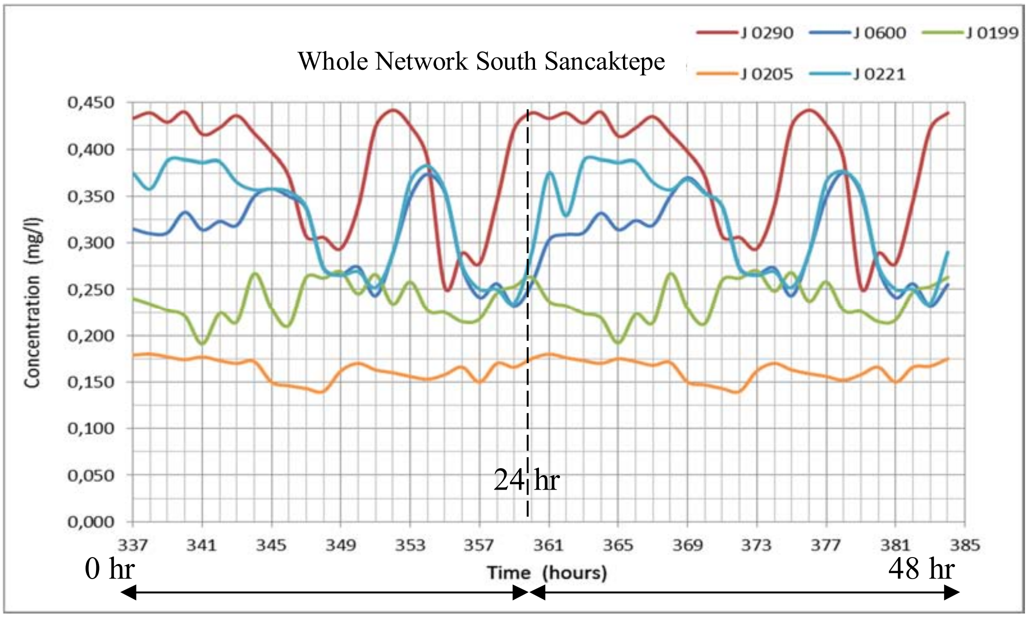


Figure 5.48: ASKI Pump Operation Chlorine Concentrations (South Sancaktepe Whole Network Case)

Examining the concentrations of the entrance point (J-0290) at South Sancaktepe District it is very clear that the concentration fluctuation is a direct reason of the pump operation. Pumps are in operation during 19:00-07:00 time intervals as a reason the observed concentrations are high during the night period between 337 - 343 hour time intervals. The pumps shutoff at t=343 hr and the concentrations start to drop just at this time.

The pumps shutoff during 07:00–11:00 time intervals forcing the concentrations to drop at high rates. 3-SMS (LG) starts operation again between 11:00 – 16:00 time intervals referring to 347 – 352 time intervals yet the concentrations start to increase at t=349. This is due to the tank's influence on the junction when the pump is off, the junction receives water from the tank until t=349 the effects of the pump on concentration cannot be observed due to the mixing of the fresh concentrations from the pump conflict in the mainline and drop down before the arrival of South Sancaktepe entrance. Arriving t= 355 hr. pump operation starts again the effects on concentrations are observed at t=355 hr. and concentrations start to increase at a high rate.

Dead end junctions such as J-0205 are not affected from the pump schedule precisely but these junctions are definitely affected by the daily demand. When the daily demand is in increasing trend the concentration starts to increase as a result of the fresh water coming into the junction.

According to drinking water regulations, maximum chlorine concentration should not exceed 0.50 mg/l and minimum chlorine concentration should not be below 0.10 mg/l. Junctions considered in South Sancaktepe District have chlorine concentrations which are in safe limits. This means chlorine concentration is enough for disinfection and does not exceed the maximum limits.

5.5.1.3 North Sancaktepe District

North Sancaktepe District consisting of 92 junctions, has a boundary with South Sancaktepe. As a result of this condition, it is expected that under DMA and Whole Network (Uninsulated Network) operating conditions the system will perform differently due to the interactions between these boundaries. The model is set up for the chlorine parameters and pump schedule as mentioned above then EPS study is performed for 384 hours.

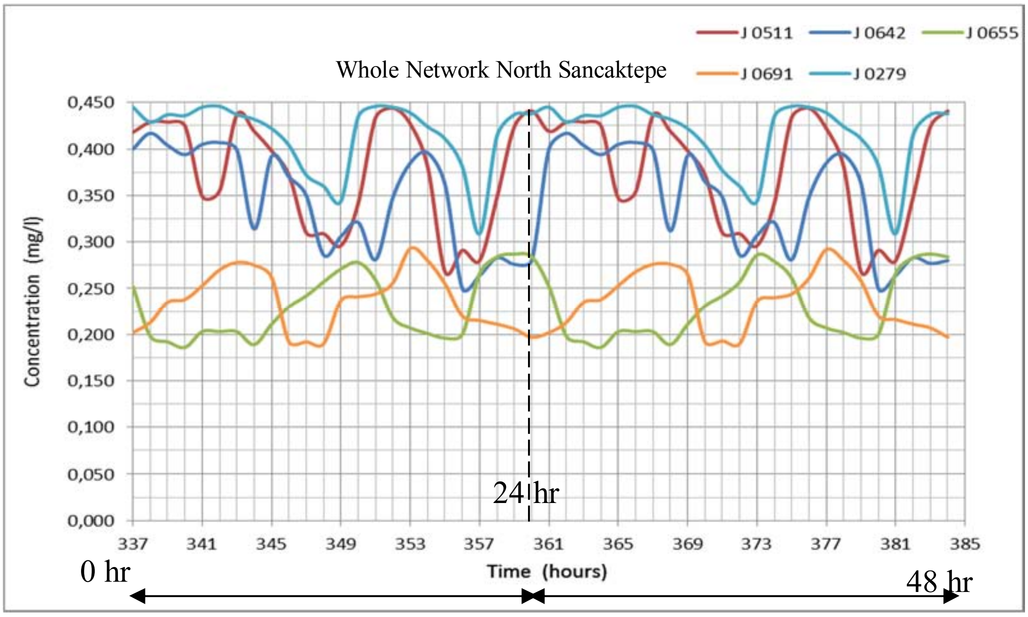


Figure 5.49: ASKI Pump Operation Chlorine Concentrations (North Sancaktepe Whole Network Case)

Examining the concentrations of the entrance point (J-0511) at North Sancaktepe District it is very clear that the concentration fluctuation is a direct reason of the pump operation. Pumps are in operation during 19:00-07:00 time intervals as a reason the observed concentrations are high during the night period between 337 - 343 hour time intervals. The pumps shutoff at t=343 hr and the concentrations start to drop just at this time.

The pumps shutoff during 07:00–11:00 time intervals forcing the concentrations to drop at high rates. 3-SMS (LG) starts operation again between 11:00 – 16:00 time intervals referring to 347 – 352 time intervals yet the concentrations start to increase at t=349. This is due to the tank's influence on the junction when the pump is off, the junction receives water from the tank until t=349 the effects of the pump on concentration cannot be observed due to the mixing of the fresh concentrations from the pump conflict in the mainline and drop down before the arrival of North Sancaktepe entrance. Arriving t=

355 hr. pump operation starts again the effects on concentrations are observed at t=355 hr. and concentrations start to increase at a high rate.

Dead end junctions such as J-0691 are not affected from the pump schedule precisely but these junctions are definitely affected by the daily demand. When the daily demand is in increasing trend the concentration starts to increase as a result of the fresh water coming into the junction.

According to drinking water regulations, maximum chlorine concentration should not exceed 0.50 mg/l and minimum chlorine concentration should not be below 0.10 mg/l. Junctions considered in North Sancaktepe District have chlorine concentrations which are in safe limits. This means chlorine concentration is enough for disinfection and does not exceed the maximum limits.

5.5.1.4 Şehit Kubilay District

Şehit Kubilay District consisting of 156 junctions, mostly receives water from the main line passing from the north-east part of the area. In addition to this line, it has boundaries with East Çiğdemtepe and South Sancaktepe. As a result of this the system will perform differently due to the interactions between these boundaries. This means the chlorine concentrations will vary for these conditions. EPS study is performed for 384 hours.

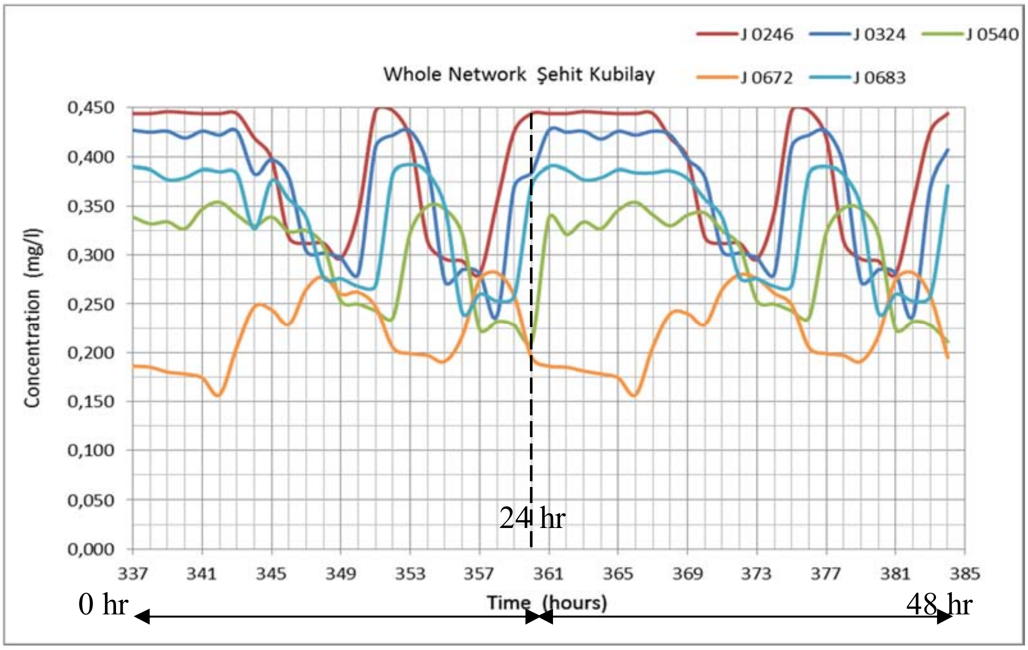


Figure 5.50: ASKI Pump Operation Chlorine Concentrations (Şehit Kubilay Whole Network Case)

Examining the Figure 5.50, J-0246 which is at the entrance of the district has the highest concentration compared to other junctions in the area. J - 0324 has a lower concentration than J-0246 due to the small distance from the entrance. The middle point junction J-0683 has lower concentrations compared to the entrance junctions, this junction and the surrounding middle point junctions show the overall average concentrations of the Şehit Kubilay District. J-0540 which is far away from the entrance has even 0.10 mg/l less concentration in comparison to the entrance junctions. J-0672 is the most distant junction in Şehit Kubilay District and this junction is defined as the dead end junction as it does not transmit water to neighboring junctions. The concentration of J-0672 is the lowest concentration in the district as also shown in Figure 5.50. Examining the overall concentrations of the district, although the peak occurring times shift due to the pump run and shut off times of the pumps, it is observed that in ASKI Pump operation Scenario there is not a certain change in the ordering of the junctions according to concentrations from maximum to minimum.

Examining the concentrations of the entrance point (J-0246) at Şehit Kubilay District it is very clear that the concentration fluctuation is a direct reason of the pump operation. The pumps are in operation during night (19:00-07:00 hr) the observed concentrations are high during the night period between 337 - 342 hour time intervals. The pumps shutoff at t=343 hr and the concentrations start to drop at this point.

The pumps shutoff during 07:00–11:00 time intervals is expected to force the concentrations to drop at high rates. 3-SMS (LG) starts operation again between 11:00 – 16:00 time intervals referring to 347 – 352 time intervals yet the concentrations are still following almost smooth line until t=349 hr. This is due to the tank's influence on the junction when the pump is off, the junction receives water from the tank until t=349 the effects of the pump on concentration can be observed after t=349. Arriving t= 355 hr. pump operation starts again the effects on concentrations are observed at t=357 hr. after a 2 hours shift due to the influence of the tank. The shifting occurring at the entrance junction is transferred to the middle junctions as the time passes for the water to reach from the entrance to distant points. This cycle continues for all the calculation period and is valid for all the junctions except dead end ones.

Dead end junctions such as J-0672 are not affected from the pump schedule precisely but these junctions are definitely affected by the daily demand. When the daily demand is in increasing trend the concentration starts to increase as a result of the fresh water coming into the junction.

According to drinking water regulations, maximum chlorine concentration should not exceed 0.50 mg/l and minimum chlorine concentration should not be below 0.10 mg/l. Junctions considered in Şehit Kubilay District have chlorine concentrations which are in safe limits. This means chlorine concentration is enough for disinfection and does not exceed the maximum limits.

5.5.1.5 East Çiğdemtepe District

East Çiğdemtepe District consisting of 66 junctions, mostly receives water from the main line passing from the north-east part of the area. In addition to this line, it has boundaries with West Çiğdemtepe and Şehit Kubilay. As a result of this the system will perform differently due to the interactions between these boundaries. This means the chlorine concentrations will vary for these conditions.

The model is set up for the chlorine parameters and pump schedule as mentioned above then EPS study is performed for 384 hours.

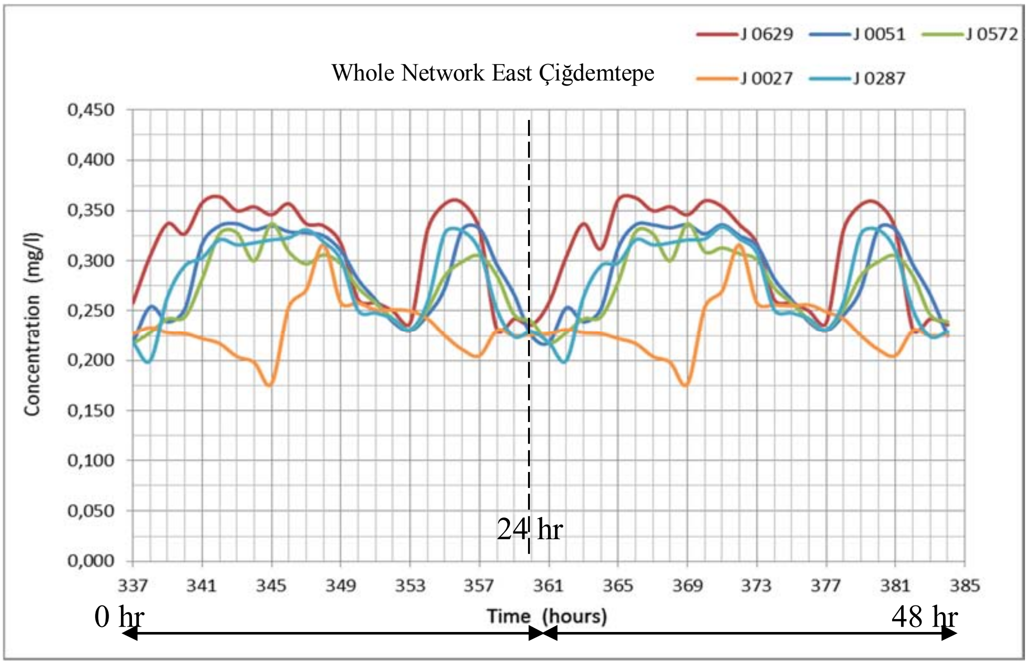


Figure 5.51: ASKI Pump Operation Chlorine Concentrations (East Çiğdemtepe Whole Network Case)

Examining the Figure 5.51, J-0629 which is at the entrance of the district has the highest concentration compared to other junctions in the area. J - 0051 has a lower concentration than J-0287 due to the small distance from the entrance.

The middle point junction J-0572 has lower concentrations compared to the entrance junctions, this junction and the surrounding middle point junctions show the overall average concentrations of the East Çiğdemtepe District. J-0027 is the most distant junction in East Çiğdemtepe District and this junction is defined as the dead end junction as it does not transmit water to neighboring junctions. The concentration of J-0027 is the lowest concentration in the district as also shown in Figure 5.51. Examining the overall concentrations of the district, although the peak occurring times shift due to the pump run and shut off times of the pumps, it is observed that in ASKI Pump operation Scenario there is not a certain change in the ordering of the junctions according to concentrations from maximum to minimum.

Examining the concentrations of the entrance point (J-0629) at East Çiğdemtepe District it is very clear that the concentration fluctuation is a direct reason of the pump operation. The pumps are in operation during the evening and night (19:00-07:00 hr) the observed concentrations are high during the night period between 337 - 342 hour time intervals. The pumps shutoff at t=343 hr and the concentrations start to drop at this point.

The pumps shutoff during 07:00–11:00 time intervals is expected to force the concentrations to drop at high rates. 3-SMS (LG) starts operation again between 11:00 – 16:00 time intervals referring to 347 – 352 time intervals yet the concentrations are still following almost smooth line until t=349 hr. This is due to the tank's influence on the junction when the pump is off, the junction receives water from the tank until t=349 the effects of the pump on concentration can be observed after t=349. Arriving t= 355 hr. pump operation starts again the effects on concentrations are observed at t=357 hr. after a 2 hours shift due to the influence of the tank. The shifting occurring at the entrance junction is transferred to the middle junctions as the time passes for the water to reach from the entrance to distant points. This cycle continues for all the calculation period and is valid for all the junctions except dead end ones.

Dead end junctions such as J-0027 are not affected from the pump schedule precisely but these junctions are definitely affected by the daily demand. When the daily demand is in increasing trend the concentration starts to increase as a result of the fresh water coming into the junction.

According to drinking water regulations, maximum chlorine concentration should not exceed 0.50 mg/l and minimum chlorine concentration should not be below 0.10 mg/l. Junctions considered in East Çiğdemtepe District have chlorine concentrations which are in safe limits. This means chlorine concentration is enough for disinfection and does not exceed the maximum limits.

5.5.1.6 West Çiğdemtepe District

West Çiğdemtepe District consisting of 111 junctions, mostly receives water from the main line passing from the north-east part of the area. In addition to this line, it has a boundary with East Çiğdemtepe.

As a result of this the system will perform differently due to the interactions between these boundaries. This means the chlorine concentrations will vary for these conditions. The model is set up for the chlorine parameters and pump schedule as mentioned above then EPS study is performed for 384 hours.

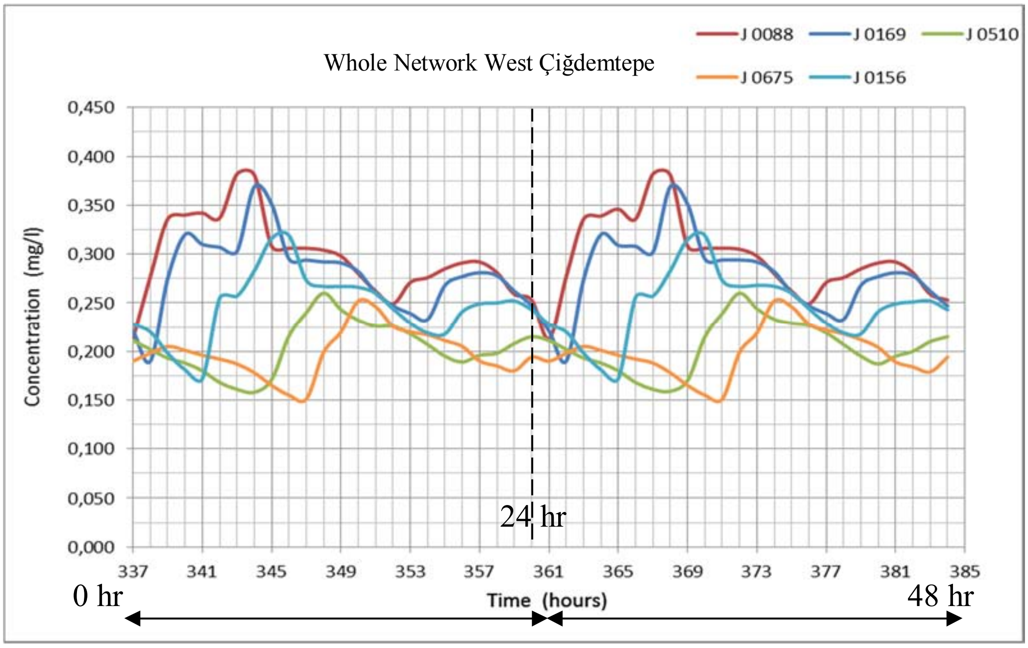


Figure 5.52: ASKI Pump Operation Chlorine Concentrations (West Çiğdemtepe Whole Network Case)

Examining the Figure 5.52, J-0088 which is at the entrance of the district has the highest concentration compared to other junctions in the area. J - 0169 has a lower concentration than J-0156 due to the small distance from the entrance. The middle point junction J-0510 has lower concentrations compared to the entrance junctions, this junction and the surrounding middle point junctions show the overall average concentrations of the West Çiğdemtepe District. J-0675 is the most distant junction in West Çiğdemtepe District and this junction is defined as the dead end junction as it does not transmit water to neighboring junctions. The concentration of J-0675 is the lowest concentration in the district as also shown in Figure 5.52. Examining the overall concentrations of the district, although the peak occurring times shift due to the pump run and shut off times of the pumps, it is observed that in ASKI Pump operation Scenario there is not a certain change in the ordering of the junctions according to concentrations from maximum to minimum.

Examining the concentrations of the entrance point (J-0088) at West Çiğdemtepe District it is very clear that the concentration fluctuation is a direct reason of the pump operation. The pumps are in operation during the evening and night (19:00-07:00 hr) the observed concentrations are high during the night period between 339 - 344 hour time intervals. The pumps shutoff at t=343 hr and the concentrations start to drop at t=344 hr.

The pumps shutoff during 07:00–11:00 time intervals is expected to force the concentrations to drop at high rates. 3-SMS (LG) starts operation again between 11:00 – 16:00 time intervals referring to 347 – 352 time intervals yet the concentrations are in decreasing trend until t=352 hr. This is due to the tank's influence on the junction when the pump is off, the junction receives water from the tank until t=352 the effects of the pump on concentration can be observed after t=352. Arriving t= 355 hr. pump operation starts again the effects on concentrations are observed at t=361 hr. after 6 hours shift due to the influence of the tank. The shifting occurring at the entrance junction is transferred to the middle junctions as the time passes for the water to reach from the entrance to distant points. This cycle continues for all the calculation period and is valid for all the junctions except dead end ones.

Dead end junctions such as J-0675 are not affected from the pump schedule precisely but these junctions are definitely affected by the daily demand. When the daily demand is in increasing trend the concentration starts to increase as a result of the fresh water coming into the junction.

According to drinking water regulations, maximum chlorine concentration should not exceed 0.50 mg/l and minimum chlorine concentration should not be below 0.10 mg/l. Junctions considered in West Çiğdemtepe District have chlorine concentrations which are in safe limits. This means chlorine concentration is enough for disinfection and does not exceed the maximum limits.

5.5.2 Insulated System (DMA Case)

Insulated system as previously mentioned means that all isolation valves are closed and the districts receive water from a single entrance.

5.5.2.1 Yayla District

Yayla District has no boundaries with other districts which makes it completely insulated. The model is set up for the chlorine parameters and pump schedule as mentioned above then EPS study is performed for 384 hours. Several junctions are examined and certain ones which represent the general concentrations of Yayla District are chosen. These junctions were shown in the previous Uninsulated System case. These junctions are named as J-0188, J-0211, J-0343, J-0348 and J-0291 as provided in Figure 5.13.

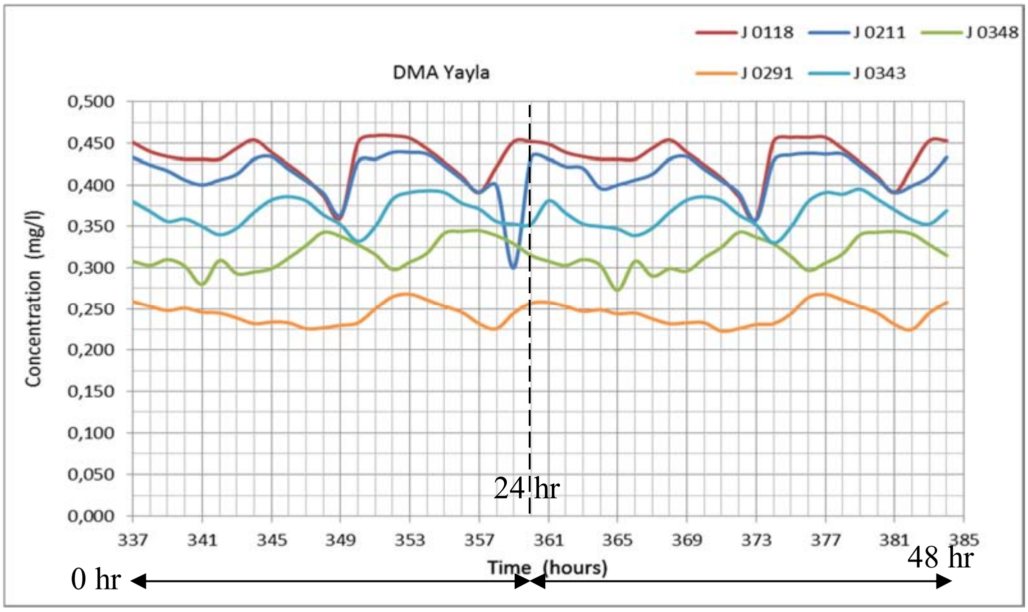


Figure 5.53: ASKI Pump Operation Chlorine Concentrations (Yayla DMA Case)

Examining the Figure 5.53, J-0118 which is at the entrance of the district has the highest concentration compared to other junctions in the area. J - 0211 has a lower concentration than J-0348 due to the small distance from the entrance. The middle point junction J-0343 has lower concentrations compared to the entrance junctions, this junction and the surrounding middle point junctions show the overall average concentrations of the Yayla District. J-0291 is the most distant junction in Yayla District and this junction is defined as the dead end junction as it does not transmit water to neighboring junctions. The concentration of J-0291 is the lowest concentration in the district as also shown in Figure 5.53. Examining the overall concentrations of the district, although the peak occurring times shift due to the pump run and shut off times of the pumps, it is observed that in ASKI Pump operation Scenario there is no change in the ordering of the junctions according to concentrations from maximum to minimum. In Yayla District the same comments previously made for the uninsulated case is also valid for insulated case.

Examining the concentrations of the entrance point (J-0118) at Yayla District it is very clear that the concentration fluctuation is a direct reason of the pump operation. The pumps are in operation during the evening and night (19:00-07:00 hr) the observed concentrations are high during the night period between 337 - 344 hour time intervals. The pumps shutoff at t=344 hr and the concentrations start to drop at this point.

The pumps shutoff during 07:00–11:00 time intervals is expected to force the concentrations to drop at high rates. 3-SMS (LG) starts operation again between 11:00 – 16:00 time intervals referring to 347 – 352 time intervals yet the concentrations are decreasing until t=349 hr. This is due to the tank's influence on the junction when the pump is off, the junction receives water from the tank until t=349 the effects of the pump on concentration can be observed after t=349. Arriving t= 355 hr. pump operation starts again the effects on concentrations are observed at t=357 hr. after a 2 hours shift due to the influence of the tank. The shifting occurring at the entrance junction is transferred to the middle junctions as the time passes for the water to reach from the entrance to distant points. This cycle continues for all the calculation period and is valid for all the junctions except dead end ones.
Dead end junctions such as J-0291 are not affected from the pump schedule precisely but these junctions are definitely affected by the daily demand. When the daily demand is in increasing trend the concentration starts to increase as a result of the fresh water coming into the junction.

According to drinking water regulations, maximum chlorine concentration should not exceed 0.50 mg/l and minimum chlorine concentration should not be below 0.10 mg/l. Also for insulated case junctions considered in Yayla District have chlorine concentrations which are in safe limits. This means chlorine concentration is enough for disinfection and does not exceed the maximum limits.

5.5.2.2 South Sancaktepe District

South Sancaktepe District consists of 115 junctions, including dead end junctions. This area, mostly receives water from the transmission line passing from the north part of the area. In Uninsulated case this district only receives water from the main transmission line. This means the chlorine concentrations will vary for these conditions. The model is set up for the chlorine parameters and physical conditions.

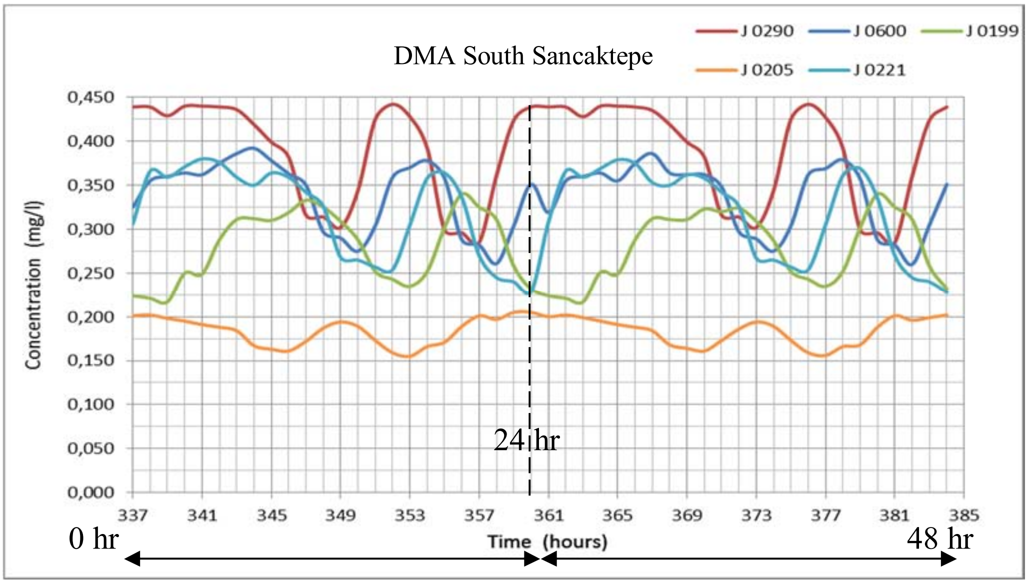


Figure 5.54: ASKI Pump Operation Chlorine Concentrations (South Sancaktepe DMA Case)

Examining Figure 5.54 concentrations of the entrance point (J-0290) at South Sancaktepe District it is very clear that the concentration fluctuation is a direct reason of the pump operation. Pumps are in operation during 19:00 - 07:00 time intervals as a reason the observed concentrations are high during the night period between 337 - 343 hour time intervals. The pumps shutoff at t=343 hr and the concentrations start to drop just at this time.

The pumps shutoff during 07:00–11:00 time intervals forcing the concentrations to drop at high rates. 3-SMS (LG) starts operation again between 11:00 – 16:00 time intervals referring to 347 – 352 time intervals yet the concentrations start to increase at t=349. This is due to the tank's influence on the junction when the pump is off, the junction receives water from the tank until t=349 the effects of the pump on concentration cannot be observed due to the mixing of the fresh concentrations from the pump conflict in the mainline and drop down before the arrival of South Sancaktepe entrance. Arriving t= 355 hr. pump operation starts again the effects on concentrations are observed at t=357 hr. and concentrations start to increase at a high rate.

Dead end junctions such as J-0205 are not affected from the pump schedule precisely but these junctions are definitely affected by the daily demand. When the daily demand is in increasing trend the concentration starts to increase as a result of the fresh water coming into the junction.

Compared to uninsulated case, in this case all junctions except J 0199 have the same fluctuations of chlorine concentrations. J 0199 follows a slightly more straight line compared to insulated case. This is probably due to the entrance of fresh water from the main line due to open isolation valves. Mixing of water decreases the sudden increase and drops in chlorine concentrations. In insulated case these valves are closed therefore concentrations fluctuate as a result of the pump operation.

According to drinking water regulations, maximum chlorine concentration should not exceed 0.50 mg/l and minimum chlorine concentration should not be below 0.10 mg/l. Also for insulated case, junctions considered in South Sancaktepe District have chlorine concentrations which are in safe limits. This means chlorine concentration is enough for disinfection and does not exceed the maximum limits.

5.5.2.3 North Sancaktepe District

North Sancaktepe District consisting of 92 junctions, mostly receives water from the main line passing from the south part of the area. In addition to this pipe line, it has a boundary with South Sancaktepe. In this scenario the isolation valves are closed therefore the district only receives water from the main line.

The model is set up for the chlorine parameters as mentioned above, and EPS study is performed for 384 hours.

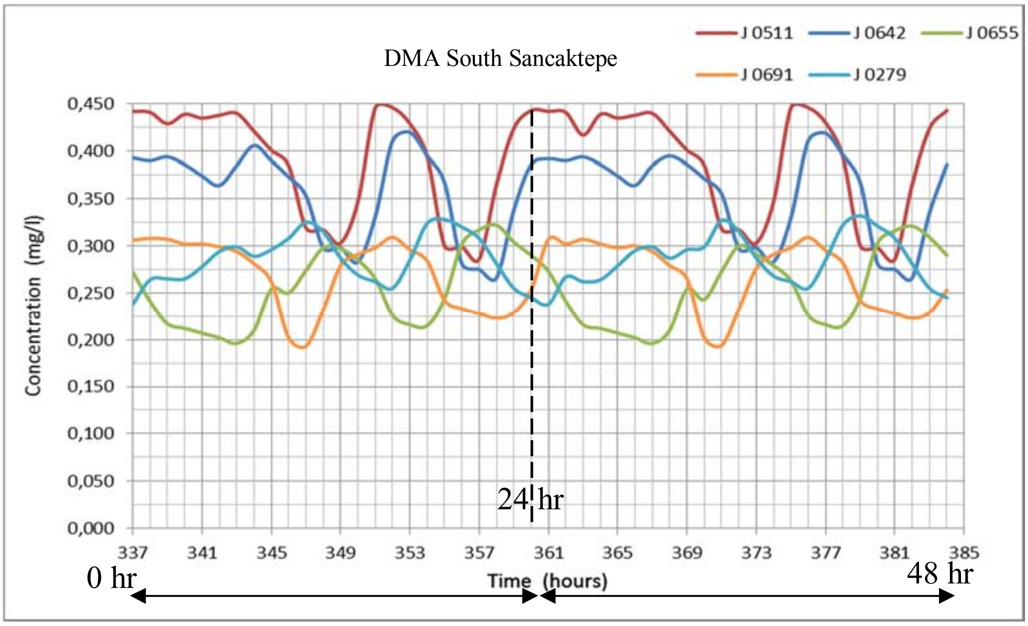


Figure 5.55: ASKI Pump Operation Chlorine Concentrations (North Sancaktepe DMA Case)

Examining the concentrations of the entrance point (J-0511) at North Sancaktepe District it is very clear that the concentration fluctuation is a direct reason of the pump operation. Pumps are in operation during 19:00-07:00 time intervals as a reason the observed concentrations are high during the night period between 337 - 343 hour time intervals. The pumps shutoff at t=343 hr and the concentrations start to drop just at this time.

The pumps shutoff during 07:00–11:00 time intervals forcing the concentrations to drop at high rates. 3-SMS (LG) starts operation again between 11:00 – 16:00 time intervals referring to 347 – 352 time intervals yet the concentrations start to increase at t=349. This is due to the tank's influence on the junction when the pump is off, the junction receives water from the tank until t=349 hr the effects of the pump on concentration cannot be observed until t=349 hr due to the mixing of the fresh concentrations from the pump conflict in the mainline and drop down before the arrival of North Sancaktepe entrance. Arriving t= 355 hr. pump operation starts again the effects on concentrations are observed at t=355 hr. and concentrations start to increase at a high rate.

Dead end junctions such as J-0691 are not affected from the pump schedule precisely but these junctions are definitely affected by the daily demand. When the daily demand is in increasing trend the concentration starts to increase as a result of the fresh water coming into the junction.

Compared to uninsulated case chlorine concentrations behave nearly the same except J-0279. This junction receives water from the main line in uninsulated case causing its concentrations to increase just as an entrance junction. In insulated case the valve is closed therefore this junction's behavior turns back to similar fluctuation behavior as observed in other junctions.

According to drinking water regulations, maximum chlorine concentration should not exceed 0.50 mg/l and minimum chlorine concentration should not be below 0.10 mg/l. Also for insulated case junctions considered in North Sancaktepe District have chlorine concentrations which are in safe limits. This means chlorine concentration is enough for disinfection and does not exceed the maximum limits.

5.5.2.4 Şehit Kubilay District

Şehit Kubilay District consisting of 156 junctions, mostly receives water from the main line passing from the north part of the area. In addition to this line, it has boundaries with East Çiğdemtepe and South Sancaktepe. In this scenario Şehit Kubilay District only receives water from the main line.

The model is set up for the chlorine parameters as mentioned above, and EPS study is performed for 384 hours.

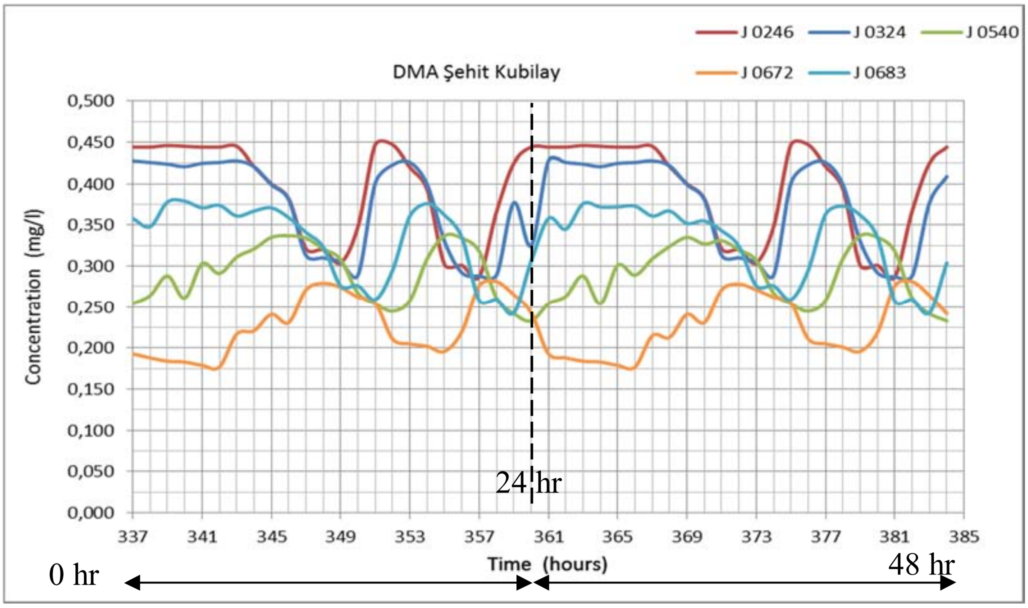


Figure 5.56: ASKI Pump Operation Chlorine Concentrations (Şehit Kubilay DMA Case)

Examining the Figure 5.56, J-0246 which is at the entrance of the district has the highest concentration compared to other junctions in the area. J - 0324 has a lower concentration than J-0246 due to the small distance from the entrance. The middle point junction J-0683 has lower concentrations compared to the entrance junctions, this junction and the surrounding middle point junctions show the overall average concentrations of the Şehit Kubilay District. J-0540 which is far away from the entrance has even 0.10 mg/l less concentration in comparison to the entrance junctions. J-0672 is the most distant junction in Şehit Kubilay District and this junction is defined as the dead end junction as it does not transmit water to neighboring junctions. The concentration of J-0672 is the lowest concentration in the district as also shown in Figure 5.56. Examining the overall concentrations of the district, although the peak occurring times shift due to the pump run and shut off times of the pumps, it is observed that in ASKI Pump operation Scenario there is not no change in the ordering of the junctions according to concentrations from maximum to minimum.

Examining the concentrations of the entrance point (J-0246) at Şehit Kubilay District it is very clear that the concentration fluctuation is a direct reason of the pump operation. The pumps are in operation during night (19:00-07:00 hr) the observed concentrations are high during the night period between 337 - 343 hour time intervals. The pumps shutoff at t=343 hr and the concentrations start to drop at this point.

The pumps shutoff during 07:00–11:00 time intervals is expected to force the concentrations to drop at high rates. 3-SMS (LG) starts operation again between 11:00 – 16:00 time intervals referring to 347 – 352 time intervals yet the concentrations are still following almost smooth line until t=349 hr. This is due to the tank's influence on the junction when the pump is off, the junction receives water from the tank until t=349 the effects of the pump on concentration can be observed after t=349. Arriving t= 355 hr. pump operation starts again the effects on concentrations are observed at t=357 hr. after a 2 hours shift due to the influence of the tank. The shifting occurring at the entrance junction is transferred to the middle junctions as the time passes for the water to reach from the entrance to distant points. This cycle continues for all the calculation period and is valid for all the junctions except dead end ones.

Dead end junctions such as J-0672 are not affected from the pump schedule precisely but these junctions are definitely affected by the daily demand. When the daily demand is in increasing trend the concentration starts to increase as a result of the fresh water coming into the junction.

Compared to uninsulated case chlorine concentrations behave nearly the same there are very small differences in concentrations yet the concentrations fluctuations follow almost the same pattern. There is not a certain difference between uninsulated and insulated case this is because there are not any isolation valves in connection with the main line.

According to drinking water regulations, maximum chlorine concentration should not exceed 0.50 mg/l and minimum chlorine concentration should not be below 0.10 mg/l. Also for insulated case junctions considered in Şehit Kubilay District have chlorine concentrations which are in safe limits. This means chlorine concentration is enough for disinfection and does not exceed the maximum limits.

5.5.2.5 East Çiğdemtepe District

East Çiğdemtepe District consisting of 66 junctions, mostly receives water from the main line passing from the north-east part of the area. In addition to this line, it has boundaries with West Çiğdemtepe and Şehit Kubilay. In this scenario the district only receives water from the main line.

The model is set up for the pump schedule and EPS study is performed for 384 hours.

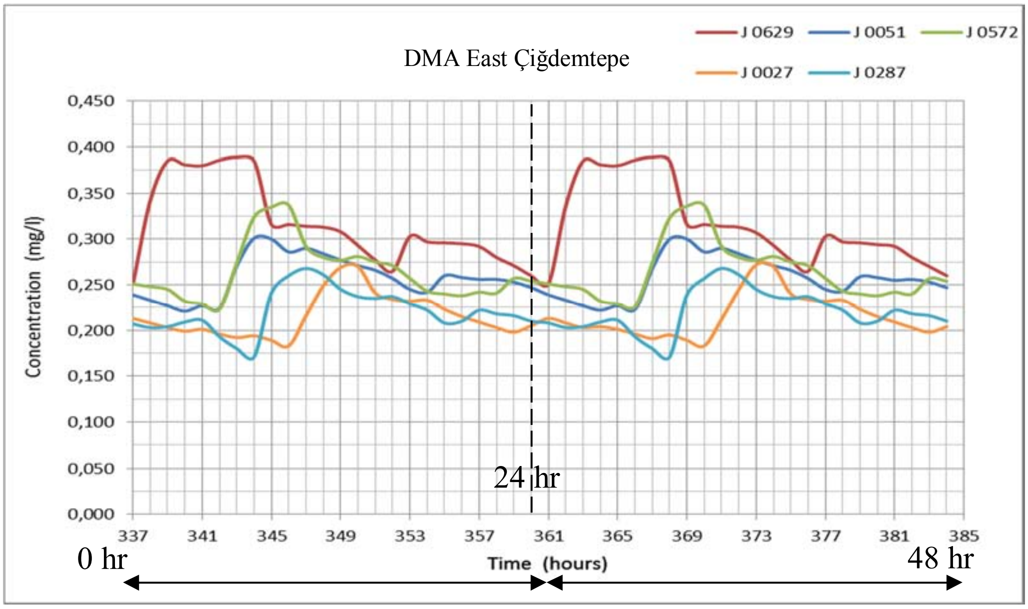


Figure 5.57: ASKI Pump Operation Chlorine Concentrations (East Çiğdemtepe DMA Case)

Examining the Figure 5.57, J-0629 which is at the entrance of the district has the highest concentration compared to other junctions in the area. J - 0051 has a lower concentration than J-0287 due to the small distance from the entrance. The middle point junction J-0572 has lower concentrations compared to the entrance junctions, this junction and the surrounding middle point junctions show the overall average concentrations of the East Çiğdemtepe District. J-0027 is the most distant junction in East Çiğdemtepe District and this junction is defined as the dead end junction as it does not transmit water to neighboring junctions. The concentration of J-0027 is the lowest concentration in the district as also shown in Figure 5.57. Examining the overall concentrations of the district, although the peak occurring times shift due to the pump run and shut off times of the pumps, it is observed that in ASKI Pump operation Scenario there is not a certain change in the ordering of the junctions according to concentrations from maximum to minimum.

Examining the concentrations of the entrance point (J-0629) at East Çiğdemtepe District it is very clear that the concentration fluctuation is a direct reason of the pump operation. The pumps are in operation during the evening and night (19:00-07:00 hr) the observed concentrations are high during the night period between 337 - 344 hour time intervals. The pumps shutoff at t=343 hr and the concentrations start to drop at t=343.

The pumps shutoff during 07:00–11:00 time intervals is expected to force the concentrations to drop at high rates. 3-SMS (LG) starts operation again between 11:00 – 16:00 time intervals referring to 347 – 352 time intervals yet the concentrations are still following almost smooth line until t=352 hr. This is due to the tank's influence on the junction when the pump is off, the junction receives water from the tank until t=352 the effects of the pump on concentration can be observed after t=352. Arriving t= 355 hr. pump operation starts again the effects on concentrations are observed at t=361 hr. after 6 hours shift due to the influence of the tank. The shifting occurring at the entrance junction is transferred to the middle junctions as the time passes for the water to reach from the entrance to distant points. This cycle continues for all the calculation period and is valid for all the junctions except dead end ones.

Dead end junctions such as J-0027 are not affected from the pump schedule precisely but these junctions are definitely affected by the daily demand. When the daily demand is in increasing trend the concentration starts to increase as a result of the fresh water coming into the junction.

Compared to uninsulated case chlorine concentrations behave nearly the same except the concentration values. The concentrations observed are greater in insulated case. This issue is due to the less mixing of fresh water entering the system due to the closed isolation valves.

According to drinking water regulations, maximum chlorine concentration should not exceed 0.50 mg/l and minimum chlorine concentration should not be below 0.10 mg/l. Junctions considered in East Çiğdemtepe District have chlorine concentrations which are in safe limits. This means chlorine concentration is enough for disinfection and does not exceed the maximum limits.

5.5.2.6 West Çiğdemtepe District

West Çiğdemtepe District consisting of 111 junctions, mostly receives water from the main line passing from the north-east part of the area. In addition to this line, it has a long boundary with East Çiğdemtepe. In this scenario the district only receives water from the main line.

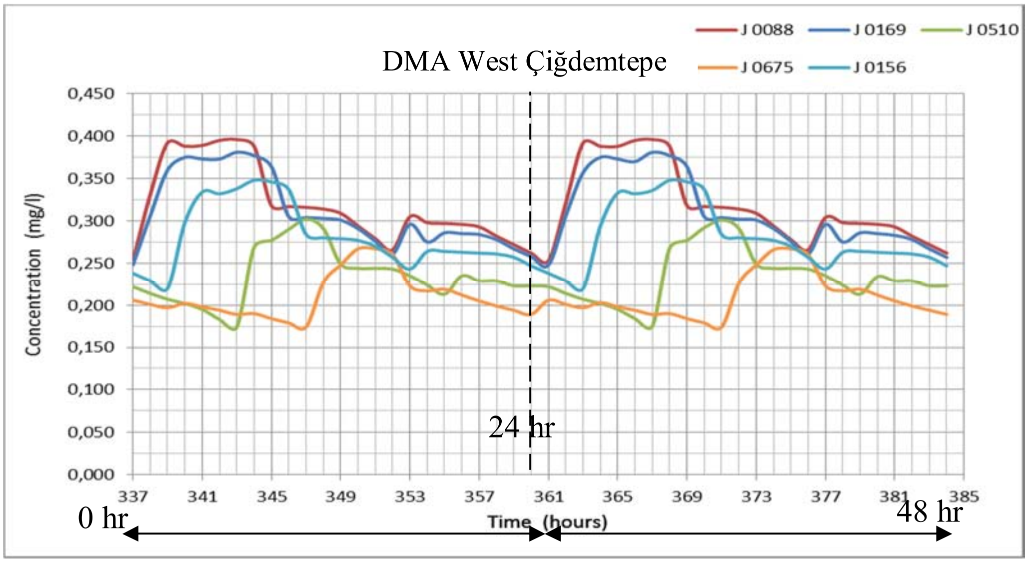


Figure 5.58: ASKI Pump Operation Chlorine Concentrations (West Çiğdemtepe DMA Case)

Examining the Figure 5.58, J-0088 which is at the entrance of the district has the highest concentration compared to other junctions in the area. J - 0169 has a lower concentration than J-0156 due to the small distance from the entrance.

The middle point junction J-0510 has lower concentrations compared to the entrance junctions, this junction and the surrounding middle point junctions show the overall average concentrations of the West Çiğdemtepe District. J-0675 is the most distant junction in West Çiğdemtepe District and this junction is defined as the dead end junction as it does not transmit water to neighboring junctions. The concentration of J-0675 is the lowest concentration in the district as also shown in Figure 5.58. Examining the overall concentrations of the district, although the peak occurring times shift due to the pump run and shut off times of the pumps, it is observed that in ASKI Pump operation Scenario there is not a certain change in the ordering of the junctions according to concentrations from maximum to minimum.

Examining the concentrations of the entrance point (J-0088) at West Çiğdemtepe District it is very clear that the concentration fluctuation is a direct reason of the pump operation. The pumps are in operation during the evening and night (19:00-07:00 hr) the observed concentrations are high during the night period between 339 – 344 hour time intervals. The pumps shutoff at t=343 hr and the concentrations start to drop at t=344 hr.

The pumps shutoff during 07:00–11:00 time intervals is expected to force the concentrations to drop at high rates. 3-SMS (LG) starts operation again between 11:00 – 16:00 time intervals referring to 347 – 352 time intervals yet the concentrations are still following almost smooth line until t=352 hr. This is due to the tank's influence on the junction when the pump is off, the junction receives water from the tank until t=352 the effects of the pump on concentration can be observed after t=352. Arriving t= 355 hr. pump operation starts again the effects on concentrations are observed at t=361 hr. after 6 hours shift due to the influence of the tank. The shifting occurring at the entrance junction is transferred to the middle junctions as the time passes for the water to reach from the entrance to distant points. This cycle continues for all the calculation period and is valid for all the junctions except dead end ones.

Dead end junctions such as J-0675 are not affected from the pump schedule precisely but these junctions are definitely affected by the daily demand. When the daily demand is in increasing trend the concentration starts to increase as a result of the fresh water coming into the junction.

Compared to uninsulated case chlorine concentrations behave nearly the same there are very small differences in concentrations yet the concentrations fluctuations does not follow the same pattern. In DMA case concentrations reach to peak point and remain constant for a certain duration. While in uninsulated case concentrations drop very sudden. This issue is related with the isolation valve located very close to the entrance junction when this valve is open fresh water concentration is dispersed into this area lowering the concentrations in the overall system.

According to drinking water regulations, maximum chlorine concentration should not exceed 0.50 mg/l and minimum chlorine concentration should not be below 0.10 mg/l. Also for insulated case junctions considered in West Çiğdemtepe District have chlorine concentrations which are in safe limits. This means chlorine concentration is enough for disinfection and does not exceed the maximum limits.

CHAPTER 6

DISCUSSION OF RESULTS

In this chapter, the results of the case study are discussed in further details, to be able to understand the water quality behavior of the pressure zone N8.3.

Being far from a source point also means the time passing for the fresh water to arrive into the junction takes longer time. To be able to explain this issue more clearly, a useful tool called *"Trace Analysis"* is used.

A trace analysis is performed when performing a water quality analysis to determine the percentage of water at each node coming from a specified node. Trace analysis provides the time of travel when the fresh water comes in to a junction from the source node. In this study trace nodes (junctions) are selected as Tank (T53) and Reservoir (P23). Although trace points might be selected as any hydraulic element of the network, selecting Tank and Reservoir as trace nodes provide travel time data for all junctions characterizing the whole system. Trace analysis is performed for every DMA and travel time for each junction is determined.

Travel time from the tank is available only if the water is being supplied from the Tank (T53), which means flow has to pass by the tank to the junction. Some junctions directly receive flow from the reservoir (P23) while some others are affected by the Tank (T53). Trace analysis also provides information of percentage of water being supplied from Tank (T53) at certain time intervals. In addition there are junctions that never receive flow from the Tank (T53), travel time values cannot be calculated for these junctions.

For uninsulated case the trace node is defined as the main entrance of the district such as J-0118(entrance junction of Yayla). For uninsulated case the water flow is not only transmitted from the main line which means there are also interactions with the neighboring zones. Therefore; trace node cannot be defined as the entrance node. For this case two trace nodes are defined, which are the reservoir and the Tank (T53). As a result, two different travel times are calculated. To be able to analyze the travel time as a whole, a weighted travel time equation (6.1) is offered. This equation also considers the concentrations of the trace nodes therefore; it is a more effective way of calculating travel time. While calculating the weighted travel time average chlorine concentrations of the Pump Station (P23) and Tank (T53) is taken into consideration.

$$W_t = [\, t(res) \times C(res) + t(tank) \times C(tank) \,] \;/\; [\, C(res) + C(tank) \,] \qquad (6.1)$$

W_t : Weighted travel time

t(res) : Travel time from pump station (P23) to junction

C(res) : Average concentration at the pump station (P23)

t(tank) : Travel time from Tank (T53) to junction

C(tank) : Average concentration at the Tank (T53)

6.1 Chlorine Concentration and Travel Time Relationship

Concentration travel time relationship is inspected throughout all scenarios. Yet *"Single Pump Operation Scenario"* travel time relationship is the only case presented in this study.

6.1.1 Yayla District

Yayla District chlorine concentration versus time graphs are provided in Chapter 5. In this chapter travel time values for the same junctions will be calculated using trace analysis. For the calculation of weighted travel time equation 6.1 is used for Uninsulated / Whole Network case. Since there is a single entrance for Insulated / DMA case weighted time is not need to be used.

Table 6.1: Yayla District Concentration and Travel Time Relationship (Uninsulated /Whole network)

Whole Network	Concentration		Travel Time	Entrance Conc.	Travel Time	Entrance Conc.	Weighted travel time (W_t)
	Max	Min	Reservoir		Tank		
	(mg/l)		(hrs.)	(mg/l)	(hrs.)	(mg/l)	(hrs.)
J 0118	0,456	0,429	2,00	0,500	N/A	0,275	2,00
J 0211	0,439	0,405	3,50	0,500	N/A	0,275	3,50
J 0343	0,395	0,343	5,75	0,500	N/A	0,275	5,75
J 0348	0,352	0,297	8,50	0,500	N/A	0,275	8,50
J 0291	0,269	0,233	13,25	0,500	N/A	0,275	13,25

Table 6.2: Yayla District Concentration and Travel Time Relationship (Insulated / DMA network)

DMA	Concentration		Travel Time
	Max	Min	
	(mg/l)		(hrs.)
J 0118	0,456	0,429	0,25
J 0211	0,439	0,405	1,00
J 0343	0,395	0,343	2,75
J 0348	0,352	0,297	7,50
J 0291	0,269	0,232	12,50

For the Uninsulated case (Table 6.1), J 0291 having a weighted travel time of 13.25 hours has the lowest concentration of chlorine, although J 0118 which has a weighted travel time of 2.00 hours has the maximum concentration of chlorine compared to other junctions. It is certain that, travel time and concentration are two dependent variables, as travel time increases chlorine concentrations drop down to lower values. As presented in Figure 6.1b minimum and maximum concentrations of chlorine and travel time values of junctions show a very high relationship. For maximum concentrations correlation coefficient R is 0.99, for minimum concentrations correlation coefficient R is 0.97.

For the Insulated case (Table 6.2), J 0291 having a travel time of 12.50 hours from the main entrance has the lowest concentration of chlorine, although J 0118 which has a travel time of 0.25 hours from the main entrance has the maximum concentration of chlorine compared to other junctions. The assumption “as travel time increases chlorine concentrations drop down to lower values” is also valid for DMA travel time. As presented in Figure 6.2b minimum and maximum concentrations of chlorine and travel time values of junctions show a very high relationship. Also for this case maximum concentrations correlation coefficient R is 0.99 and minimum concentrations correlation coefficient R is 0.97.

Figure 6.1a, 6.2a provides the concentration graphs again, to show the overall change under uninsulated and insulated cases. For DMA and whole network, maximum and minimum concentrations varying over time is plotted in Figure 6.1b and 6.2b respectively. Maximum and minimum values of concentration decrease as travel time increases.

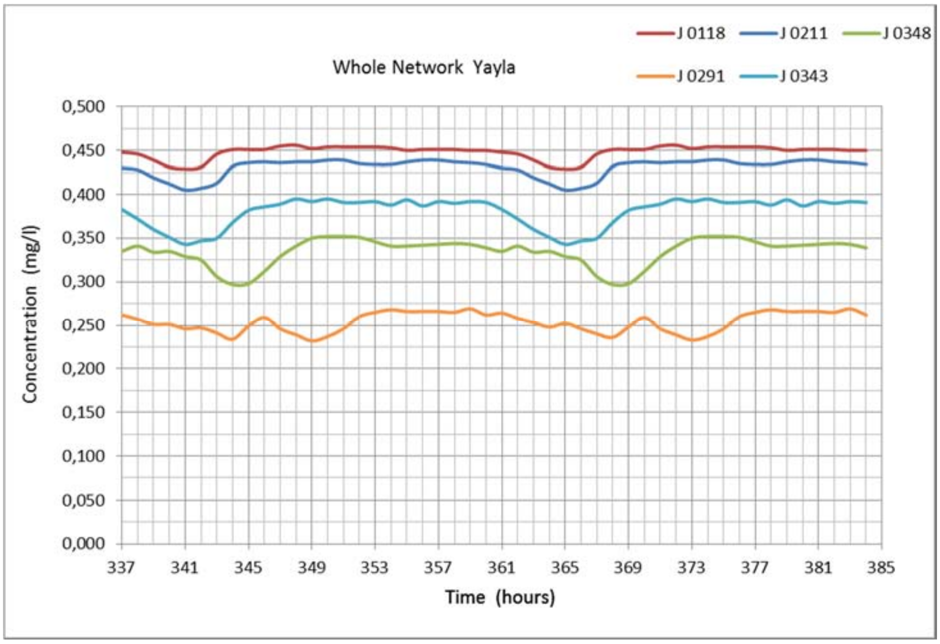


Figure 6.1a: Yayla District Chlorine Concentrations Single Pump Operation (Whole Network / Uninsulated Scenario)

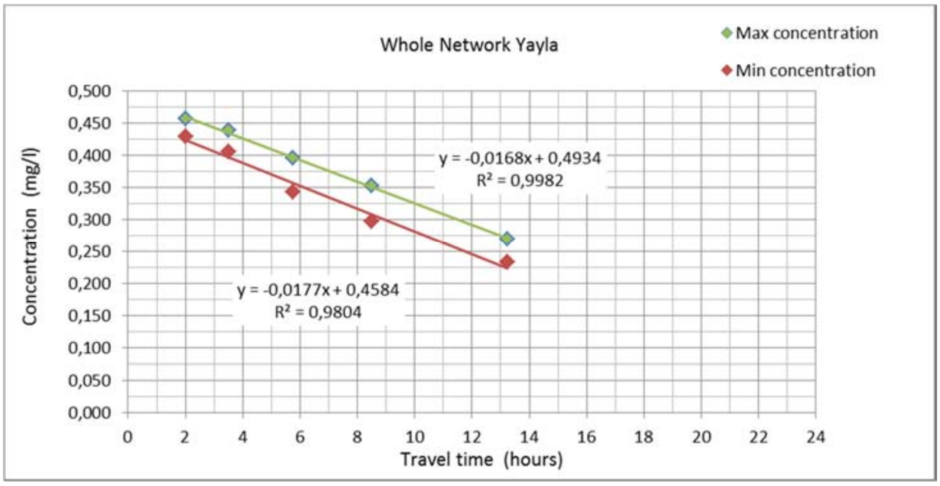


Figure 6.1b: Yayla District Concentration and Travel Time Relationship (Whole Network / Uninsulated Scenario)

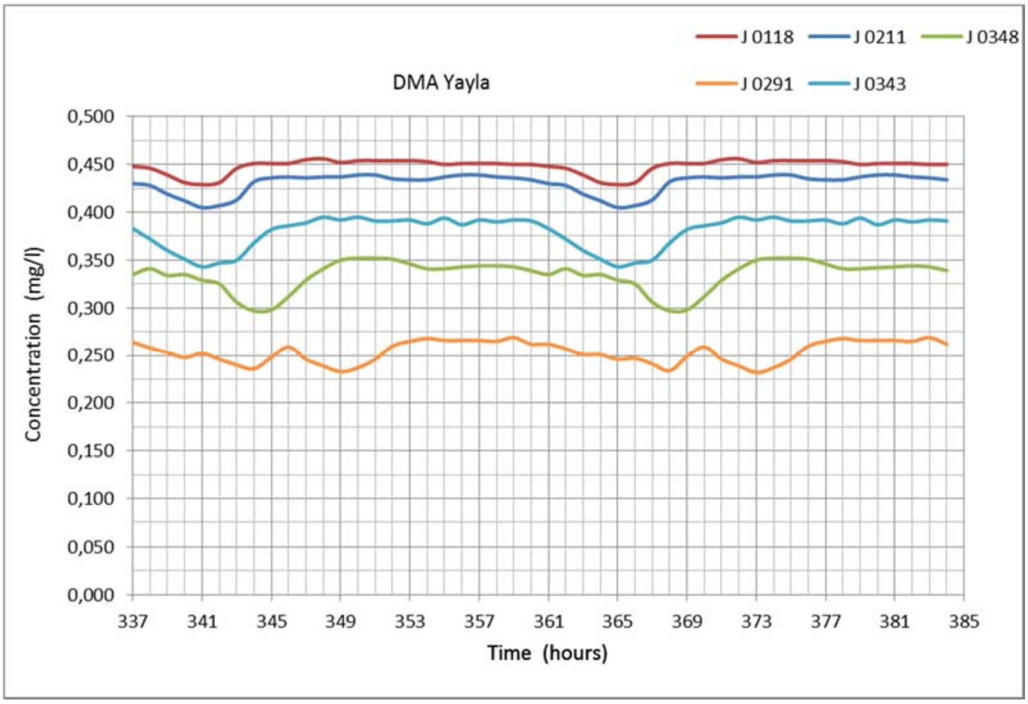


Figure 6.2a: Yayla District Chlorine Concentrations Single Pump Operation (Insulated / DMA Scenario)

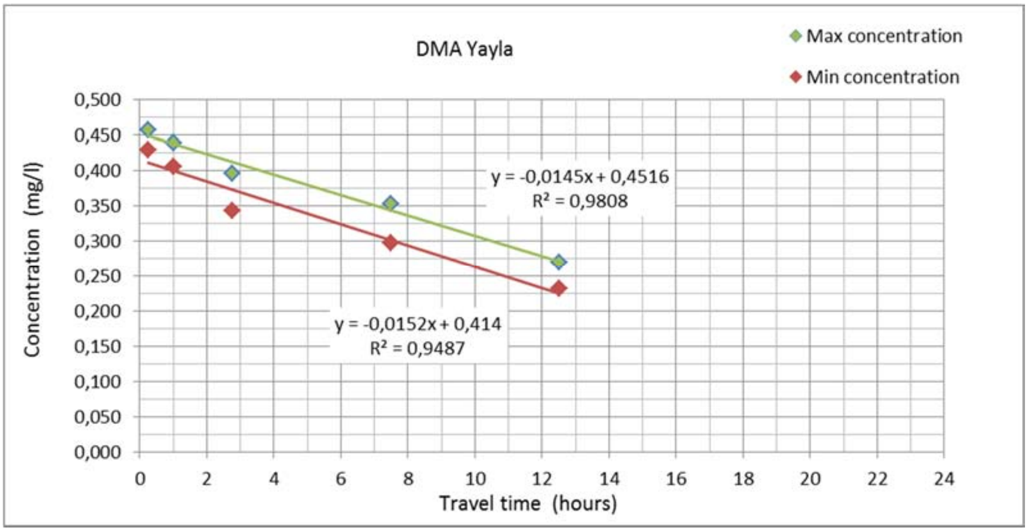


Figure 6.2b: Yayla District Concentration and Travel Time Relationship (Insulated / DMA Scenario)

6.1.2 South Sancaktepe District

South Sancaktepe District chlorine concentration versus time graphs are provided in Chapter 5. In this chapter travel time values for the same junctions will be calculated using trace analysis. For the calculation of weighted travel time equation 6.1 is used for Uninsulated / Whole Network case. Since there is a single entrance for Insulated / DMA case weighted time is not need to be used.

Table 6.3: South Sancaktepe District Concentration and Travel Time Relationship (Uninsulated /Whole network)

Whole Network	Concentration		Travel Time	Entrance Conc.	Travel Time	Entrance Conc.	Weighted travel time(W_t)
	Max	Min	Reservoir		Tank		
	(mg/l)		(hrs.)	(mg/l)	(hrs.)	(mg/l)	(hrs.)
J 0290	0,440	0,438	1,50	0,500	N/A	0,275	1,50
J 0600	0,377	0,318	4,75	0,500	N/A	0,275	4,75
J 0221	0,397	0,369	5,00	0,500	N/A	0,275	5,00
J 0199	0,313	0,269	11,75	0,500	N/A	0,275	11,75
J 0205	0,203	0,182	23,50	0,500	N/A	0,275	23,50

Table 6.4: South Sancaktepe District Concentration and Travel Time Relationship (Insulated / DMA network)

DMA	Concentration		Travel Time
	Max	Min	
	(mg/l)		(hrs.)
J 0290	0,440	0,438	0,25
J 0600	0,394	0,369	1,75
J 0221	0,384	0,351	4,75
J 0199	0,342	0,312	7,00
J 0205	0,220	0,204	19,50

For the Uninsulated case (Table 6.3), J-0205 having a weighted travel time of 23.50 hours has the lowest concentration of chlorine, although J-0290 which has a weighted travel time of 1.50 hours has the maximum concentration of chlorine compared to other junctions. It is certain that, travel time and concentration are two dependent variables, as travel time increases chlorine concentrations drop down to lower values. As presented in Figure 6.3b minimum and maximum concentrations of chlorine and travel time values of junctions show a very high relationship. For maximum concentrations correlation coefficient R is 0.99, for minimum concentrations correlation coefficient R is 0.94.

Figure 6.3a, 6.3b provides the concentration graphs again, to show the overall change under uninsulated and insulated cases. For the Insulated case (Table 6.4), J-0290 having a travel time of 0.25 hours from the main entrance has the highest concentration of chlorine, although J-0205 which has a travel time of 19.50 hours from the main entrance has the lowest concentration of chlorine compared to other junctions. The assumption “as travel time increases chlorine concentrations drop down to lower values” is also valid for DMA travel time. As presented in Figure 6.4b minimum and maximum concentrations of chlorine and travel time values of junctions show a very high relationship. Also for this case maximum concentrations correlation coefficient R is 0.99 and minimum concentrations correlation coefficient R is 0.97.

Figure 6.3a, 6.4a provides the concentration graphs again, to show the overall change under uninsulated and insulated cases. For DMA and whole network, maximum and minimum concentrations varying over time is plotted in Figure 6.3b and 6.4b respectively. Maximum and minimum values of concentration decrease as travel time increases.

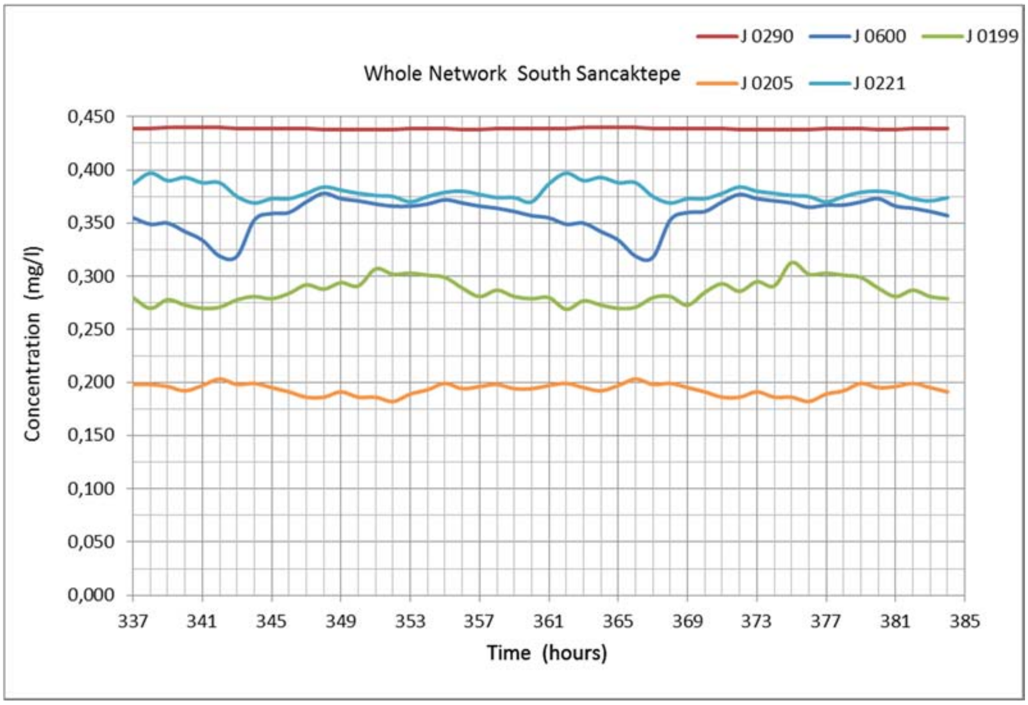


Figure 6.3a: South Sancaktepe Chlorine Concentrations District Single Pump Operation (Whole Network / Uninsulated Scenario)

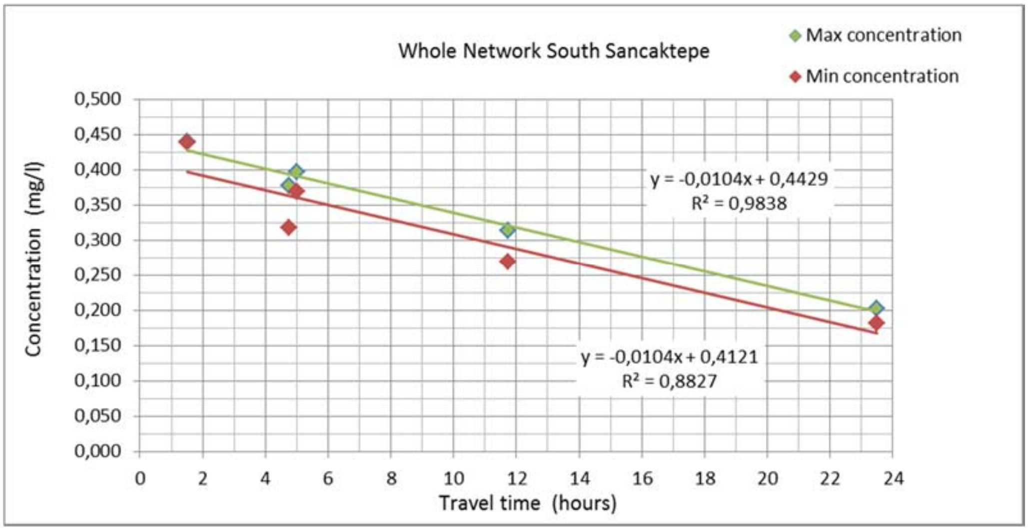


Figure 6.3b: South Sancaktepe District Concentration and Travel Time Relationship (Whole Network / Uninsulated Scenario)

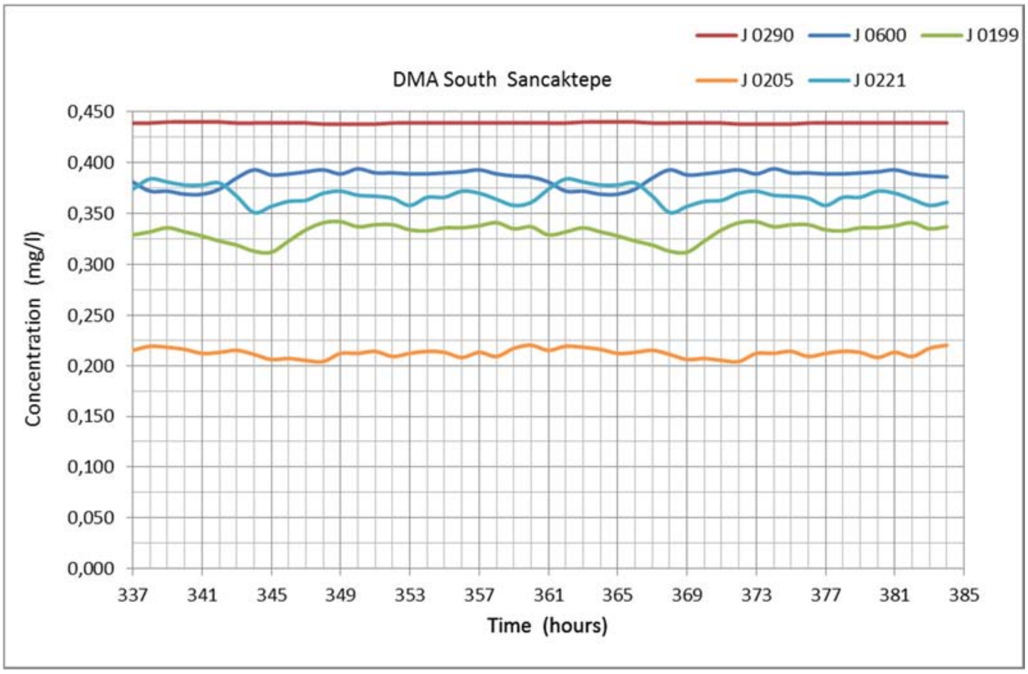


Figure 6.4a: South Sancaktepe Chlorine Concentrations District Single Pump Operation (Insulated / DMA Scenario)

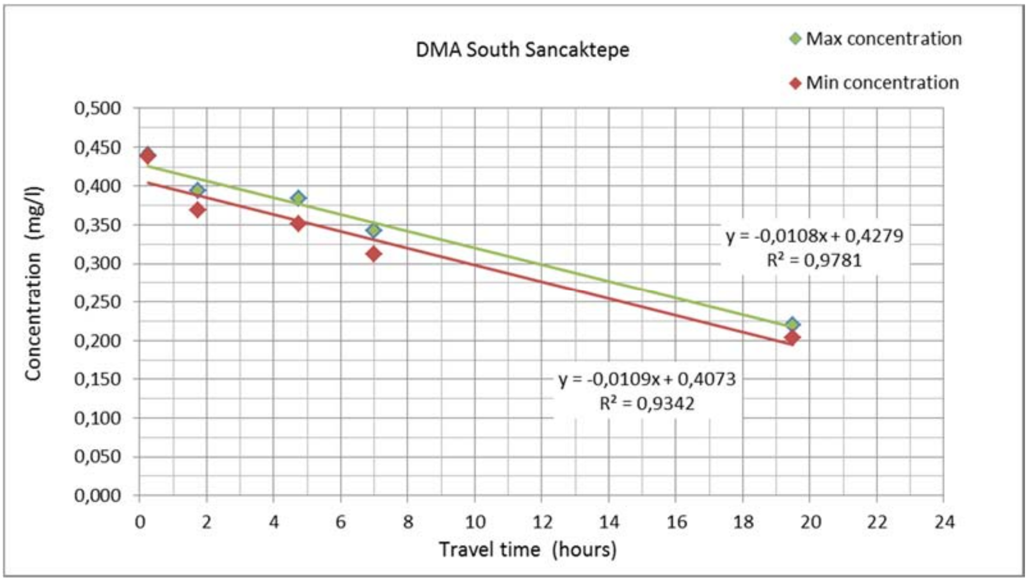


Figure 6.4b: South Sancaktepe District Concentration and Travel Time Relationship (Insulated / DMA Scenario)

6.1.3 North Sancaktepe District

North Sancaktepe District chlorine concentration versus time graphs are provided in Chapter 5. In this chapter travel time values for the same junctions will be calculated using trace analysis. For the calculation of weighted travel time equation 6.1 is used for Uninsulated / Whole Network case. Since there is a single entrance for Insulated / DMA case weighted time is not need to be used.

Table 6.5: North Sancaktepe District Concentration and Travel Time Relationship (Uninsulated /Whole network)

Whole Network	Concentration		Travel Time	Entrance Conc.	Travel Time	Entrance Conc.	Weighted travel time(W_t)
	Max	Min	Reservoir		Tank		
	(mg/l)		(hrs.)	(mg/l)	(hrs.)	(mg/l)	(hrs.)
J 0511	0,442	0,425	5,25	0,500	N/A	0,275	5,25
J 0642	0,397	0,355	4,25	0,500	N/A	0,275	4,25
J 0279	0,438	0,434	1,50	0,500	N/A	0,275	1,50
J 0655	0,309	0,254	11,00	0,500	N/A	0,275	11,00
J 0691	0,305	0,264	14,25	0,500	N/A	0,275	14,25

Table 6.6: North Sancaktepe District Concentration and Travel Time Relationship (Insulated / DMA network)

DMA	Concentration		Travel Time
	Max	Min	
	(mg/l)		(hrs.)
J 0511	0,443	0,435	0,25
J 0642	0,418	0,361	2,25
J 0279	0,352	0,313	7,50
J 0655	0,324	0,277	10,25
J 0691	0,326	0,290	13,50

For the Uninsulated case (Table 6.5), J-0691 having a weighted travel time of 14.25 hours has the lowest concentration of chlorine, although J-0511 and J-0279 which have weighted travel time of 5.25 and 1.50 hours respectively have the maximum concentrations of chlorine compared to other junctions. J 0279 has a direct connection with the main transmission line in whole network case resulting in higher concentrations as mentioned in Case Study chapter. For whole network case travel time of J 0279 is calculated as 1.50 hours while in DMA case travel time is 7.50 hours which results in the rapid concentration change. It is certain that, travel time and concentration are two dependent variables, as travel time increases chlorine concentrations drop down to lower values. As presented in Figure 6.5b minimum and maximum concentrations of chlorine and travel time values of junctions show a very high relationship. For maximum concentrations correlation coefficient R is 0.92, for minimum concentrations correlation coefficient R is 0.90.

For the Insulated case (Table 6.4), J-0511 having a travel time of 0.25 hours from the main entrance has the highest concentration of chlorine, although J-0691 which has a travel time of 13.50 hours from the main entrance has the lowest concentration of chlorine compared to other junctions. The assumption "as travel time increases chlorine concentrations drop down to lower values" is also valid for DMA travel time. As presented in Figure 6.6b minimum and maximum concentrations of chlorine and travel time values of junctions show a very high relationship. Also for this case maximum concentrations correlation coefficient R is 0.97 and minimum concentrations correlation coefficient R is 0.91.

Figure 6.5a, 6.6a provides the concentration graphs again, to show the overall change under uninsulated and insulated cases. For DMA and whole network, maximum and minimum concentrations varying over time is plotted in Figure 6.5b and 6.6b respectively. Maximum and minimum values of concentration decrease as travel time increases.

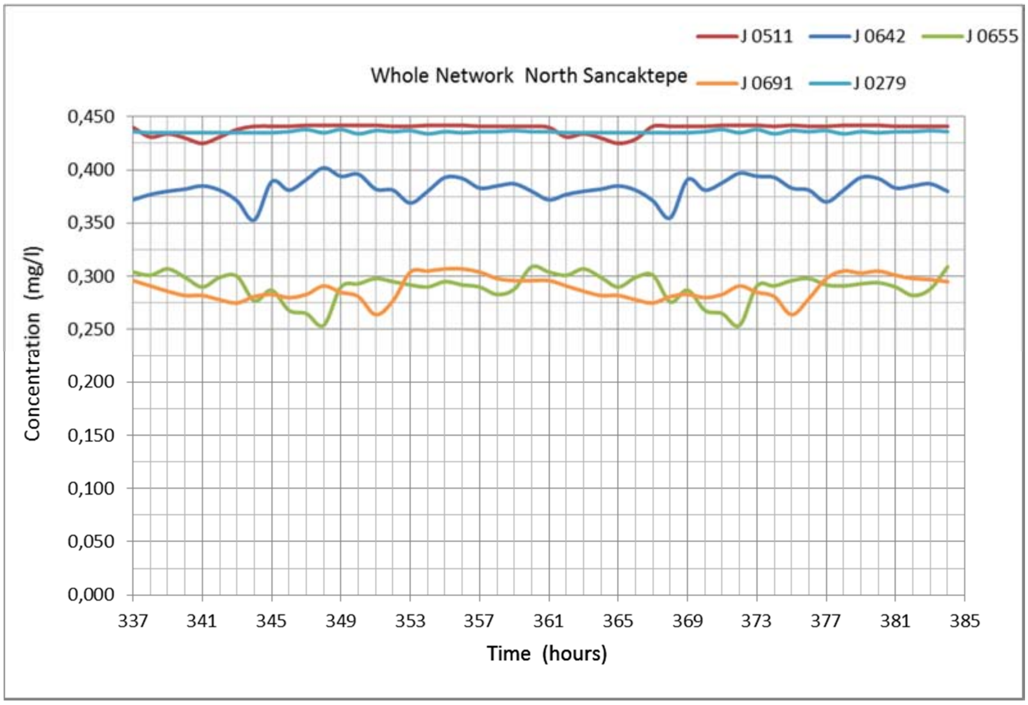


Figure 6.5a: North Sancaktepe District Chlorine Concentrations Single Pump Operation (Whole Network / Uninsulated Scenario)

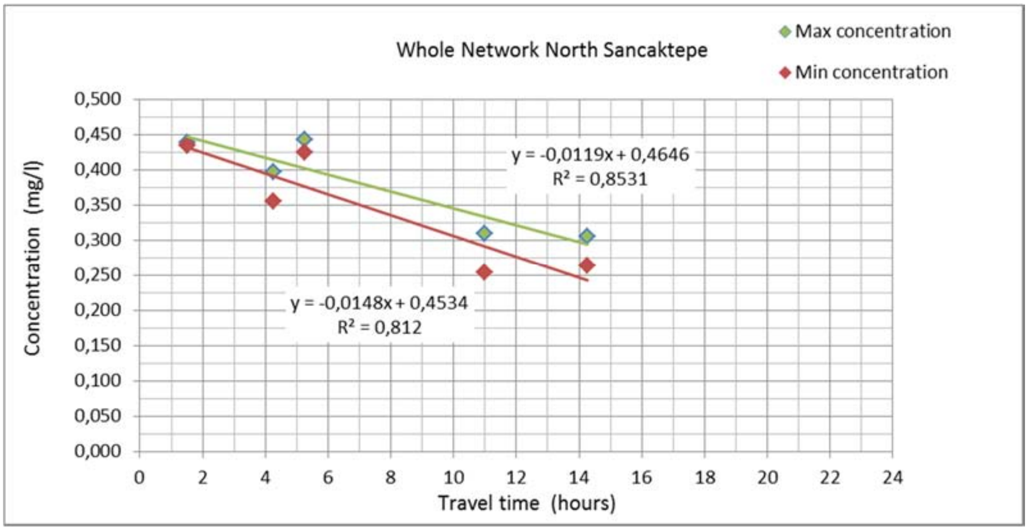


Figure 6.5b: North Sancaktepe District Concentration and Travel Time Relationship (Whole Network / Uninsulated Scenario)

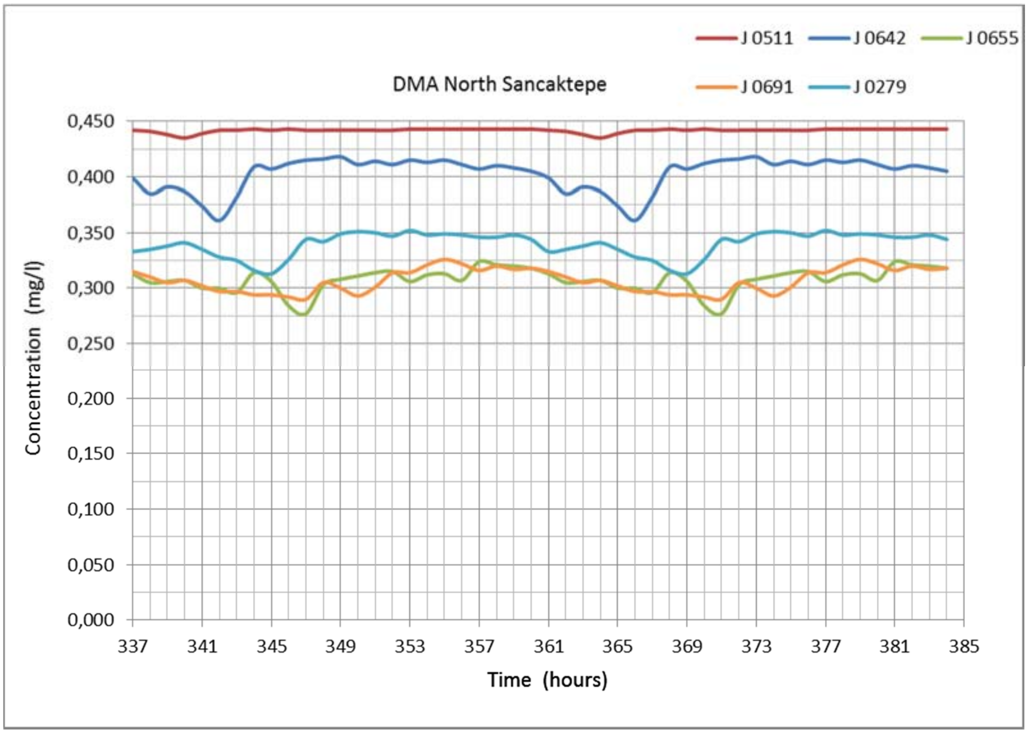


Figure 6.6a: North Sancaktepe District Chlorine Concentrations Single Pump Operation (Insulated / DMA Scenario)

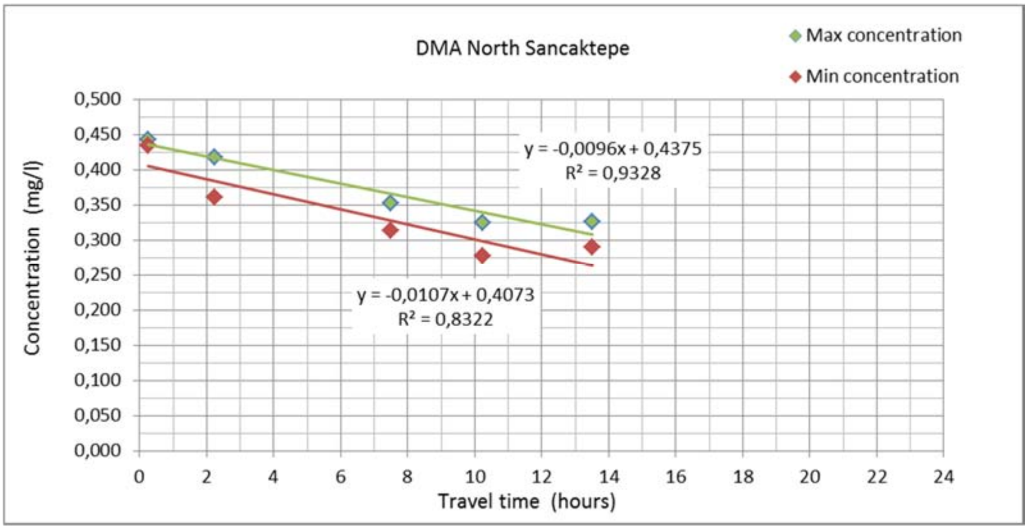


Figure 6.6b: North Sancaktepe District Concentration and Travel Time Relationship (Insulated / DMA Scenario)

6.1.4 Şehit Kubilay District

Şehit Kubilay District chlorine concentration versus time graphs are provided in Chapter 5. In this chapter travel time values for the same junctions will be calculated using trace analysis. For the calculation of weighted travel time equation 6.1 is used for Uninsulated / Whole Network case. Since there is a single entrance for Insulated / DMA case weighted time is not need to be used.

Table 6.7: Şehit Kubilay District Concentration and Travel Time Relationship (Uninsulated /Whole network)

Whole network	Concentration		Travel Time	Entrance Conc.	Travel Time	Entrance Conc.	Weighted travel time (W_t)
	Max	Min	Reservoir		Tank		
	(mg/l)		(hrs.)	(mg/l)	(hrs.)	(mg/l)	(hrs.)
J 0246	0,445	0,424	1,50	0,500	0,28	N/A	1,50
J 0324	0,429	0,415	1,75	0,500	0,28	N/A	1,75
J 0683	0,393	0,375	2,50	0,500	0,28	N/A	2,50
J 0540	0,356	0,322	4,25	0,500	0,28	N/A	4,25
J 0672	0,285	0,232	9,50	0,500	0,28	N/A	9,50

Table 6.8: Şehit Kubilay District Concentration and Travel Time Relationship (Insulated / DMA network)

DMA	Concentration		Travel Time
	Max	Min	
	(mg/l)		(hrs.)
J 0246	0,445	0,444	0,25
J 0324	0,430	0,424	0,50
J 0683	0,379	0,362	3,00
J 0540	0,347	0,309	4,25
J 0672	0,286	0,233	8,50

For the Uninsulated case (Table 6.7), J-0246 having a weighted travel time of 1.50 hours has the highest concentration of chlorine, although J-0672 which has a weighted travel time of 9.50 hours has the lowest concentration of chlorine compared to other junctions. It is certain that, travel time and concentration are two dependent variables, as travel time increases chlorine concentrations drop down to lower values. As presented in Figure 6.7b minimum and maximum concentrations of chlorine and travel time values of junctions show a very high relationship. For maximum concentrations correlation coefficient R is 0.97, for minimum concentrations correlation coefficient R is 0.98.

For the Insulated case (Table 6.8), J-0246 having a travel time of 0.25 hours from the main entrance has the highest concentration of chlorine, although J-0672 which has a travel time of 8.50 hours from the main entrance has the lowest concentration of chlorine compared to other junctions. The assumption “as travel time increases chlorine concentrations drop down to lower values” is also valid for DMA travel time. As presented in Figure 6.8b minimum and maximum concentrations of chlorine and travel time values of junctions show a very high relationship. Also for this case maximum concentrations correlation coefficient R is 0.99 and minimum concentrations correlation coefficient R is 0.99.

Figure 6.7a, 6.8a provides the concentration graphs again, to show the overall change under uninsulated and insulated cases. For DMA and whole network, maximum and minimum concentrations varying over time is plotted in Figure 6.7b and 6.8b respectively. Maximum and minimum values of concentration decrease as travel time increases.

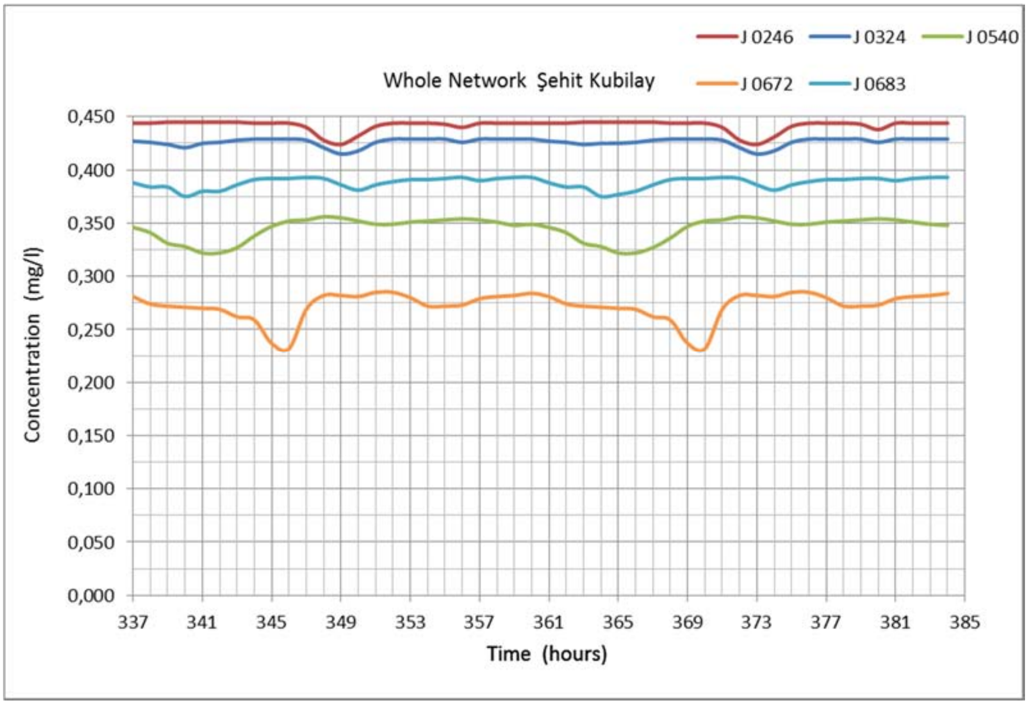


Figure 6.7a: Şehit Kubilay District Chlorine Concentrations Single Pump Operation (Whole Network / Uninsulated Scenario)

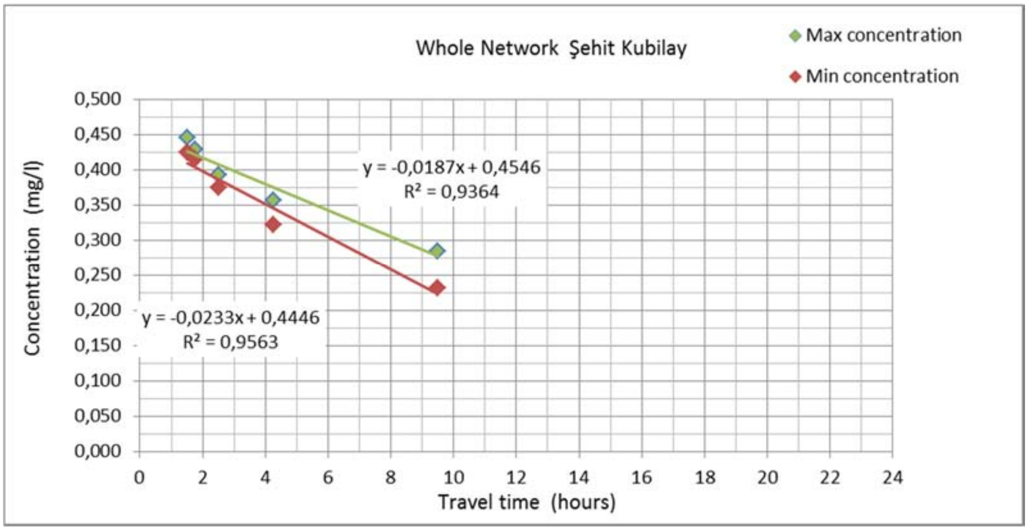


Figure 6.7b: Şehit Kubilay District Concentration and Travel Time Relationship (Whole Network / Uninsulated Scenario)

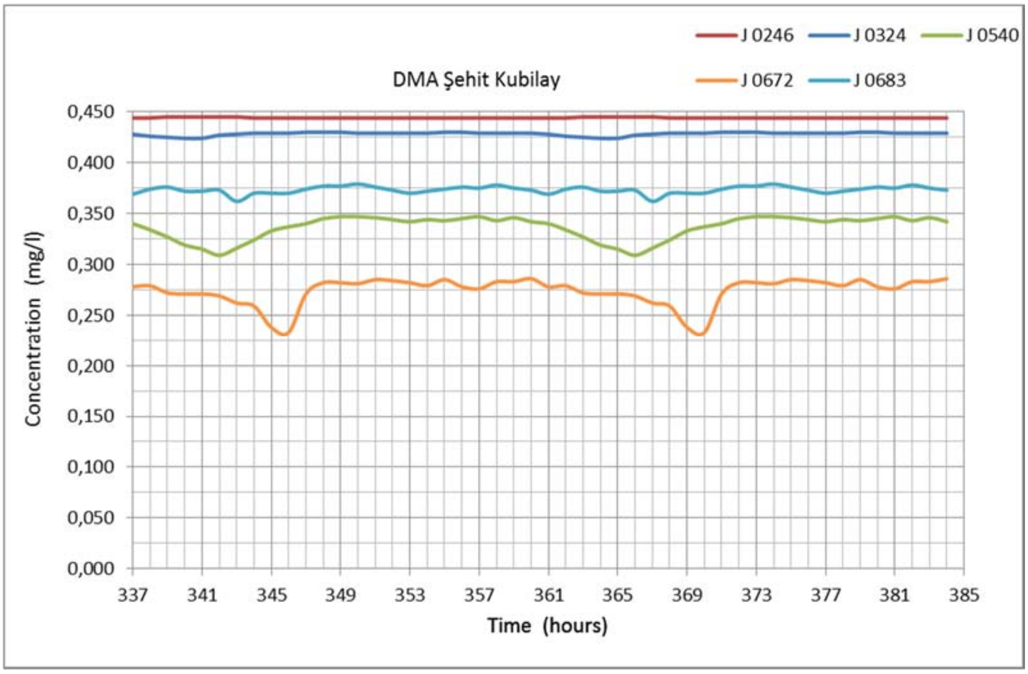


Figure 6.8a: Şehit Kubilay District Chlorine Concentrations Single Pump Operation (Insulated / DMA Scenario)

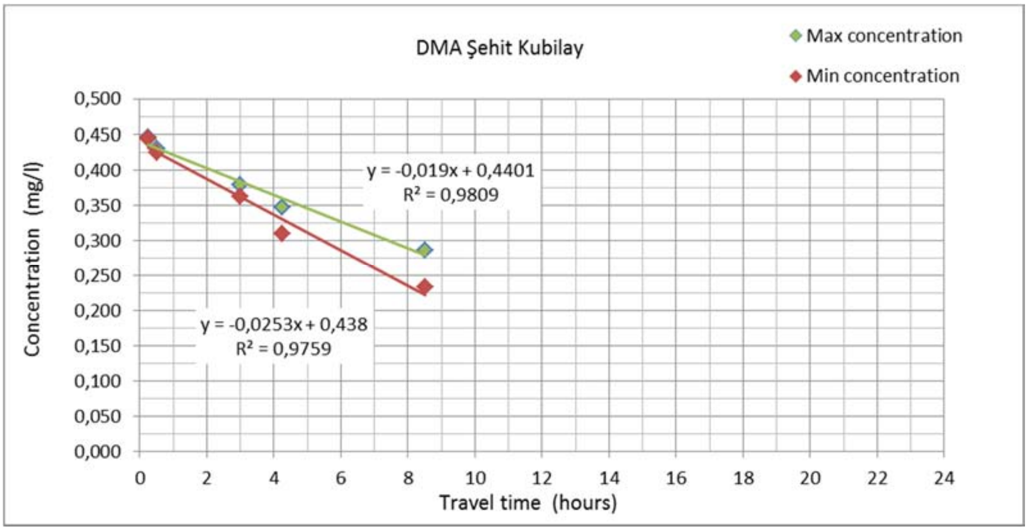


Figure 6.8b: Şehit Kubilay District Concentration and Travel Time Relationship (Insulated / DMA Scenario)

6.1.5 West Çiğdemtepe District

West Çiğdemtepe District chlorine concentration versus time graphs are provided in Chapter 5. In this chapter travel time values for the same junctions will be calculated using trace analysis. For the calculation of weighted travel time equation 6.1 is used for Uninsulated / Whole Network case. Since there is a single entrance for Insulated / DMA case weighted time is not need to be used.

Table 6.9: West Çiğdemtepe District Concentration and Travel Time Relationship (Uninsulated /Whole network)

Whole Network	Concentration		Travel Time	Entrance Conc.	Travel Time	Entrance Conc.	Weighted travel time(W_t)
	Max	Min	Reservoir		Tank		
	(mg/l)		(hrs.)	(mg/l)	(hrs.)	(mg/l)	(hrs.)
J 0088	0,363	0,220	4,00	0,500	10,75	0,275	6,40
J 0169	0,353	0,213	4,75	0,500	11,00	0,275	6,97
J 0156	0,311	0,188	6,50	0,500	11,75	0,275	8,36
J 0510	0,261	0,165	9,25	0,500	14,00	0,275	10,94
J 0675	0,252	0,156	11,75	0,500	16,25	0,275	13,35

Table 6.10: West Çiğdemtepe District Concentration and Travel Time Relationship (Insulated / DMA network)

DMA	Concentration		Travel Time
	Max	Min	
	(mg/l)		(hrs.)
J 0088	0,388	0,271	0,25
J 0169	0,373	0,260	0,25
J 0156	0,341	0,240	1,00
J 0510	0,294	0,211	5,00
J 0675	0,264	0,183	10,75

For the Uninsulated case (Table 6.9), J-0088 having a weighted travel time of 6.40 hours has the highest concentration of chlorine, although J-0675 which has a weighted travel time of 13.35 hours has the maximum concentration of chlorine compared to other junctions. It is certain that, travel time and concentration are two dependent variables, as travel time increases chlorine concentrations drop down to lower values. As presented in Figure 6.9b minimum and maximum concentrations of chlorine and travel time values of junctions show a very high relationship. For maximum concentrations correlation coefficient R is 0.96, for minimum concentrations correlation coefficient R is 0.97.

For the Insulated case (Table 6.10), J-0675 having a travel time of 10.75 hours from the main entrance has the lowest concentration of chlorine, although J-0088 which has a travel time of 0.25 hours from the main entrance has the maximum concentration of chlorine compared to other junctions. The assumption "as travel time increases chlorine concentrations drop down to lower values" is also valid for DMA travel time. As presented in Figure 6.10b minimum and maximum concentrations of chlorine and travel time values of junctions show a very high relationship. Also for this case maximum concentrations correlation coefficient R is 0.93 and minimum concentrations correlation coefficient R is 0.95.

Figure 6.9a, 6.10a provides the concentration graphs again, to show the overall change under uninsulated and insulated cases. For DMA and whole network, maximum and minimum concentrations varying over time is plotted in Figure 6.9b and 6.10b respectively. Maximum and minimum values of concentration decrease as travel time increases.

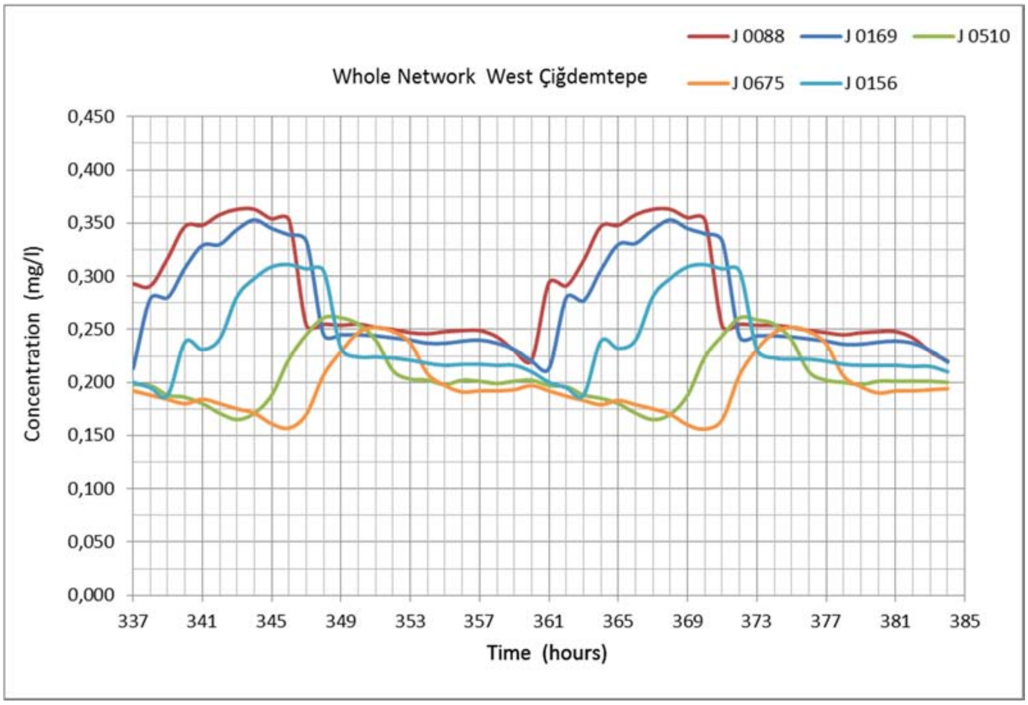


Figure 6.9a: West Çiğdemtepe District Chlorine Concentrations Single Pump Operation (Whole Network / Uninsulated Scenario)

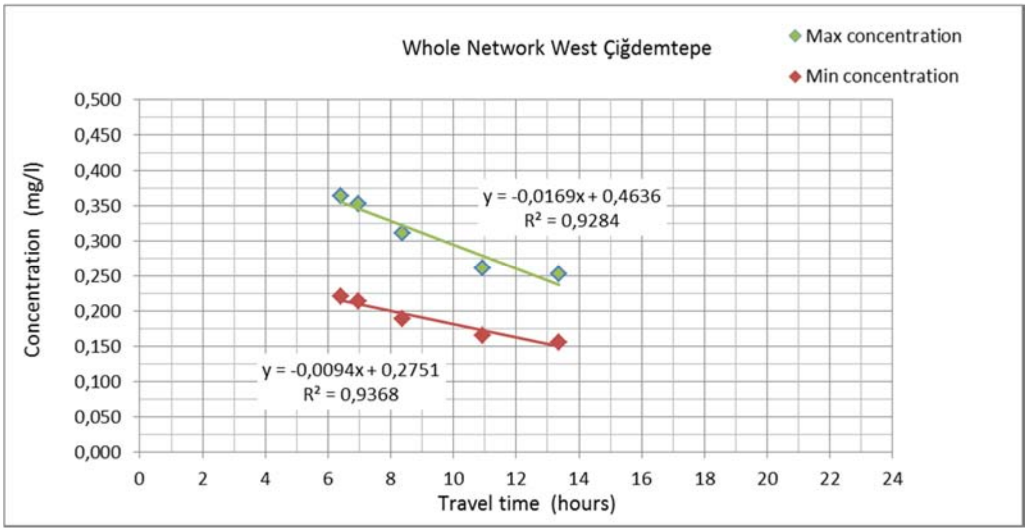


Figure 6.9b: West Çiğdemtepe District Concentration and Travel Time Relationship (Whole Network / Uninsulated Scenario)

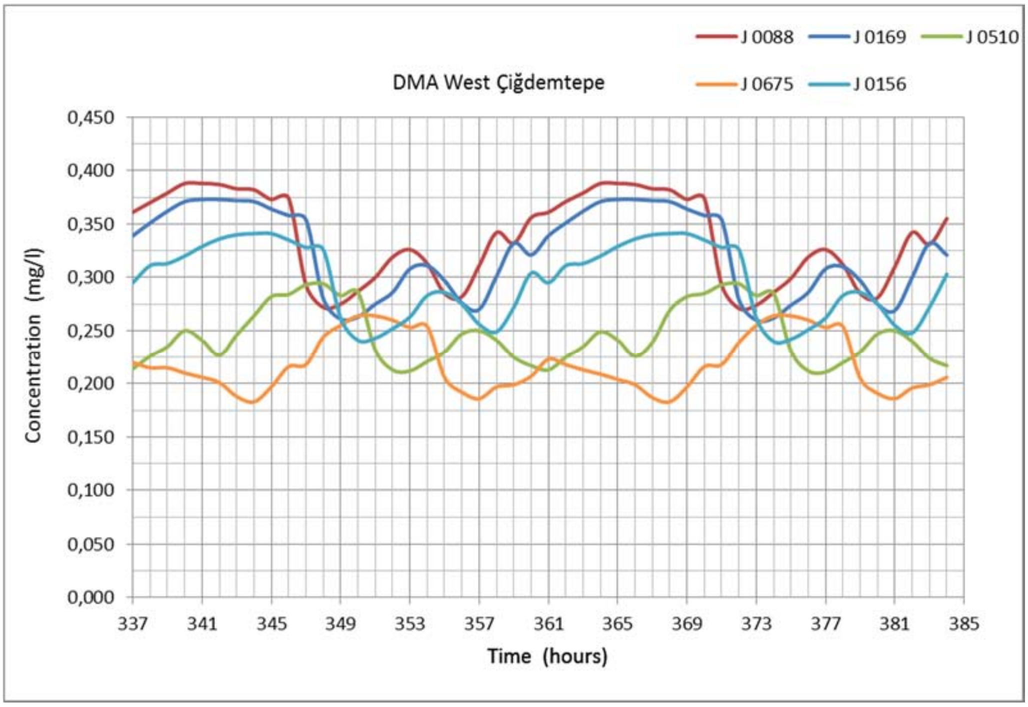


Figure 6.10a: West Çiğdemtepe District Chlorine Concentrations Single Pump Operation (Insulated / DMA Scenario)

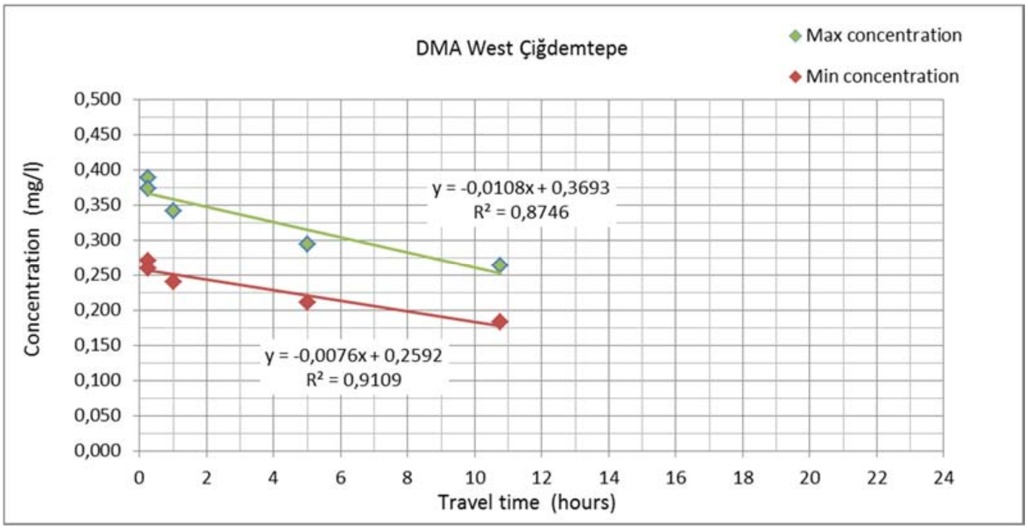


Figure 6.10b: West Çiğdemtepe District Concentration and Travel Time Relationship (Insulated / DMA Scenario)

6.1.6 East Çiğdemtepe District

East Çiğdemtepe District chlorine concentration versus time graphs are provided in Chapter 5. In this chapter travel time values for the same junctions will be calculated using trace analysis. For the calculation of weighted travel time equation 6.1 is used for Uninsulated / Whole Network case. Since there is a single entrance for Insulated / DMA case weighted time is not need to be used.

Table 6.11: East Çiğdemtepe District Concentration and Travel Time Relationship (Uninsulated /Whole network)

Whole network	Concentration		Travel Time	Entrance Conc.	Travel Time	Entrance Conc.	Weighted travel time(W_t)
	Max	Min	Reservoir		Tank		
	(mg/l)		(hrs.)	(mg/l)	(hrs.)	(mg/l)	(hrs.)
J 0629	0,367	0,336	5,75	0,500	N/A	0,275	5,75
J 0051	0,342	0,312	6,50	0,500	N/A	0,275	6,50
J 0287	0,344	0,300	6,75	0,500	N/A	0,275	6,75
J 0572	0,333	0,280	6,25	0,500	11,50	0,275	8,11
J 0027	0,302	0,175	10,50	0,500	14,75	0,275	12,01

Table 6.12: East Çiğdemtepe District Concentration and Travel Time Relationship (Insulated / DMA network)

DMA	Concentration		Travel Time
	Max	Min	
	(mg/l)		(hrs.)
J 0629	0,380	0,270	0,25
J 0051	0,321	0,247	2,75
J 0287	0,279	0,196	7,50
J 0572	0,333	0,239	5,50
J 0027	0,274	0,187	10,00

For the Uninsulated case (Table 6.11), J-0027 having a weighted travel time of 12.01 hours has the lowest concentration of chlorine, although J-0629 which has a weighted travel time of 5.75 hours has the maximum concentration of chlorine compared to other junctions. It is certain that, travel time and concentration are two dependent variables, as travel time increases chlorine concentrations drop down to lower values. As presented in Figure 6.11b minimum and maximum concentrations of chlorine and travel time values of junctions show a very high relationship. For maximum concentrations correlation coefficient R is 0.99, for minimum concentrations correlation coefficient R is 0.96.

For the Insulated case (Table 6.12), J-0027 having a travel time of 10.00 hours from the main entrance has the lowest concentration of chlorine, although J-0629 which has a travel time of 0.25 hours from the main entrance has the maximum concentration of chlorine compared to other junctions. The assumption "as travel time increases chlorine concentrations drop down to lower values" is also valid for DMA travel time. As presented in Figure 6.12b minimum and maximum concentrations of chlorine and travel time values of junctions show a very high relationship. Also for this case maximum concentrations correlation coefficient R is 0.92 and minimum concentrations correlation coefficient R is 0.97.

Figure 6.11a, 6.12a provides the concentration graphs again, to show the overall change under uninsulated and insulated cases. For DMA and whole network, maximum and minimum concentrations varying over time is plotted in Figure 6.11b and 6.12b respectively. Maximum and minimum values of concentration decrease as travel time increases.

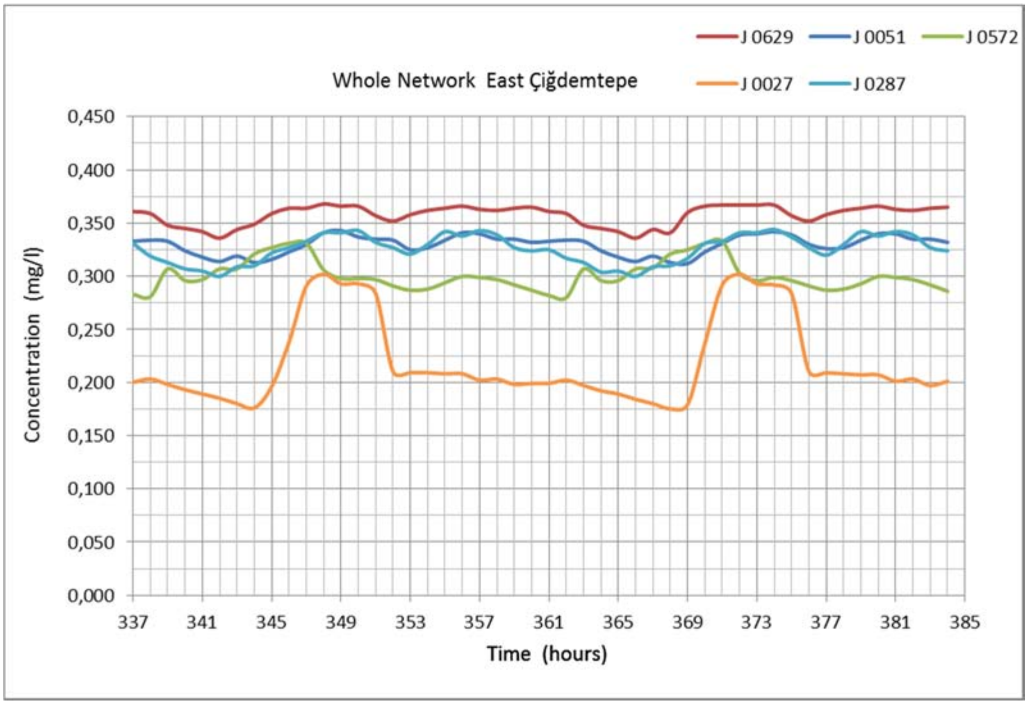


Figure 6.11a: East Çiğdemtepe District Chlorine Concentrations Single Pump Operation (Whole Network / Uninsulated Scenario)

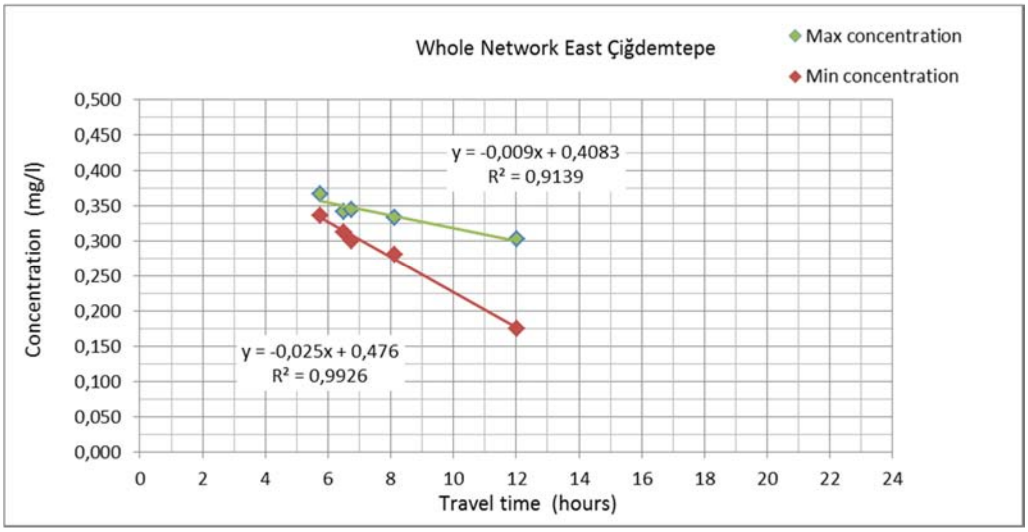


Figure 6.11b: East Çiğdemtepe District Chlorine Concentrations Concentration and Travel Time Relationship (Whole Network / Uninsulated Scenario)

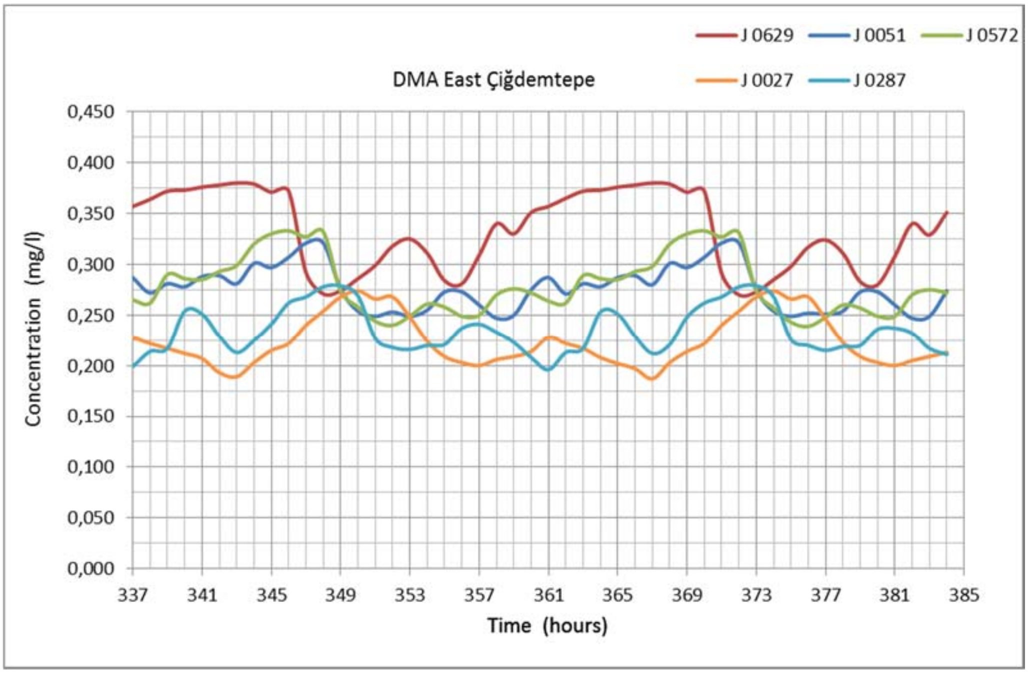


Figure 6.12a: East Çiğdemtepe District Chlorine Concentrations Single Pump Operation (Insulated / DMA Scenario)

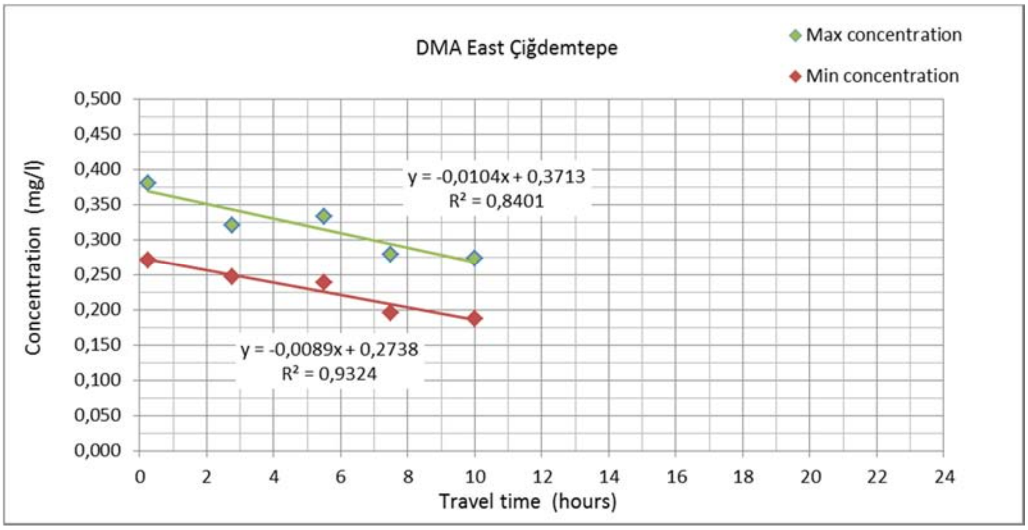


Figure 6.12b: East Çiğdemtepe District Concentration and Travel Time Relationship (Insulated / DMA Scenario)

6.2 Minimum Chlorine Concentrations

In this case study mainly 3 different scenarios are studied. These are (i)*"Continuous Single Pump Operation"*, (ii) *"Multi Pumps Operating According to Optimum Pump Schedule"* and (iii) *"ASKI Pump Operation"* for Uninsulated/Insulated cases. In the previous chapter, several junctions at the districts are examined to present a brief view of the area for chlorine concentrations. However, the locations where minimum concentrations occur are not yet known, to overcome this issue the model is examined for the last 48 hours examining the minimum concentration occurring junctions.

6.2.1 Yayla District

Minimum concentrations for Yayla District is presented in Figure 6.13. It is observed that minimum concentrations occur at the dead end point junctions. These minimum concentration occurring junctions are J-0291 for continuous pump operation, J-0382 for Optimum Pump Schedule and J-0123 for ASKI Pump Operation. The extreme minimum concentration occurs in Optimum Pump Schedule Scenario this is due to the shut off of the pumps for a long period. This minimum concentration which is 0.133 mg/l is still in the limits required for drinking water standards.

Yayla District has no isolation valves therefore Uninsulated or Insulated Conditions of the system act actually the same meaning the minimum concentrations and magnitudes are the same for both Uninsulated and Insulated Conditions of the district.

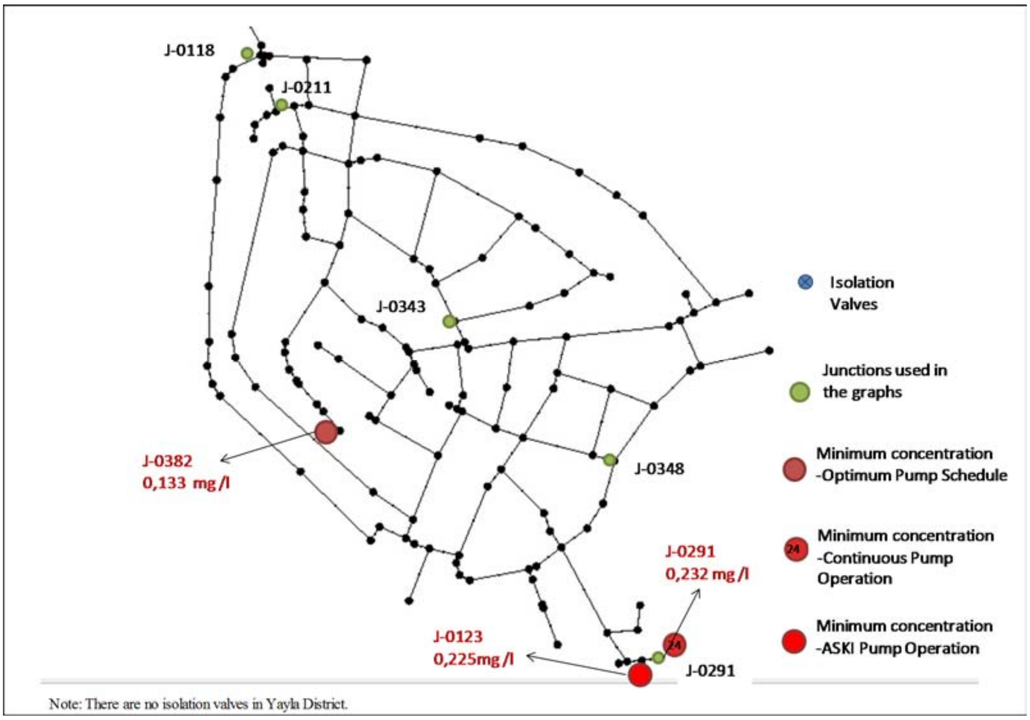


Figure 6.13: Junctions considered for Yayla District, Concentrations for Different Scenarios (Uninsulated / Insulated Case)

6.2.2 South Sancaktepe District

Minimum concentration occurring junctions in South Sancaktepe District for Insulated and Uninsulated cases are presented in Figure 6.14, 6.15 respectively. It is observed that minimum concentrations occur at the dead end point junctions. In this district through all scenarios minimum concentration occurring junction is J-0205 for all scenarios.

For insulated case, the extreme minimum concentration occurs in *"Optimum Pump Schedule Scenario"* this is due to the shut off of the pumps for a long period. The minimum concentration which is 0.109 mg/l is still in the limits required for drinking water standards.

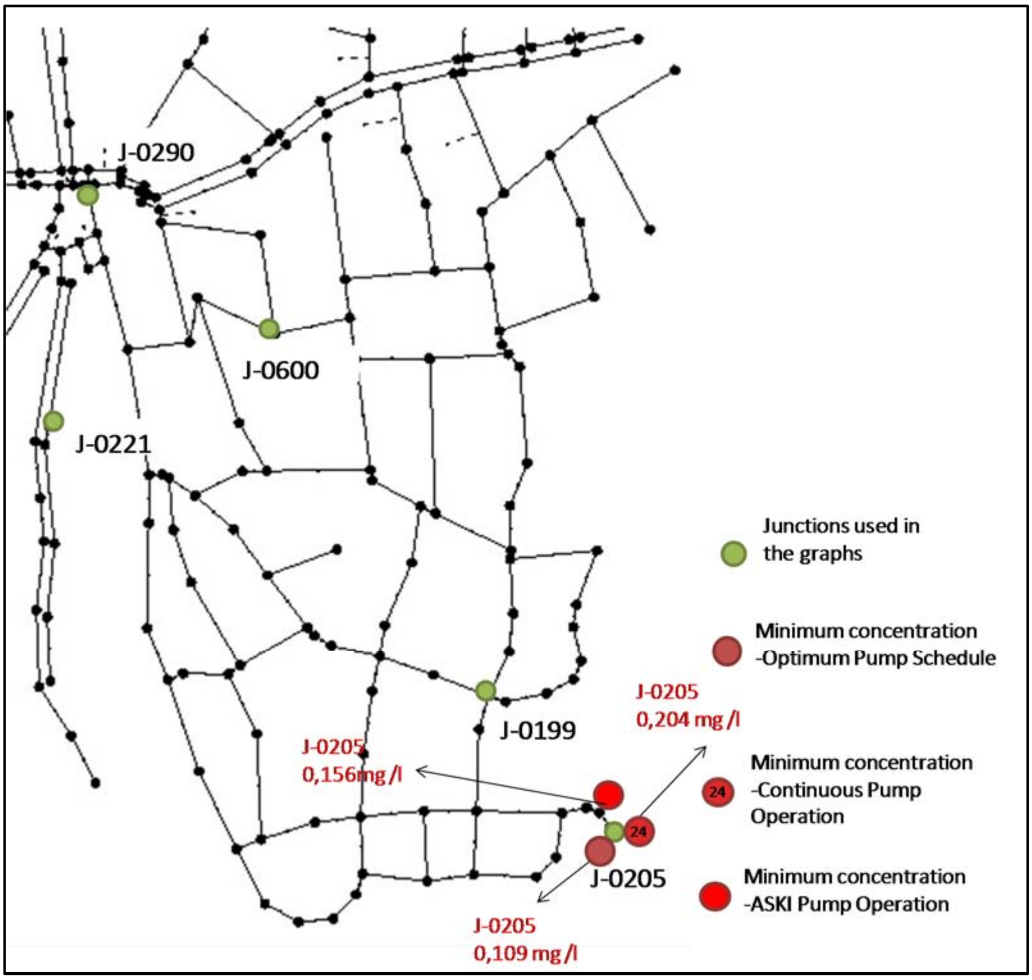


Figure 6.14: Junctions used for South Sancaktepe District, Concentrations for Different Scenarios – Insulated Case

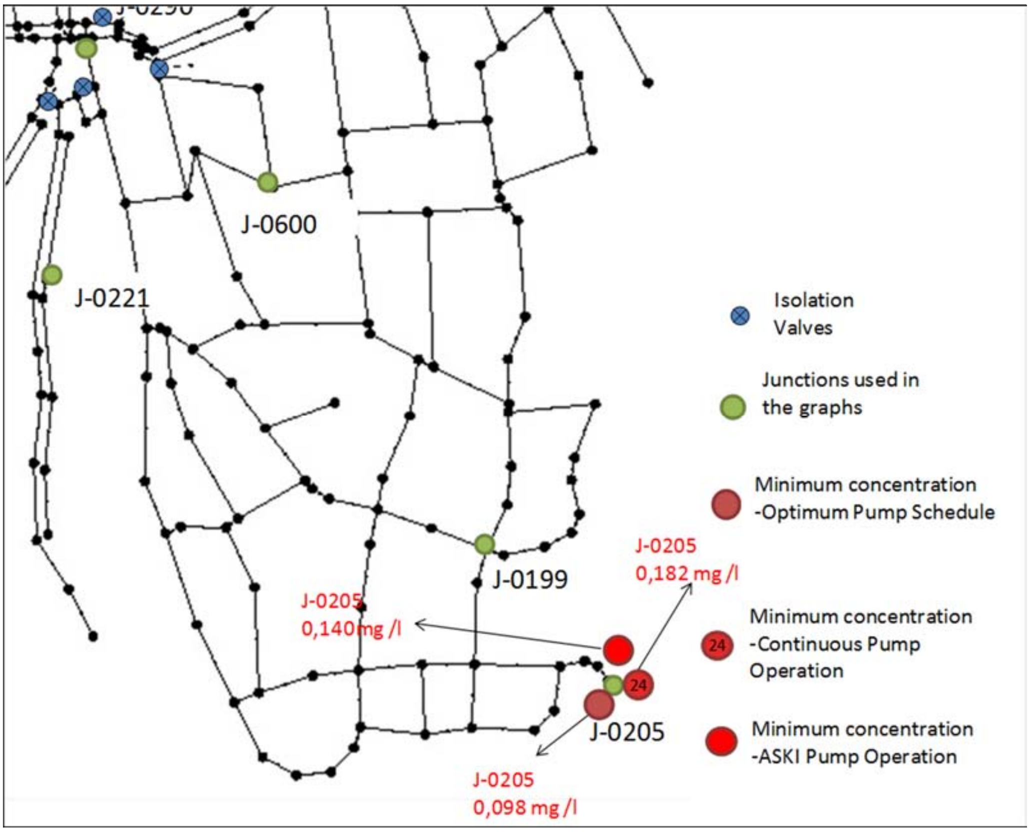


Figure 6.15: Junctions used for South Sancaktepe District, Concentrations for Different Scenarios – Uninsulated Case

For uninsulated case, the extreme minimum concentration occurs in *"Optimum Pump Schedule Scenario"* this is due to the shut off of the pumps for a long period. The minimum concentration which is 0.098 mg/l is not in the limits required according to drinking water standards.

6.2.3 North Sancaktepe District

North Sancaktepe District has interaction with neighboring zones therefore Uninsulated or Insulated Conditions of the system will have different results.

Minimum concentration occurring junctions in North Sancaktepe District for Insulated and Uninsulated case are presented in Figure 6.16, 6.17 respectively.

It is observed that minimum concentrations occur at the dead end point junctions. Minimum concentration occurring junction is J-0645 for all scenarios.

For insulated case, the extreme minimum concentration occurs in *"Optimum Pump Schedule Scenario"* this is due to the shut off of the pumps for a long period. Although the minimum concentration which is 0.107 mg/l is still in the limits required for drinking water standards.

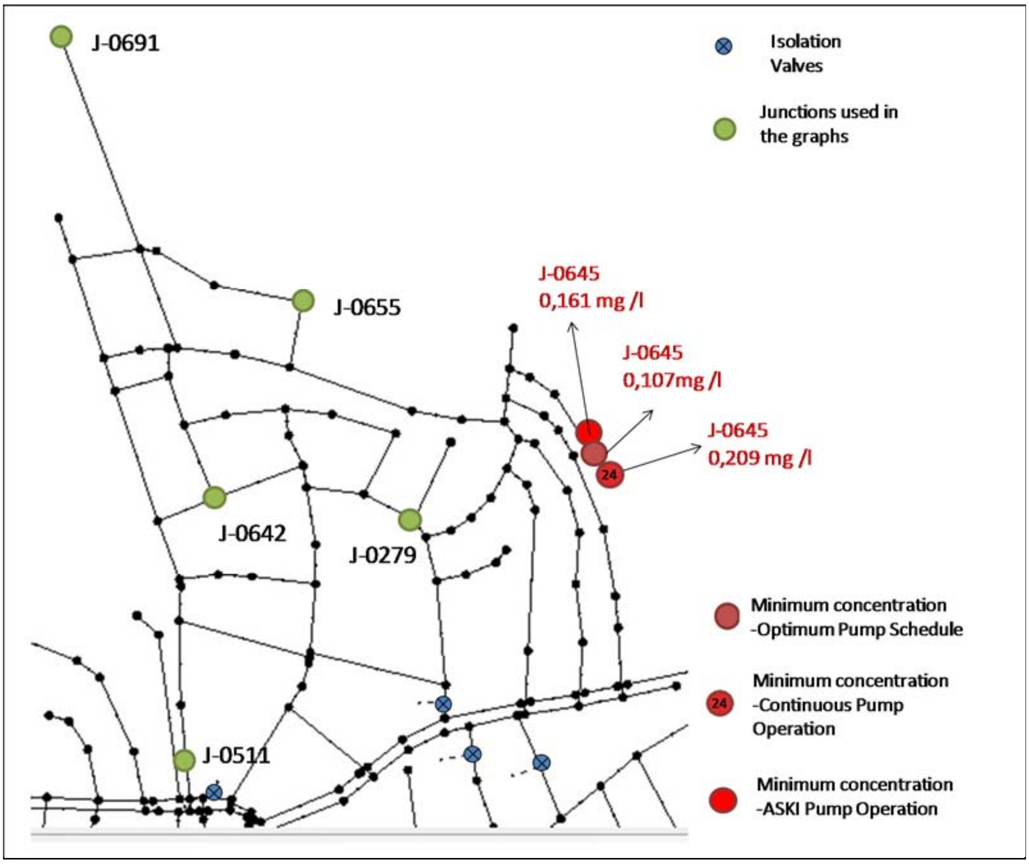


Figure 6.16: Junctions used for North Sancaktepe District, Concentrations for Different Scenarios– Insulated Case

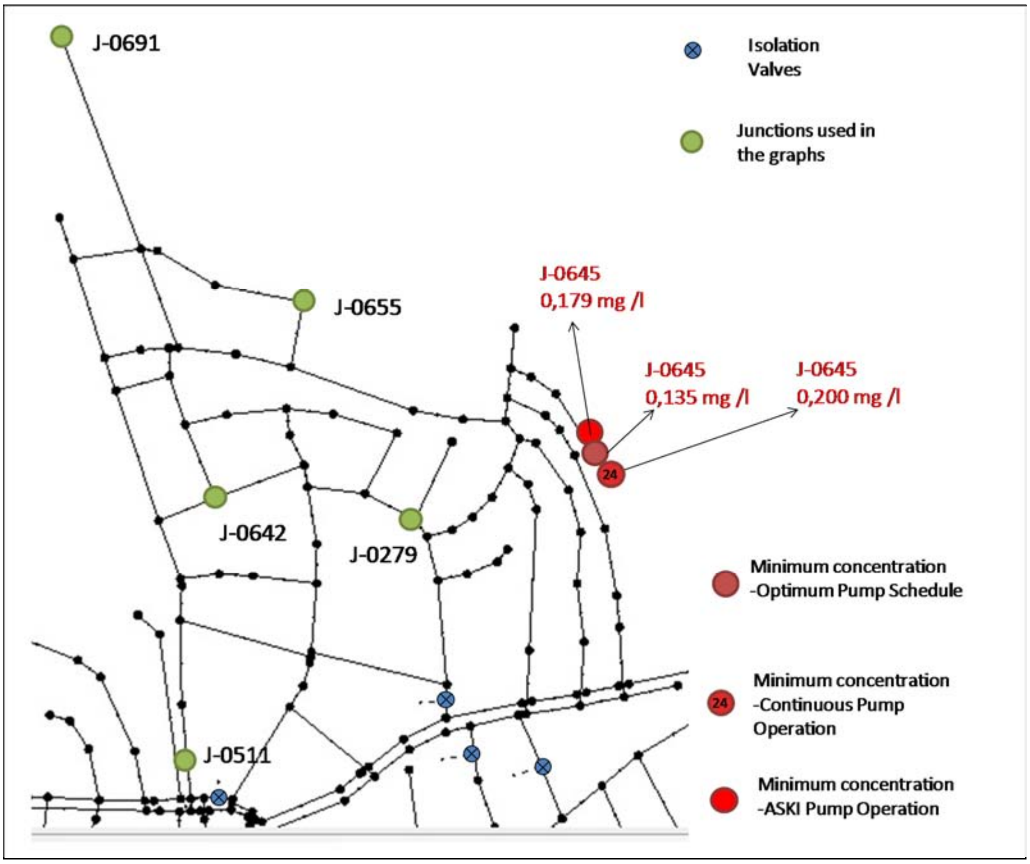


Figure 6.17: Junctions used for North Sancaktepe District, Concentrations for Different Scenarios – Uninsulated Case

For uninsulated case, the extreme minimum concentration occurs in *"Optimum Pump Schedule Scenario"* this is due to the shut off of the pumps for a long period. The minimum concentration which is 0.135 mg/l is still in the limits required for drinking water standards.

6.2.4 Şehit Kubilay District

Şehit Kubilay District has interaction with neighboring zones therefore Uninsulated or Insulated Conditions of the system will have different results.

Minimum concentration occurring junctions in Şehit Kubilay District for Insulated and Uninsulated case are presented in Figure 6.18, 6.19 respectively.

It is observed that minimum concentrations occur at the dead end point or junctions that are far from the source.

For insulated case, the extreme minimum concentration occurs in *"Optimum Pump Schedule Scenario"* this is due to the shut off of the pumps for a long period. The minimum concentration which is 0.106 mg/l (J-0690) is not in the limits required for drinking water standards. For "*Single Pump Operation (Continuous for 24 hours)"* J-0690 has a minimum concentration of 0,205 mg/l while for *"ASKI Pump Operation"* J-0042 has a minimum concentration of 0,158 mg/l.

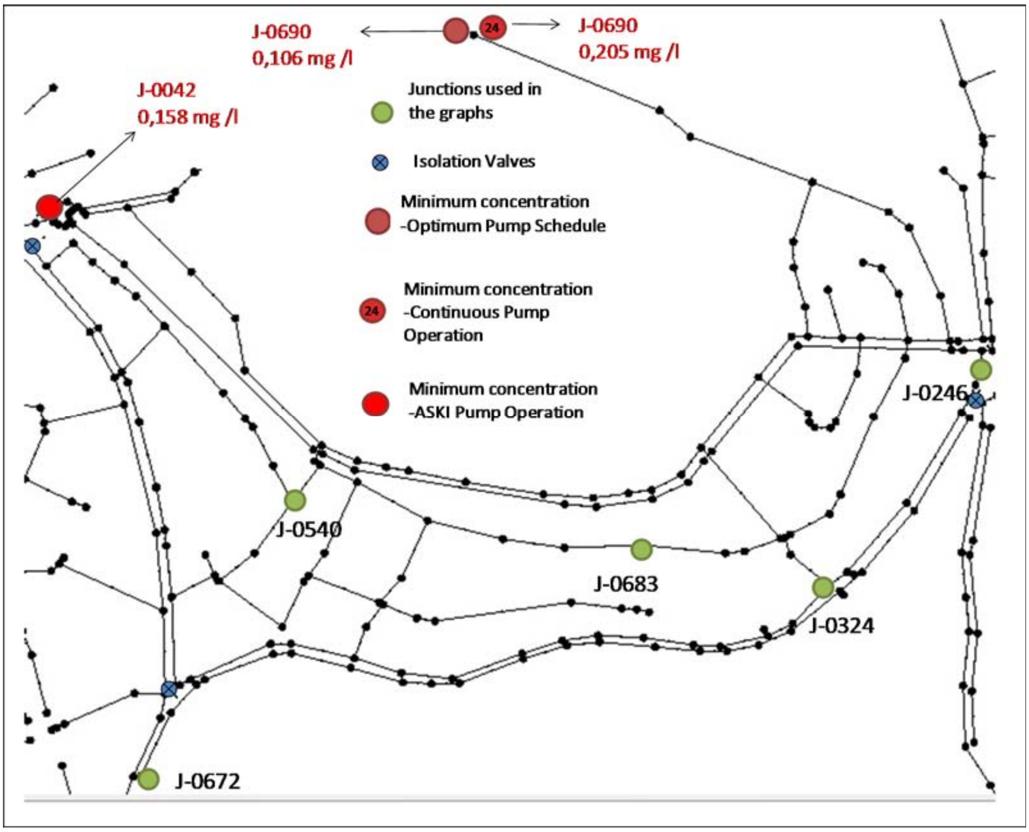


Figure 6.18: Junctions used for Şehit Kubilay District, Concentrations for Different Scenarios– Insulated Case

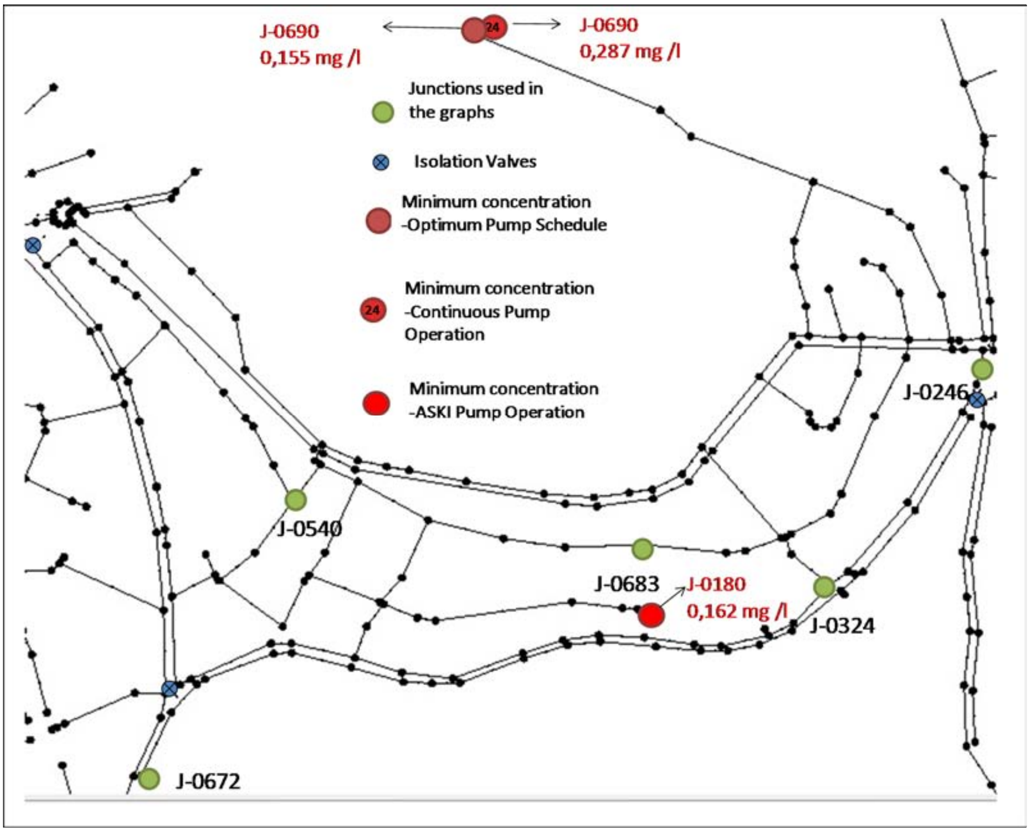


Figure 6.19: Junctions used for Şehit Kubilay District, Concentrations for Different Scenarios– Uninsulated Case

For insulated case, the extreme minimum concentration occurs in *"Optimum Pump Schedule Scenario"* this is due to the shut off of the pumps for a long period. Although the minimum concentration which is 0.155 mg/l (J-0690) is not in the limits required for drinking water standards. For "*Single Pump Operation (Continuous for 24 hours)"* J-0690 has a minimum concentration of 0,287 mg/l while for *"ASKI Pump Operation"* J-0180 has a minimum concentration of 0,162 mg/l. Minimum concentrations observed in Şehit Kubilay district are in allowable limits.

6.2.5 East Çiğdemtepe District

East Çiğdemtepe District has interaction with neighboring zones therefore Uninsulated or Insulated Conditions of the system will have different results.

Minimum concentration occurring junctions in East Çiğdemtepe District for Insulated and Uninsulated cases are presented in Figure 6.20, 6.21 respectively. It is observed that minimum concentrations occur at the dead end point junctions.

For insulated case, the extreme minimum concentration occurs in *"Optimum Pump Schedule Scenario"* this is due to the shut off of the pumps for a long period. The minimum concentration which is 0.132 mg/l (J-0027) is not in the limits required for drinking water standards. For "*Single Pump Operation (Continuous for 24 hours)"* J-0027 has a minimum concentration of 0,187 mg/l while for *"ASKI Pump Operation"* J-0027 has a minimum concentration of 0,183 mg/l.

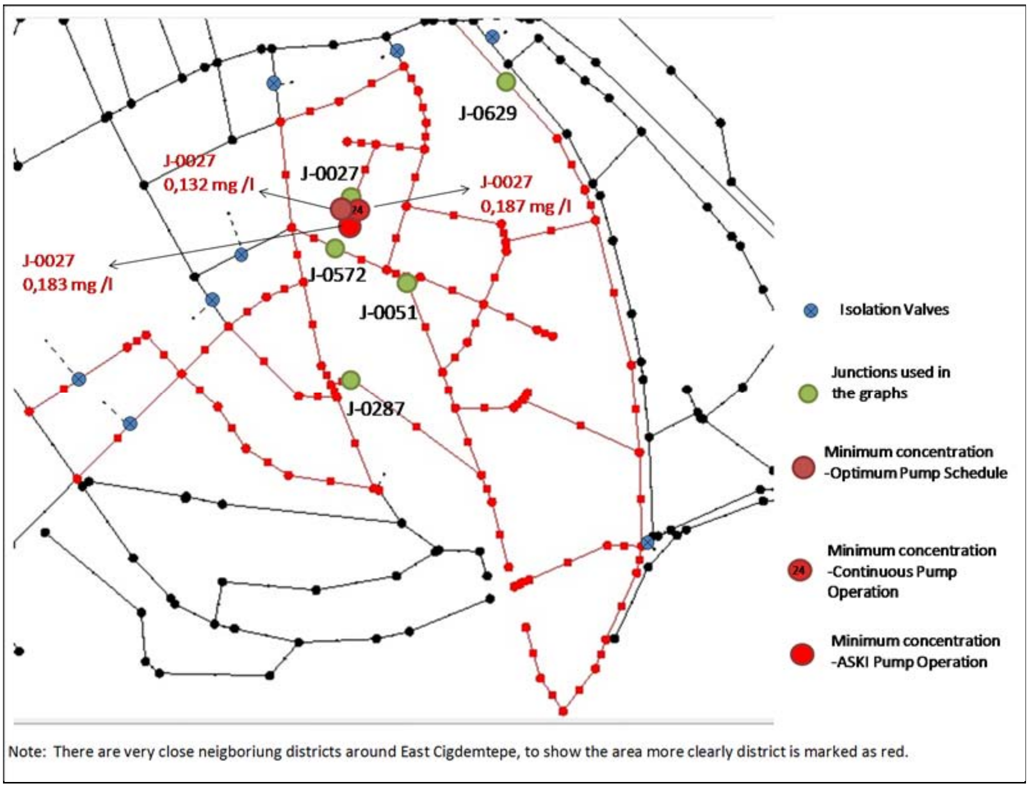


Figure 6.20: Junctions used for East Çiğdemtepe District, Concentrations for Different Scenarios– Insulated Case

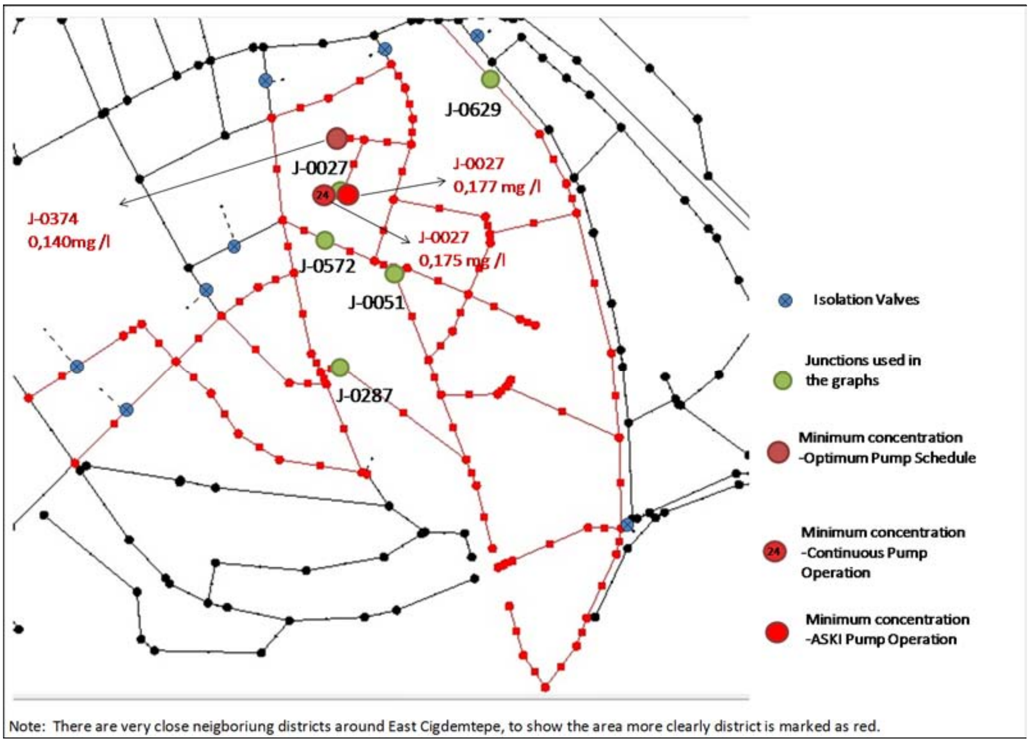


Figure 6.21: Junctions used for East Çiğdemtepe District, Concentrations for Different Scenarios– Uninsulated Case

For uninsulated case, the extreme minimum concentration occurs in *"Optimum Pump Schedule Scenario"* this is due to the shut off of the pumps for a long period. The minimum concentration which is 0.140 mg/l (J-0374) is not in the limits required for drinking water standards. For "*Single Pump Operation (Continuous for 24 hours)"* J-0027 has a minimum concentration of 0,175 mg/l while for *"ASKI Pump Operation"* J-0027 has a minimum concentration of 0,177 mg/l. Observed minimum concentrations are within the limits of drinking water standards.

6.2.6 West Çiğdemtepe District

West Çiğdemtepe District has interaction with neighboring zones therefore Uninsulated or Insulated Conditions of the system will have different results.

Minimum concentration occurring junctions in West Çiğdemtepe District for Insulated and Uninsulated case are presented in Figure 6.22, 6.23 respectively. It is observed that minimum concentrations occur at the dead end point or junctions that are far from the source.

For insulated case, the extreme minimum concentration occurs in *"Optimum Pump Schedule Scenario"* this is due to the shut off of the pumps for a long period. Although the minimum concentration which is 0.088 mg/l (J-0041) is not in the limits required for drinking water standards. For "*Single Pump Operation (Continuous for 24 hours)"* J-0041 has a minimum concentration of 0,128 mg/l while for *"ASKI Pump Operation"* J-0041 has a minimum concentration of 0.111 mg/l.

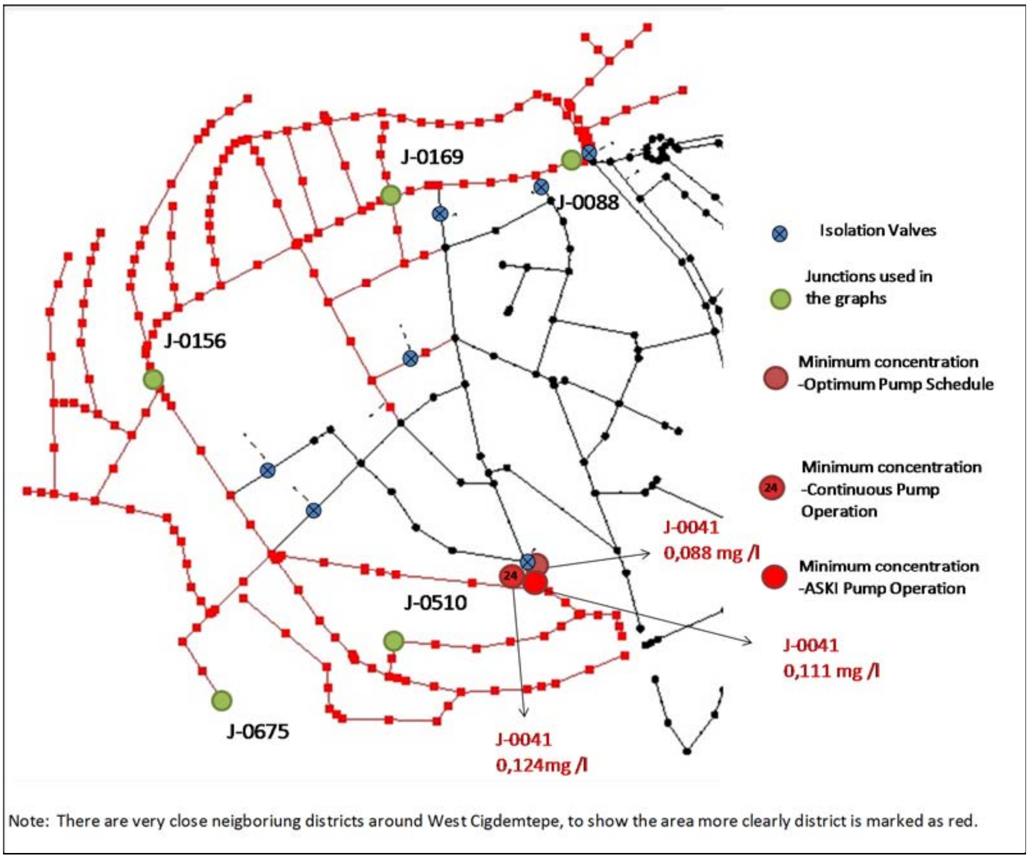


Figure 6.22: Junctions used for West Çiğdemtepe District, Concentrations for Different Scenarios– Insulated Case

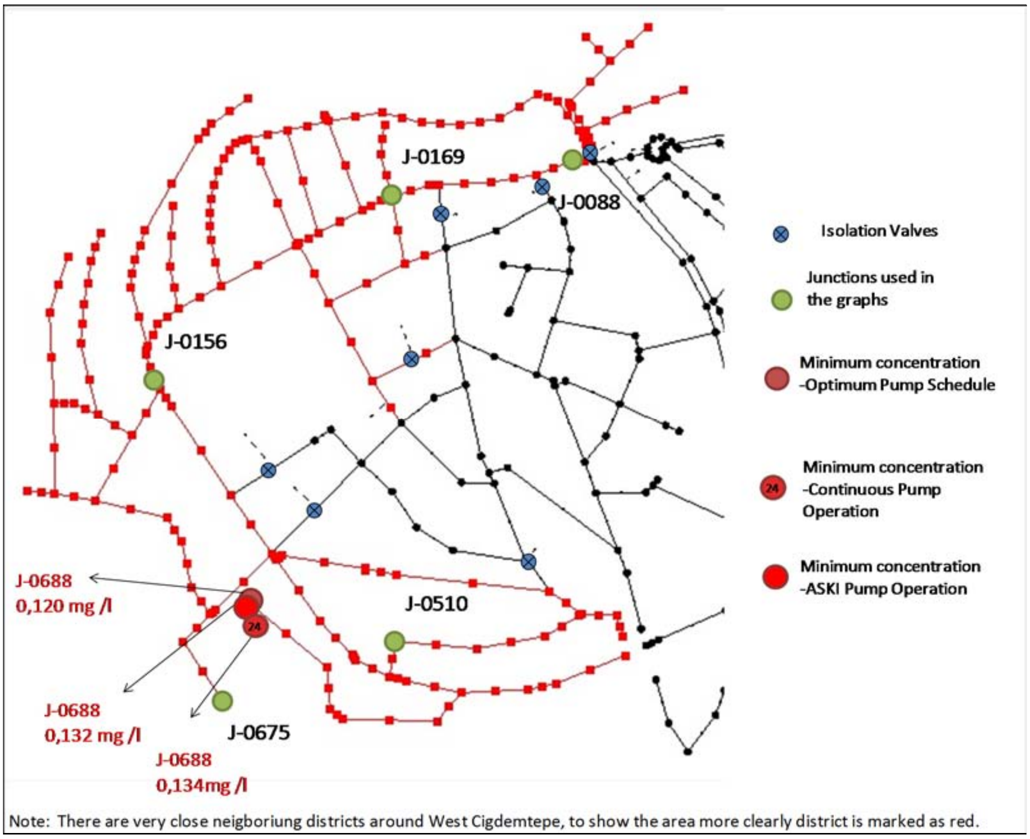


Figure 6.23: Junctions used for West Çiğdemtepe District, Concentrations for Different Scenarios– Uninsulated Case

For uninsulated case, the extreme minimum concentration occurs in *"Optimum Pump Schedule Scenario"* this is due to the shut off of the pumps for a long period. The minimum concentration which is 0.120 mg/l (J-0688) is still in the limits required for drinking water standards. For "*Single Pump Operation (Continuous for 24 hours)"* J-0688 has a minimum concentration of 0,134 mg/l while for *"ASKI Pump Operation"* J-0688 has a minimum concentration of 0.120 mg/l.

6.3 Summary Tables of Chlorine Concentrations

Along this study chlorine concentrations for all districts are calculated under various operating conditions. A summary of the overall results is provided in Table 6.13. Table 6.13 contains Yayla, South Sancaktepe, North Sancaktepe, Şehit Kubilay, East Çiğdemtepe and West Çiğdemtepe districts. This table provides the maximum, minimum and average chlorine concentrations at the mouth entrances. Also minimum and maximum concentrations in the overall districts are provided by the occurrence times under all operating conditions.

In (i) Single Pump Operation Scenario, concentrations are always above 0.10 mg/l at all junctions of the district. This scenario has the least minimum concentration problem among other scenarios. In (ii) Multi Pumps Operation Scenario, concentrations below 0.20 mg/l are observed even at the mouth entrances of the districts. According to drinking water regulations the minimum concentration of chlorine should not be lower than 0.10 mg/l. The mouth entrance chlorine concentrations in all districts are in the safe limits. West Çiğdemtepe District, Insulated Case has a minimum concentration of 0.088 mg/l which is not in the limits. If the pumps are scheduled to operate in optimum way, precautions must be taken to solve this issue. Possible precautions are considered under conclusion and recommendations. In (iii) ASKI Pump Operation Scenario, concentrations at the in all junctions of the districts are in safe limits. Throughout all scenarios there are concentration levels are almost satisfactory.

Table 6.13: Summary Table of Chlorine Concentration Values– Yayla, South Sancaktepe and North Sancaktepe, Şehit Kubilay, East Çiğdemtepe and West Çiğdemtepe Districts

Districts	Units	1. Single pump operation (Continuous for 24 hours)		2. Multi Pumps Operating According to Optimum Pump Schedule		3. ASKI Pump Operation	
		Network Operating Conditions					
		Insulated	Uninsulated	Insulated	Uninsulated	Insulated	Uninsulated
Yayla							
Mouth Ent. Concentration							
Maximum		0,456	0,456	0,455	0,455	0,457	0,457
Average	(mg/l)	0,448	0,448	0,399	0,377	0,431	0,431
Minimum		0,429	0,429	0,199	0,189	0,359	0,359
Network concentrations							
Minimum concentration	(mg/l)	0,232	0,232	0,133	0,133	0,225	0,225
Time of occurence	(hr)	13:00	13:00	9:00	9:00	9:00	9:00
Place of occcurence	(JN; DE /MP/ EJ)	J-0291 DE	J-0291 DE	J-0382 DE	J-0382 DE	J-0123 DE	J-0123 DE
Maximum concentration	(mg/l)	0,456	0,456	0,455	0,455	0,457	0,457
Time of occurence	(hr)	12:00	12:00	18:00	18:00	16:00	16:00
Place of occurence	(JN; DE /MP/ EJ)	J-0118; EJ	J-0118; EJ	J-0118; EJ	J-0118; EJ	J-0118; EJ	J-0118; EJ
South Sancaktepe							
Mouth Ent. Concentration							
Maximum		0,440	0,440	0,441	0,439	0,442	0,442
Average	(mg/l)	0,439	0,439	0,307	0,297	0,389	0,381
Minimum		0,438	0,438	0,197	0,190	0,285	0,252
Network concentrations							
Minimum concentration	(mg/l)	0,204	0,182	0,109	0,117	0,156	0,140
Time of occurence	(hr)	12:00	12:00	16:00	22:00	17:00	11:00
Place of occcurence	(JN; DE /MP/ EJ)	J-0205; DE	J-0205; DE	J-0205; DE	J-0205; DE	J-0205; DE	J-0205; DE
Maximum concentration	(mg/l)	0,440	0,440	0,441	0,439	0,442	0,442
Time of occurence	(hr)	3:00	3:00	4:00	6:00	16:00	16:00
Place of occurence	(JN; DE /MP/ EJ)	J-0290; EJ	J-0290; EJ	J-0290; EJ	J-0290; EJ	J-0290; EJ	J-0290; EJ
North Sancaktepe							
Mouth Ent. Concentration							
Maximum		0,443	0,442	0,441	0,440	0,446	0,444
Average	(mg/l)	0,442	0,439	0,308	0,282	0,391	0,376
Minimum		0,435	0,425	0,198	0,209	0,286	0,268
Network concentrations							
Minimum concentration	(mg/l)	0,209	0,200	0,107	0,135	0,161	0,179
Time of occurence	(hr)	12:00	12:00	13:00	9:00	13:00	9:00
Place of occcurence	(JN; DE /MP/ EJ)	J-0645; DE	J-0645; DE	J-0645; DE	J-0645; DE	J-0645; DE	J-0645; DE
Maximum concentration	(mg/l)	0,443	0,442	0,441	0,440	0,446	0,444
Time of occurence	(hr)	7:00	7:00	7:00	7:00	16:00	16:00
Place of occurence	(JN; DE /MP/ EJ)	J-0511; EJ	J-0511; EJ	J-0511; EJ	J-0511; EJ	J-0511; EJ	J-0511; EJ

Note: JN: Junction number; DE: dead end/MP: middle point/ EJ: entrance junction

Table 6.13 (cont'd): Summary Table of Chlorine Concentration Values– Yayla, South Sancaktepe and North Sancaktepe, Şehit Kubilay, East Çiğdemtepe and West Çiğdemtepe Districts

Districts	Units	1. Single pump operation (Continuous for 24		2. Multi Pumps Operating According to Optimum Pump		3. ASKI Pump Operation	
		Network Operating Conditions					
		Insulated	Uninsulated	Insulated	Uninsulated	Insulated	Uninsulated
Şehit Kubilay							
Mouth Ent. Concentration							
Maximum	(mg/l)	0,445	0,445	0,446	0,447	0,447	0,447
Average		0,444	0,442	0,312	0,303	0,393	0,385
Minimum		0,444	0,424	0,198	0,192	0,287	0,281
Network concentrations							
Minimum concentration	(mg/l)	0,205	0,287	0,106	0,155	0,158	0,162
Time of occurence	(hr)	9:00	7:00	8:00	22:00	11:00	7:00
Place of occcurence	(JN; DE /MP/ EJ)	J-0690; DE	J-0690; DE	J-0690; DE	J-0690; DE	J-0042; DE	J-0180; DE
Maximum concentration	(mg/l)	0,445	0,445	0,446	0,447	0,447	0,447
Time of occurence	(hr)	3:00	3:00	4:00	4:00	15:00	15:00
Place of occurence	(JN; DE /MP/ EJ)	J-0246; EJ	J-0246; EJ	J-0246; EJ	J-0246; EJ	J-0246; EJ	J-0246; EJ
East Cigdemtepe							
Mouth Ent. Concentration							
Maximum	(mg/l)	0,380	0,367	0,394	0,354	0,389	0,363
Average		0,333	0,358	0,268	0,246	0,316	0,310
Minimum		0,270	0,336	0,176	0,163	0,251	0,231
Network concentrations							
Minimum concentration	(mg/l)	0,187	0,175	0,132	0,140	0,183	0,177
Time of occurence	(hr)	6:00	7:00	10:00	8:00	10:00	9:00
Place of occcurence	(JN; DE /MP/ EJ)	J-0027; DE	J-0027; DE	J-0027; DE	J-0374; DE	J-0027; DE	J-0027; DE
Maximum concentration	(mg/l)	0,380	0,367	0,394	0,354	0,389	0,363
Time of occurence	(hr)	7:00	12:00	6:00	10:00	7:00	7:00
Place of occurence	(JN; DE /MP/ EJ)	J-0629; EJ	J-0629; EJ	J-0629; EJ	J-0629; EJ	J-0629; EJ	J-0629; EJ
West Cigdemtepe							
Mouth Ent. Concentration							
Maximum	(mg/l)	0,388	0,363	0,396	0,380	0,396	0,382
Average		0,336	0,285	0,270	0,235	0,318	0,297
Minimum		0,271	0,220	0,178	0,178	0,253	0,213
Network concentrations							
Minimum concentration	(mg/l)	0,128	0,134	0,088	0,120	0,111	0,132
Time of occurence	(hr)	10:00	13:00	21:00	08:00	21:00	13:00
Place of occcurence	(JN; DE /MP/ EJ)	J-0041; DE	J-0688; DE	J-0041; DE	J-0688; DE	J-0041; DE	J-0688; DE
Maximum concentration	(mg/l)	0,388	0,363	0,396	0,380	0,396	0,382
Time of occurence	(hr)	4:00	6:00	6:00	7:00	7:00	7:00
Place of occurence	(JN; DE /MP/ EJ)	J-0088; EJ	J-0088; EJ	J-0088; EJ	J-0088; EJ	J-0088; EJ	J-0088; EJ

Note: JN: Junction number; DE: dead end/MP: middle point/ EJ: entrance junction

6.4 Energy Costs of the System for the 3 Scenarios

In this case study mainly 3 different scenarios are studied. These are *"Single Pump Operation Continuous for 24 hours"*, *"Multi Pumps Operating According to Optimum Pump Schedule"* and *"ASKI Pump Operation"* for Uninsulated/Insulated cases. For all of these scenarios there is a certain cost for operating pumps. In this part these costs will be calculated.

Energy prices given by Enerjisa Başkent Electricity Distribution Inc. are presented in Table 6.14.

Table 6.14: Energy Prices (October 2011), (Şendil, 2013)

Time Interval	Energy Price (TL/kWh)	
	Constant Tariff	Multi Tariff
Day 06:00-17:00	0.2486	0.2336
Peak 17:00-22:00	0.2486	0.3556
Night 22:00-06:00	0.2486	0.1456

Table 6.15: Energy Costs for the 3 Scenarios

Scenario	Energy Cost (TL/day)	
	Constant Tariff	Multi Tariff
Single Pump Operation	196,126	181,187
Multi Pump Operation (Opt. Pump Schedule)	194,511	123,456
ASKI Pump Operation	187,666	146,638

According to the energy costs (Table 6.15) for the 3 scenarios the optimum pump schedule is the most economical way of operation, while ASKI operation is the second best depending on costs. Single pump operation is the most costly scenario of all, yet the concentrations observed are higher in this scenario.

CHAPTER 7

CONCLUSION AND RECOMMENDATIONS

In Turkey, the most popular disinfection material is chlorine due to its efficient oxidizing capacity besides its practicability and relatively low price among other disinfection materials. In Ankara water treatment plant also chlorine is being used for disinfection purposes. Chlorine is injected first at İvedik treatment plant; then, booster chlorination is applied at different locations. At P23 pump station, residual chlorine concentration is around 0.50 mg/l.

Ankara General Directorate of Water and Sewerage (ASKI) records chlorine concentrations at the entrance of the pumping stations in the framework of its SCADA system; furthermore, ASKI monitors chlorine concentrations at different locations of each pressure zone. However *"blind"* monitoring in the network does not provide much information to estimate the impacts of different operating conditions. This study is important in order to detect vulnerable junctions for each specific operating condition.

Water Quality model of N8.3 of Ankara Water Distribution Network was found to be successful to evaluate the lowest chlorine residual concentrations basically for (i) different pumping schedules, (ii) various operating conditions (insulated/uninsulated).

In this study (i) effects of roughness parameter, (ii) wall coefficient k_w, (iii) variation of decay constant k_b depending mainly on temperature was not investigated. Spatial variation of C (Hazen-Williams coefficient) is not considered while a coefficient of 130 is taken for all pipes. Actually, roughness parameter affects the overall performance of the system such as pressures, flow rates, flow velocity and water quality. To be able to present the actual mathematical simulation of the system calibration study should be performed for determining the valid C coefficients of the network. Also, wall coefficient (k_w) can be indirectly measured in the field in a homogeneous pipe segment having a constant diameter, material and age. Although this study does not include a field test for determining k_w coefficient, a consistent value was taken relying on literature. Moreover, decay rate coefficient k_b which is mainly dependent on temperature should be designated by laboratory tests and its variation due to seasonal temperature changes must be considered. During summer season k_b coefficient will be high due to the rapid decay of chlorine and the opposite low k_b coefficient is valid for winter season. In summer season water demand of the system is at peak levels, causing the quick arrival of highly chlorine concentrated fresh water, conflicting with the increased decay rate coefficient (k_b). While in winter season water demand of the system will be low, again conflicting with the decreased decay rate coefficient (k_b). Also this issue which is not involved in the scope of the study must also be considered by laboratory tests performed in different seasons.

In the scope of this study minimum concentrations were considered and locations having critical minimum concentrations are provided in *"6.2 Minimum Chlorine Concentrations"*. Chlorine concentrations below 0.10 mg/l is not enough for disinfection and might lead to severe health problems as a result of the formation and growth of disease causing organisms in potable water. As travel time increases, the chlorine concentrations start to drop and the lowest concentrations occur commonly in West Çiğdemtepe and East Çiğdemtepe districts due to their location being far from the concentration source point. For critical levels of chlorine necessary precautions must be taken in order to ensure the required water disinfection.

Throughout all scenarios N8.3 network was almost successful for providing adequate chlorine concentration at junctions. While a junction in West Çiğdemtepe has a concentration of 0.088 mg/l which is below the limits. Moreover, calibrated values of model parameters (C_{HW}, k_b and k_w) may aggravate the results especially for critical junctions of this 20 year old network.

Minimum concentration occurring locations are mostly dead end junctions, therefore (i) constructing loops at critical dead end junctions will provide fresh water to these junctions by the help of a few more pipe connections. As a result of the fresh water cycle in the loops, chlorine concentrations will relatively increase. Various loop forms could be modeled in order to construct the best loop to satisfy the safe levels of chlorine concentration.

Another solution method is (ii) increasing the chlorine injection level at P23 station, which will obviously increase the overall chlorine concentrations in the network.

In addition, DMA's also cause critically low levels of chlorine as a result of the closed isolation valves. This situation is observed at J-0041 which is located very close to an isolation valve in West Çiğdemtepe. Under insulated conditions J-0041 has a chlorine concentration 0.088 mg/l which is the lowest chlorine concentration of the network among all scenarios. This concentration is a direct result of the DMA formation. The main objective of forming DMA's is reducing leakage therefore; when leakage investigation is not being made, (iii) cancelling the DMA formation will increase the chlorine concentrations certainly.

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