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İÇMESUYU SİSTEMLERİNDE BASINÇ YÖNETİMİ UYGULAMALARININ MALİYET FAYDA ANALİZİ

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ÖZET

İçmesuyu yönetiminde kayıplarla mücadele günümüzde en önemli çalışmalardan biri olmuştur. Artan su ihtiyaçları ile birlikte azalan temiz su kaynakları içmesuyu sistemlerinde su kayıplarıyla mücadelenin önemini artırmıştır. Basınç yönetimi ise uluslararası literatürde en önemli su kayıp mücadele yöntemi olarak görülmektedir. Bu çalışmada su kayıp yönetimi kapsamında 4 farklı izole alt bölgede basınç yönetimi uygulanmıştır. Basınç yönetimi uygulaması yapılan izole alt bölgeler birbirinden farklı basınç düzenleme yöntemleriyle Kayseri Su ve Kanalizasyon İdaresi (KASKİ) tarafından işletilen şebekelerden seçilmiştir. Basınç düzenlemesi yapılmasının finansal olarak ne kadar fayda sağlayacağı oluşturulan algoritmalarla teorik olarak hesaplanmıştır. Teorik hesaplamaların doğruluğu gerçek saha uygulaması sonuçlarıyla kıyaslanarak algoritmanın doğruluğu test edilmiştir. Teorik hesaplamanın doğruluğunun analiz edilmesinin ardından maliyetler de hesaplanarak fayda ve maliyet analizi yapılmış ve yatırımın geri dönüş süresi hesaplanmıştır.

Anahtar Kelimeler: *İçme suyu dağıtım sistemi, basınç yönetimi, sızıntı, fayda maliyet analizi, su kaybı.*

COST-BENEFIT ANALYSIS OF PRESSURE MANAGEMENT PRACTICES IN DRINKING WATER SYSTEMS

ABSTRACT

Combating losses in drinking water has become one of the most essential freedoms today. With increasing water problems, the decreasing clean water resources have increased the fight against water losses in drinking water systems. In international literature, pressure management is the most important method of fighting against water loss. In this study, pressure management was applied in 4 different isolated sub-regions within the scope of water loss management. The isolated sub-regions under pressure management were selected from the networks operated by the Kayseri Water and Wastewater Administration (KASKİ) with different pressure regulation methods. The financial benefits of pressure regulation were theoretically calculated using algorithms. The algorithm's accuracy was tested by comparing the accuracy of the theoretical calculations with the actual field practice results. After analyzing the accuracy of the theoretical calculation, the costs were also calculated, and the return period of the investment was calculated by making a benefit and cost analysis.

Keywords: *Water distribution systems, pressure management, leakage, cost-benefit analysis, water loss.*

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1. Introduction

Today, the amount of clean drinking water is decreasing day by day due to reasons such as the increase in population, industrialization and urbanization rate, pollution of clean water resources as a result of unconscious use of water resources, and the negative impact of climate change on water resources [1]. Our world consists of 71% water and 29% land. Only 2.5% of these waters are freshwater resources that can be used for drinking water supply. 68.9% of freshwater resources are glacial, 30.8% are groundwater, and 0.3% are accessible clean drinking water resources [2]. It is a danger on a global scale that the amount of water resources used for drinking water supply is low and decreasing daily due to increasing population, urbanization, and industrialization [3].

Utilities are responsible for delivering sufficient clean water to subscribers and supporting economic growth and environmental sustainability through their services [4]. In clean water supply, it is essential to prevent water loss in the network and return this water to the system. The difference between the water supplied to the distribution system and the water reaching the subscribers is defined as water loss. Water losses are divided into two groups: administrative and physical water losses. Cracks and fractures in the pipes due to damage to the pipes due to pressure fluctuations play a significant role in the formation of water losses [1,5]. Various methods, such as pressure management, active leakage control, passive leakage control, failure management, and pipe material management, reduce physical water losses.

The practice that gives the best results among these methods is pressure management [3,6]. To effectively regulate the water pressure in the networks, district metered areas (DMA) must have been previously established [7]. In addition to reducing leaks, pressure management has other benefits, such as reducing overpressure, reducing the number of pipe bursts, and reducing operating costs [8]. On the other hand, implementing pressure management in a real network involves significant labor, equipment, and installation costs [8]. For these reasons, before implementing pressure management in the field, a cost-benefit analysis is needed for the relevant administrations to decide whether or not to implement pressure management [9].

Adedeji et al. compared pressure management, pipe rehabilitation, active leakage control, and fault management practices among physical water loss reduction methods. They stated that pressure management is the best method in terms of cost-benefit analysis since it minimizes leakage in the long term [6].

Moslehi et al. evaluated the use of pressure-regulating valves (PRV) in terms of cost-benefit. They compared leakage by replacing a fixed outlet DMA with a timed, flow-regulated method. It reduced the average zone pressure (AZP) by 3.9 m with the timed method and 5.4 m with the flow-regulated method compared to the fixed outlet method. Leakage was reduced by 120 m3 per day with the timed method and 172 m3 per day with the flow-adjusted method. The results show that the benefit from leakage reduction is the most significant contribution to the total benefit, and the flow-regulated method is the most beneficial in the analyzed network [10].

Özdemir et al. analyzed the effect of system operating pressure on water losses and minimum night flow rate (MNF) according to field data and the FAVAD equation. Firstly, faults were eliminated by acoustic listening in the isolated zone, and the MNF rate was reduced from 12.5 l/s to 6.95 l/s, saving 441 m3 of water per day in the inlet volume. In the second stage, the pressure was reduced from 9.1 bar to 3.1 bar, and the MNF rate from 6.95 l/s to 3.29 l/s with pressure management and a daily water saving of 78.44 m3 was calculated in the inlet volume. As a result, the studies showed a difference of 1.70 l/s between the values obtained from the field and those calculated according to the FAVAD equation [11].

Akdemir and Yılmaz compared the theoretical results obtained by using the Fixed and Variable Area Discharges (FAVAD) equation, which provides a link between network pressure and leakage in the DMA where pressure management is applied, with field practices data. They stated that different pressure regulation methods could not be predicted with the FAVAD equation and proposed a new method to calculate the final leakage in the network. The proposed method reduced the net benefit difference to 1.81% in the region with a net benefit difference of 58.06% in theory and practice. They found a result closer to the practice field [5].

Koşucu and Demirel aimed to compare four different pressure control methods in terms of cost-benefit by creating hydraulic models for networks with other characteristics. The study's results state that the most applicable pressure regulation method differs according to the unit water cost; in cases where the unit water cost is high, the closed circuit pressure control method will be the most appropriate choice, and as the unit water cost decreases, flow-regulated or time-regulated methods will be the most appropriate choice [12].

This study analyzes the benefits of pressure management and the potential costs of implementing this method. Unlike the literature, the study analyzed different types of pressure relief valves separately. Thus, water utilities will be able to make a more reliable cost-benefit analysis for pressure management, which is the most commonly used method of water loss management. The reliability of the algorithm is also tested by comparing the results obtained from the analysis with real data.

2. Materıals and Methods

Cracks and fractures occur in the pipes that provide water transmission to the subscribers due to the decrease in the compressive strength of the pipe due to pressure fluctuation and pipe aging. No matter how well the drinking water distribution networks are designed, it is inevitable that water losses due to leakage will occur in the existing networks [1,6]. Depending on the location of the fault and the way it occurs, different levels of leakage occur in the distribution system and are divided into three groups [13].

Background leaks occur on the pipe's bottom surface and have a low leakage flow rate. Since the leakage flow rate is minimal, the faults do not rise to the surface, and the lost water directly enters the soil. Due to the small leakage flow rate, it is difficult to detect with acoustic listeners and system monitoring [14]. Unreported leaks occur at the pipe's bottom surface, producing a moderate loss with a leak flow rate greater than undetected leaks [5,14]. Reported leaks are the leaks that occur on the upper surface of the pipe, where the leaks come to the surface under the effect of pressure. The amount of leakage is higher than uncertain and unreported leaks, but the detection and repair times are shorter since they come to the surface [13,14].

May propose a relationship between pressure and seepage based on field measurements using the Fixed and Variable Area Discharge (FAVAD) equation (Equation 1.), which is based on pressure variations, flow rate variations, and pipe material coefficient [15].

$$(L1/L0) = (P1/P0)\text{^}N1 \qquad \textbf{Eq.1}$$

In the equation, L1 (l/s) is the leakage flow rate after pressure regulation, L0 (l/s) is the initial leakage flow rate, P1 (m) is the regulated average pressure value, P0 (m) is the initial pressure value, N1 is the pipe material coefficient.

The installation of pressure-regulating valves (PRV) at the inlet of networks operating at high operating pressure has proven to be an effective way to control leakage [16]. Four basic pressure control methods are defined according to the condition of pressure-regulating valves at the critical point [17]. These are conventional fixed outlet pressure control, time-modulated pressure control, and flow-modulated pressure control (Figure 1) [18].

Fixed outlet pressure control involves using a device, normally a pressure-reducing valve (PRV), to control the maximum pressure entering a zone (Figure 1). It is the simplest form of pressure management because it involves using a PRV without extra electronic equipment [18].

Time-modulated pressure management is a method that works in conjunction with an additional device that can further reduce pressure during off-peak periods of water use (Figure 1). The main disadvantage of time-modulated control is that it does not respond to water demand and can be problematic for firefighting [18].

Flow-modulating pressure control provides more control and flexibility than the time-modulating option (Figure 1). It offers more savings than other methods but is more expensive due to the use of extra electronics. An important advantage of the flow-modulated option is that it will not interfere with the water supply in case of fire [18].

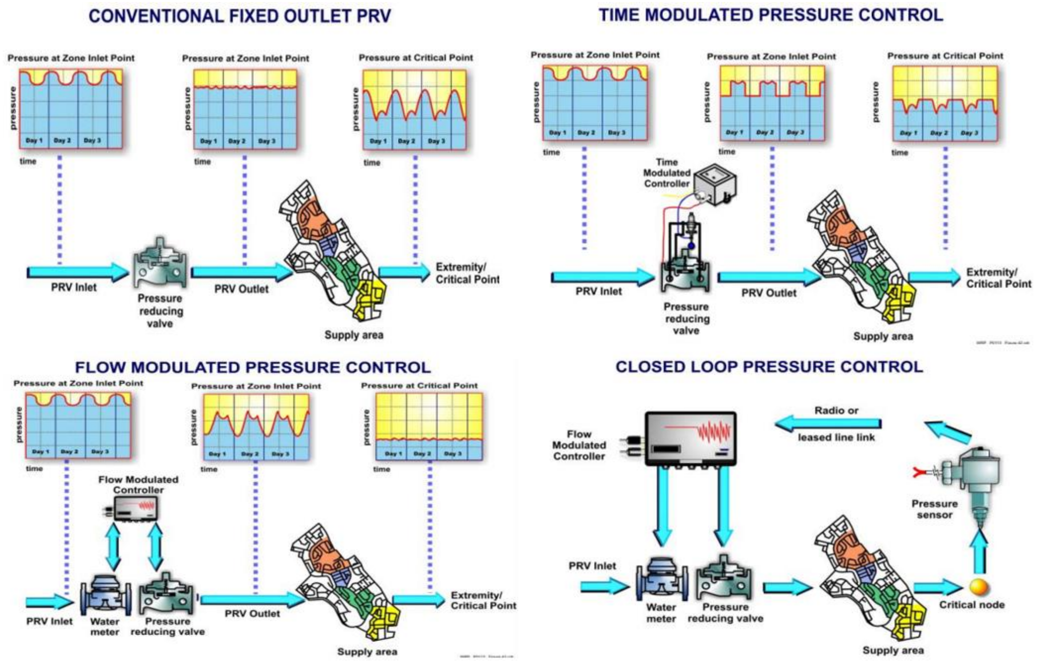

Figure 1. Pressure control methods [18]

Lambert and Thornton proposed an equation based on the FAVAD equation and dependent on the N2 coefficient to establish a relationship between pressure and number of failures [19].

$$(B1/B0) = (P1/P0)\text{^}N2 \qquad \textbf{Eq.2}$$

In the equation, B1 is the failure after pressure regulation, B0 is the failure before pressure regulation, P1 (m) is the regulated average pressure value, P0 (m) is the initial pressure value, and N2 is the failure frequency.

The FAVAD equation can calculate pressure management in drinking water distribution networks. This equation covers a single operating pressure value and gives results close to the practice area only for the constant output pressure control technique. It is inadequate for timed and flow-regulated methods operating at multiple operating pressures [3,5].

Considering the studies carried out to reduce water losses, it is clear that there is a need for a new method to calculate the economic benefits to provide a realistic result of the benefit and cost analysis for all pressure control methods in a way close to the practices area. In this study, a new algorithm has been created for this need.

In order to test the models to be established within the scope of the study, 3 DMAs in Kayseri province were examined. In this context, basic data such as network length, number of subscriber connections, network pipe type, number of faults of the relevant DMAs were obtained. In addition, pressure management was applied with different methods in these DMAs and the decreases in night flow and number of failures were monitored.

3. Practices Area

The water distribution system of Kayseri province has been selected as the study area for the creation of the algorithm that calculates how much water loss will be prevented if pressure management is applied in the real water distribution network and performs cost-benefit analysis based on the calculated result [5].

Kayseri province is located in the Central Kızılırmak Region of the Central Anatolia Region of Turkey. Kayseri Water and Canal Administration (KASKİ), which has a total water network length of 309 km, has 670000 subscribers and provides an average of 370000 m3 of water supply service per day to a population. In the study area, distribution networks can be monitored remotely with the SCADA system and a new GIS programme with SCADA-CBS integration with 95% reliability was switched to in 2020 [3,20].

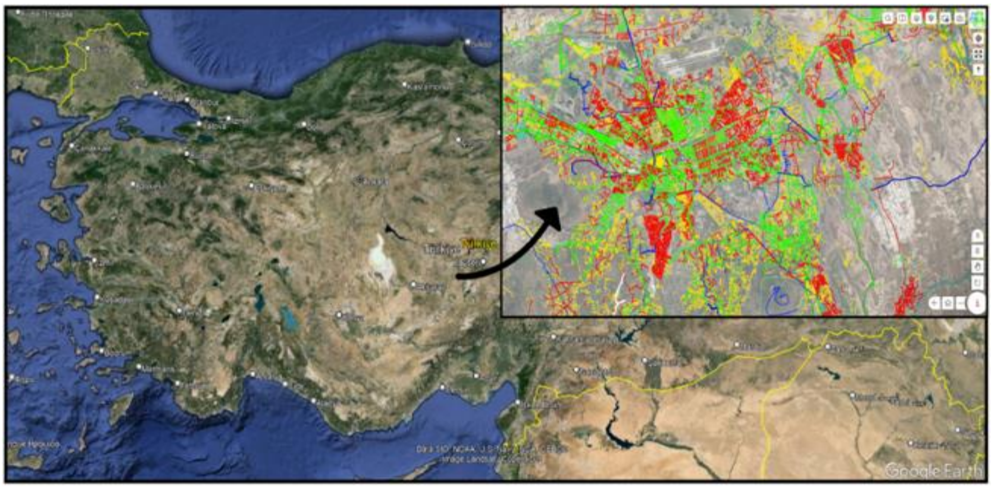

Figure 2. Practices area [3,20]

Figure 3. DMA areas [3,20]

Within the study's scope, data were taken according to measurements obtained from real isolated subregions, and the data obtained were compared with the theoretically calculated results. For this purpose, isolated subareas with different characteristics and pressures regulated by different methods were selected (Figure 2-3) [3].

4. Analyses and Assessments

Yıldırım Beyazıt 4-5 DMA operated by KASKİ was selected for the algorithm to calculate the final leakage in the fixed outlet pressure control practices. The results of the field practices and the algorithm are compared.

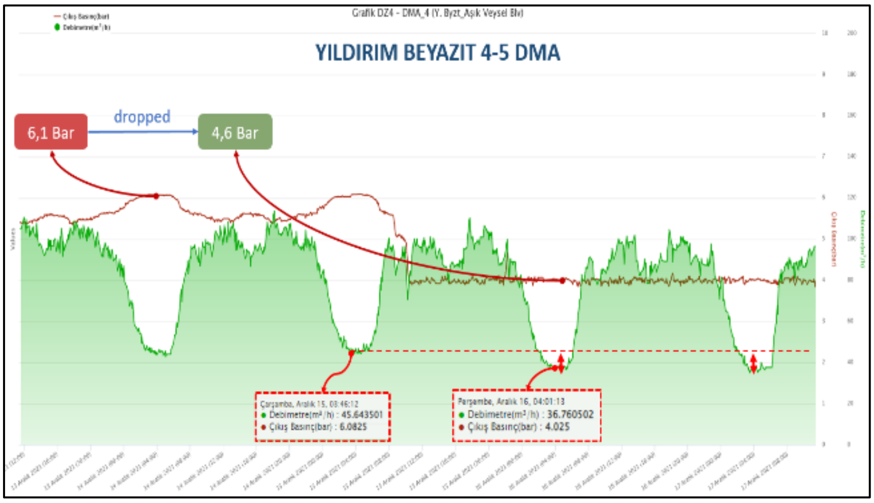

Figure 4. Yıldırım Beyazıt 4-5 DMA flow-pressure graph [3]

Before the pressure management practices in the DMA, the average inlet flow rate was 45.64 m3/h, and the average system pressure was 5.71 bar. After the pressure management practices in the lower zone, the average outlet flow rate was 36.76 m3/h, and the average system pressure was 4.67 bar (Figure 4) [3].

```
%YILDIRIM BEYAZIT 4-5 DMA ANALYSES
%calculation of the theoretical final flow rate
%unit m3/h
L0=45.64;
%unit bar
P0=5.71;
P1=4.67;
%unitless
N1=1.1;
%unit m3/h
L1=L0/(P0/P1)^N1;
%unit %
percentage_benefit=((L0-L1)*100/L0;
%unit m3/h
total_benefit=L0-L1;
%field application
%unit m3/h
application_L1=36.76;
application_total_benefit=8.88;
%comparison of theory and application
%unit m3/h
total_benefit_dif=total_benefit-application_total_benefit;
%unit %
benefit_dif=((total_benefit-application_total_benefit)*100/total_benefit;
```

Figure 5. Comparison of theory and practices, Yıldırım Beyazıt 4-5 DMA

Theoretically calculated results with actual field data result in comparison: The goal was to keep the difference below 5%. According to the results, the difference was 1.94%, which shows that the algorithm was successful (Figure 5).

Before the implementation of pressure management in the isolated sub-region, 46 failures occurred in 2020, and 48 failures occurred in 2021. Considering the average number of the last 2 years in the analyses, it is assumed that 47 failures occur annually in the network. In the isolated sub-region where pressure management with constant output was applied, 27 failures occurred after the pressure management practices (Figure 6) [3,20].

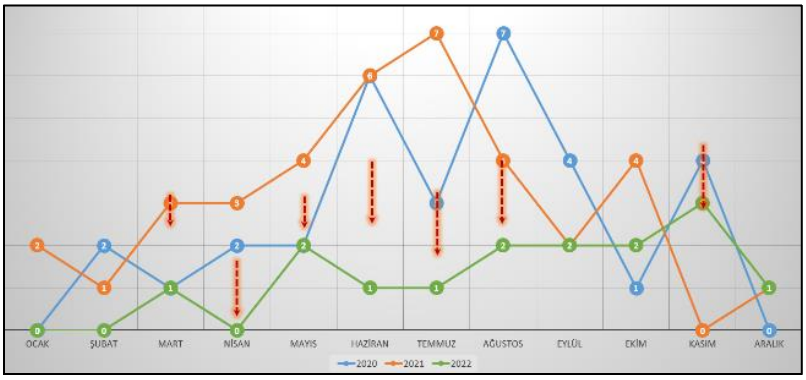

Figure 6. Yıldırım Beyazıt 4-5 DMA failure change graph [3]

In the theoretical calculation of the benefit obtained from the failure, the number of last failures in the network was calculated theoretically by considering the network's length and the annual number of first failures in the field practices (Figure 7).

```
%unit km
pipe_length=31.64;
%unit quantity
B0=47;
ref=(pipe_length*13)/100;
s=(((1-(ref/B0))*(1-(P1/P0)^3/(1-P1/P0)));
%unit %
percantage_s=(s*(1-P1/P0))*100);
%unit quanity
B1=round(B0-(B0*percantage_s/100));
%comparison of theory and application
%birim quantity
application_B1=27;
total_failure_dif=B1-application_B1;
%birim %
failure_dif=((B1-application_B1)*100)/B1;
```

```
%benefit analysis/flow
%unit TL/m3
unit_water_cost=9;
%unit TL/year
flow_benefit=L1*24*30*12*unit_water_cost;
%benefit analysis/failure
%unit quantity/year
descending_failure=B1-B0;
%unit TL/quantity
repair_cost=39600;
%unit TL/year
repair_benefit=descending_failure*repair_cost;
benefit_total=flow_benefit+repair_benefit;
```

```
%cost analysis
%unit TL/quantity
flow_meter_room=145000;
dirt_trap=12000;
border_valve=8500;
zero_pressure_test=2000;
monitoring_and_operation=52000;
prv=49500;
%unit TL
total_cost=flow_meter_room+dirt_trap+(border_valve*4)+(zero_pressure_test*
2)+monitoring_and_operation+prv;
```

```
%cost benefit analysis
if total_cost>benefit_total
    fprintf ('pressure management should be applied')
else
    fprintf ('pressure management should not be applied')
end
%unit month
recovery_period_of_investment=total_cost/benefit_cost;
%unit day
recovery_period_of_investment2=recovery_period_of_investment*30;
```

Figure 7. Comparison of theory and practices, Yıldırım Beyazıt 4-5 DMA

The actual field data results were compared with the theoretically calculated results, and the difference was 3.57%, thus achieving the set target. The cost and benefit analysis for the fixed outlet PRV determined that implementing pressure management in the drinking water distribution network was the right decision, and the return on investment was calculated as 2.44 months = 73 days (Figure 7).

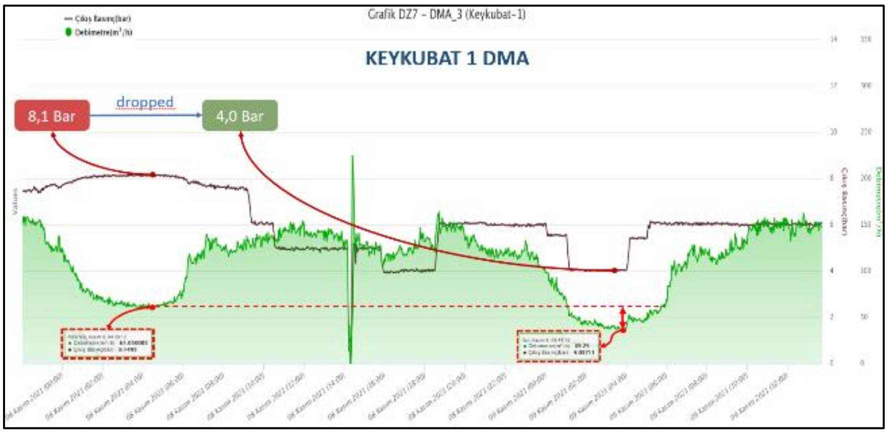

Figure 8. Keykubat 1 DMA flow-pressure graph [3]

Keykubat 1 DMA operated by KASKİ was selected for the algorithm to calculate the final leakage in the timed pressure control practices. The results of the field practices and the algorithm are compared (Figure 8).

```
%KEYKUBAT 1 DMA ANALYSES
%calculation of the theoretical final flow rate
%unit m3/h
L0=61.05;
%unit bar
P0=8.13;
P1=4.03;
%unitless
N1=1.1;
%unit m3/h
L1=L0/(P0/P1)^N1;
%unit %
percentage_benefit=((L0-L1)*100/L0;
%unit m3/h
total_benefit=L0-L1;
%field application
%unit m3/h
application_L1=36.76;
application_total_benefit=8.88;
%comparison of theory and application
%unit m3/h
total_benefit_dif=total_benefit-application_total_benefit;
%unit %
benefit_dif=((total_benefit-application_total_benefit)*100/total_benefit;
```

Figure 9. Comparison of theory and practices, Keykubat 1 DMA

Before the pressure management practices in the DMA, the average inlet flow rate was 61.05 m3/h, and the average system pressure was 8.13 bar. After the pressure management practices in the lower zone, the average outlet flow rate was 39.25 m3/h, and the average system pressure was 4.03 bar (Figure 8) [3].

Theoretically calculated results with actual field data results comparison: The goal was to keep the difference below 5%. According to the results, the difference was 2.37%, which shows that the algorithm was successful (Figure 9).

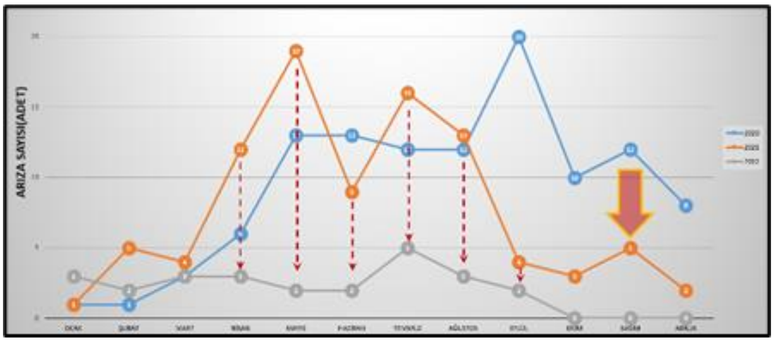

Figure 10. Keykubat 1 DMA failure change graph [3]

In the DMA, 83 faults occurred before pressure management was implemented (Figure 10). Pressure management in the DMA it is seen that 25 failures occurred after the practices. These failures are self-induced malfunctions [3].

```
%benefit analysis/flow
%unit TL/m3
unit_water_cost=9;
%unit TL/year
flow_benefit=L1*24*30*12*unit_water_cost;
%benefit analysis/failure
%unit quantity/year
descending_failure=B1-B0;
%unit TL/quantity
repair_cost=39600;
%unit TL/year
repair_benefit=descending_failure*repair_cost;
benefit_total=flow_benefit+repair_benefit;
```

```
%unit km
pipe_length=12.81;
%unit quantity
B0=83;
ref=(pipe_length*13)/100;
s=(((1-(ref/B0))*(1-(P1/P0)^3/(1-P1/P0)));
%unit %
percantage_s=(s*(1-P1/P0))*100);
%unit quanity
B1=round(B0-(B0*percantage_s/100));
%comparison of theory and application
%birim quantity
application_B1=25;
total_failure_dif=B1-application_B1;
%birim %
failure_dif=((B1-application_B1)*100)/B1;
```

```
%cost analysis
%unit TL/quantity
flow_meter_room=145000;
dirt_trap=12000;
border_valve=8500;
zero_pressure_test=2000;
monitoring_and_operation=52000;
prv=150000;
%unit TL
total_cost=flow_meter_room+dirt_trap+(border_valve*4)+(zero_pressure_test
*2)+monitoring_and_operation+prv;
```

```
%cost benefit analysis
if total_cost>benefit_total
    fprintf ('pressure management should be applied')
else
    fprintf ('pressure management should not be applied')
end
%unit month
recovery_period_of_investment=total_cost/benefit_cost;
%unit day
recovery_period_of_investment2=recovery_period_of_investment*30;
```

Figure 11. Comparison of theory and practices, Keykubat 1 DMA

The results of the real field data were compared with the theoretically calculated result, and no difference was observed. The algorithm and practice results overlapped, and the set target was achieved. As a result of the cost and benefit analysis for the timed PRV determined that implementing pressure management in the drinking water distribution network was the right decision, and the return on investment was calculated as 1.18 months = 36 days (Figure 11).

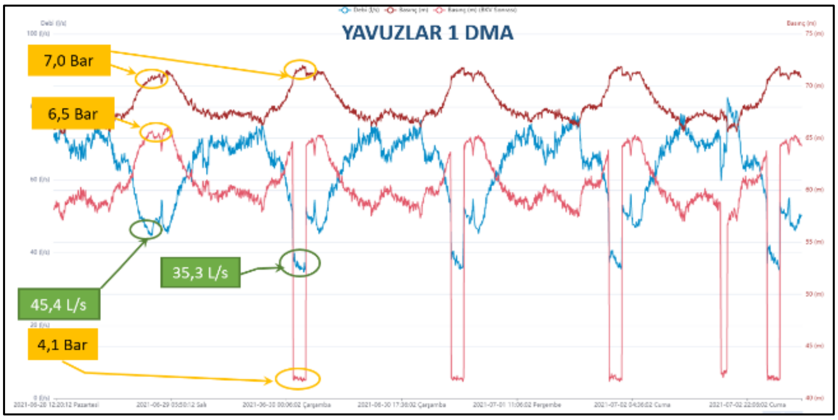

Figure 12. Yavuzlar 1 DMA flow-pressure graph [3]

Yavuzlar 1 DMA operated by KASKİ was selected for the algorithm to calculate the final leakage in the flow-sensitive pressure control practices (Figure 12). The results of the field practices and the algorithm are compared. The drinking water network was modelled in the isolated region's theoretical calculations. Graphical modeling of the network and calculations were performed with MATLAB (Figure 13).

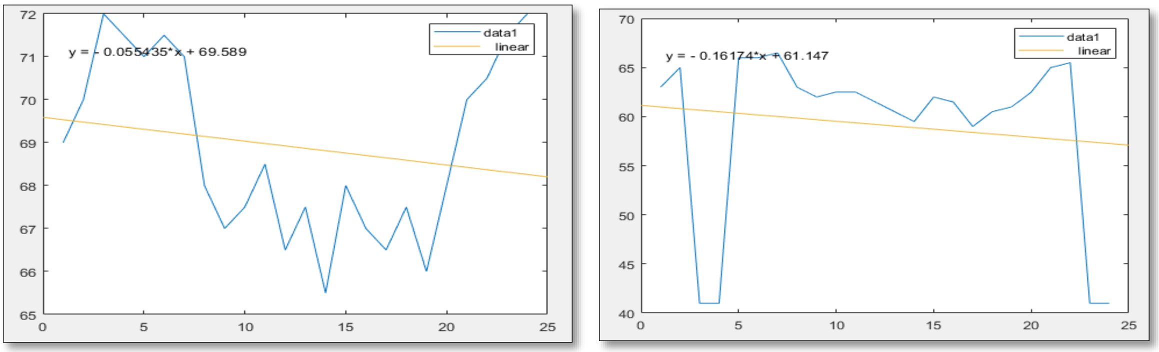

Figure 13. Modeling of the before-after pressure management for Yavuzlar 1 DMA

Based on the graphs drawn and the equations obtained, the flow rate reaching the subscribers from the distribution network before and after pressure management was calculated. The calculation considered the water supplied to the subscribers in 1 day. By taking the integral of the equation, the condition of the network before pressure management was analyzed with the definite integral.

The calculation resulted in a 1584.61 l/s flow rate passing through the network before pressure management and a 1359.86 l/s flow rate passing through the network after pressure management.

Theoretically calculated results with actual field data results comparison, it was aimed to keep the difference below 5%. According to the results, the difference was 3.25%, which shows that the algorithm was successful. In the theoretical calculation of the benefit obtained from the failure, different operating conditions of the system pressure values and the number of failures occurring in the network were taken into consideration, and the theoretical final number of failures was calculated in Figure 14.

```
%unit km
pipe_length=44.81;
%unit quantity
B0=92;
ref=(pipe_length*13)/100;
s=(((1-(ref/B0))*(1-(P1/P0)^3/(1-P1/P0)));
%unit %
percantage_s=(s*(1-P1/P0))*100);
%unit quanity
B1=round(B0-(B0*percantage_s/100));
%comparison of theory and application
%birim quantity
application_B1=24;
total_failure_dif=B1-application_B1;
%birim %
failure_dif=((B1-application_B1)*100)/B1;
```

Figure 14. Comparison of theory and practices, Yavuzlar 1 DMA

Failure results in real field data were compared with the theoretically calculated failure results, and the aim was to keep the difference below 5%. According to the results, the difference between the actual and theoretical results was 4.34%, and the set target was achieved. The costs of the flow-regulated pressure control method were determined as 447000 TL per year, and the benefits were determined as 455000 TL per month. As a result of the cost and benefit analysis for the flow-regulated PRV determined that implementing pressure management in the drinking water distribution network was the right decision, and the return on investment was calculated as 0.98 months = 29 days (Figure 14).

5. Results and Dıscussıon

In the DMA where fixed outlet pressure management was applied, according to actual field data, the flow rate before pressure management was 45.64 m3/h and the pressure was 5.71 bar; after pressure management, the flow rate was 36.76 m3/h, and the pressure was 4.67 bar. Theoretically, the flow rate was calculated as 36.58 m3/h when pressure management was applied with the constant outlet method. Theoretically, the net benefit from the flow rate was 8.88 m3/h in field practices and 9.06 m3/h. When the actual and theoretical results are compared, a difference of 0.18 m3/h in the net benefit is obtained from the flow rate, which is 1.94% in percentage terms. The result is within the limits of ±5%, sufficient for the algorithm to be successful (Table 1).

Pressure management has the additional benefit of reducing the number of faults in the network When the benefits are analyzed, according to the actual field data, 47 faults occurred in the region according to the average of the last 2 years' data without pressure management practices in the network, and the number of faults decreased to 27 after pressure management was applied in the region. Theoretically, the number of failures in the region after pressure management is calculated as 28. When the actual field data results are compared with the theoretical results, the difference in the benefit obtained from the failure was 3.57%, and this value was within the desired ± 5% limits. The first flow rate and the first number of failures were taken in the theoretical analyses according to the field practice results. Benefit and cost analyses were made according to the theoretically calculated flow rate and number of failures. As a result of the calculations, it was found that the practices of pressure management in the relevant distribution network have a monthly benefit of 121385 TL, and the cost of pressure management amortized in 2.44 months ~ 73 days.

According to the actual field data in the DMA where timed pressure management was applied, the flow rate before pressure management was 61.05 m3/h, and the pressure was 8.13 bar; after pressure management, the flow rate was 39.25 m3/h, and the pressure was 4.03 bar. Theoretically, the flow rate was calculated as 38.72 m3/h when pressure management was applied with the timed method. Theoretically, the net benefit from the flow rate was 21.8 m3/h in field practices and 22.33 m3/h. When the actual and theoretical results are compared, a difference of 0.53 m3/h in the net benefit is obtained from the flow rate of 2.37% in percentage terms. The result is within ±5%, sufficient for the algorithm to be successful (Table 1).

When the benefits arising from the additional benefit of pressure management, which is the reduction of the number of faults in the network, are examined, according to the actual field data, 83 faults occurred in the region before pressure management was applied. The number of faults decreased to 25 after pressure management was applied in the region. Theoretically, the number of faults in the region after pressure management is calculated as 25. When the actual field data results are compared with the theoretical results, there is no difference in the benefit obtained from the failure. This result is within the desired ±5% limits.

The first flow rate and the first number of failures were taken in the theoretical analyses according to the field practice results. Benefit and cost analyses were made according to the theoretically calculated flow rate and number of faults. As a result of the calculations, it was found that pressure management practices in the relevant distribution network have a monthly benefit of 336095 TL, and the cost of pressure management is amortized in 1.18 months ~ 36 days.

According to the actual field data in the DMA where flow-adjusted pressure management was applied, the flow rate before pressure management was 163.44 m3/h, and the pressure was 7.0 bar; after pressure management, the flow rate was 127.08 m3/h, and the pressure was 4.1 bar. When pressure management was applied with the flow-regulated method, 36.36 m3/h net benefits were gained from the flow rate in field practices and 35.17 m3/h theoretically. When the actual and theoretical results are compared, a difference of 1.19 m3/h in the net benefit is obtained from the flow rate of 3.26% in percentage terms. The result is within the limits of ±5%, sufficient for the algorithm to be successful.

According to the field practice results, the theoretical analysis takes the first flow rate and fault numbers (Table 1).

When the additional benefit of pressure management, which is due to the reduction in the number of faults in the network, is examined, according to the actual field data, 92 faults occurred in the region before the pressure management was applied. The number of faults decreased to 24 after pressure management was applied in the region. Theoretically, the number of faults in the region after pressure management is calculated as 23. When the actual field data results are compared with the theoretical results, the difference in the benefit obtained from the failure was -4.37% and remained within the desired ±5% limits.

Benefit and cost analyses were performed according to the theoretically calculated flow rate and number of faults. The calculations found that the monthly benefit of the pressure management practices in the relevant distribution network was 455635 TL, and the cost of the pressure management practices was amortized in 0.98 months ~ 29 days.

When the analysis results are analyzed,

• It is seen that the most costly method is the flow-regulated method, followed by time-regulated and fixed output methods.

• In addition to being the most costly method, it has been tested by analyses that the flow-adjusted method is the method that provides the most benefit. After the flow-adjusted method, the method that provides the highest financial benefit is the time-adjusted and constant output method, respectively.

The recommendations within the scope of this study are as follows:

•To decrease water resources, subscribers should take water-saving measures individually.

•The amount of water used in agriculture exceeds drinking and utility water. For this reason, conscious irrigation should be done in agriculture.

•Water channel administrations should prevent the losses that occur in the provision of water transmission from the source to the end user. The works out here prevent more water loss than the measures taken individually.

•Sustainability of the studies within the scope of water loss management should be ensured.

•Pressure management and the joint work of academic studies and water administration practices should be expanded.

Table 1. Field practices and theoretical calculation results of different pressure control practices

	Field Practices (YB-4/5)	**Theoretical Calculation (YB-4/5)**	**Field Practices (K-1)**	**Theoretical Calculation (K-1)**	**Field Practices (Y-1)**	**Theoretical Calculation (Y-1)**
Flow (L0)	45.64 m^3/h	45.64 m^3/h	61.05 m^3/h	61.05 m^3/h	163.44 m^3/h	163.44 m^3/h
Flow (L1)	36.76 m^3/h	36.58 m^3/h	39.25 m^3/h	38.72 m^3/h	127.08 m^3/h	128.27 m^3/h
Failure (B0)	47	47	83	83	92	92
Failure (B0)	27	28	25	25	24	23

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Declaration of Ethical Standards

This article's author(s) declares that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

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