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Balancing And Water Without Income With Economic Justification And The Need To Improve The Distribution Network (Study Of The Area Covered By Reservoir 91 Tehran)

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Abstract

Limitation of rainfall along with increasing population growth as well as severe limitation of renewable resources, management and reform of consumption pattern has become more necessary. One of the most important methods of consumption management is reducing water without revenue and water losses in water supply systems. Non-revenue water is measured by the difference between water produced and consumption, which is divided into apparent and actual losses. In order to prioritize based on the benefits obtained, it is necessary to review and evaluate all operational steps of reducing water without revenue. The aim is to carry out balancing studies and determine the various components of non-revenue water by the (International Water Association) method upgrade the network to a system based on separate zones and pressure zones and develop a water distribution network analysis model in Reservoir 91, Zone 1 of Tehran Water and Sewerage. This project can be used by decision makers in the field of water and wastewater. Field measurements and economic calculations of non-revenue water balancing show the need to reform the water distribution network. In this paper, while presenting a series of necessary measures to reduce apparent and actual waste, the need to reduce leakage has been compared economically with the comparison of related revenues and costs. Indicators for evaluating non-revenue water in the study area have been calculated so that in measuring cost / revenue can be the lowest cost in improving the water supply situation.

Keywords: Non-revenue water; Balancing; Minimum overnight flow; Apparent loss; Actual loss.

History of the importance of controlling and measuring water without revenue

Non-revenue water is unmeasured water that is somehow unavailable between production sources and subscribers and does not generate revenue for water and Sewerage Companies. The global volume of non-revenue water is estimated at 346 million cubic meters per day or 126 billion cubic meters per year (Liemberger and Wyatt, 2019). Considering the conservative price of just $ 0.31 per cubic meter of water, the cost / value of lost water is estimated at $ 39 billion a year. Not only is this a major financial concern, but the increase in non-revenue water, in the face of increasing water scarcity and climate change, is preventing it from achieving its goals of full service coverage, at a reliable level and at an affordable price. (Liemberger and Wyatt, 2019). Reducing water loss from water supply systems is often considered as one of the most important ways to improve the productivity of water supply services. However, the costs of water loss and its effects must be weighed against the benefits of managing and reducing it, and the optimal target level of water loss must be determined (Ahopelto and Vahala, 2020). In scientific and systematic approaches, economic factors such as the costs of improving facilities, energy and maintenance affect the quality and pressure of water. Identifying the physical and operational factors that affect the leakage process in the water network can provide a way to detect leaks. (Jang et al., 2018).

Pressure control in urban water distribution networks reduces water losses, delays asset degradation, and facilitates repair operations. (Berardi et al., 2019). Inaccuracies of meters, unauthorized branching and unauthorized use, reading errors, leaks and overflows from reservoir s, leaks from distribution network pipes, broken pipes, unintended problems in water treatment processes, malfunctioning controllers of distribution network and water withdrawal from fire hydrants are examples of non-revenue water. Uncounted water in urban water distribution networks is defined as the difference between the volume of incoming water and the volume of water consumed (Lambert and McKenzie, 2002). Unaccounted for water is divided into two categories: non-physical and physical losses (leakage). Given the scarcity of water resources, population growth, increasing per capita water consumption and rising water supply costs, the optimal use of available water resources has become a vital issue (Berardi et al., 2019). Studies in Ghana show that water billed meterd consumption (BMC) are 85% of billed authorized consumption (BAC), and the other 15% is billed unmetered consumption (BUC) (Amoatey et al., 2018).

The total water entering the system is divided into two categories: non-revenue water and revenue water. The results showed that the average apparent loss, real loss and non-revenue water (NRW) from 2010 to 2014 in Oman were approximately 19.5%, 21% and 40%, respectively. The average cost of annual non-revenue water (NRW) was estimated at approximately $ 9.4 million between 2010 and 2014, which is approximately 33% of the country's total revenue budget (Al-Bulushi et al., 2018).

Permitted consumption and water loss are also among the other divisions regarding water consumption. Eligible costs include measured and non-measured costs with and without income. That part of the water entering the system that is not part of the permitted uses is referred to as wastage (Petroulias et al., 2016).

By definition, water loss is equal to the difference between the input and output currents of the network (shared consumption and output from the DMA range). This loss is divided into apparent loss and actual loss (Aboelnga et al., 2018). Apparent loss includes unauthorized use, measurement equipment error, and data and system management error. Actual loss also includes distribution network leaks, transmission line leaks, reservoir leaks, and subscriber leaks. Lack of active leakage control (ALC), overpressure, poor performance and maintenance, poor quality of underground assets, vibration and incoming traffic load and corrosion are the reasons for leakage in the network (Samir et al., 2017).

In apparent loss, the amount of water is actually used by the consumer, but due to the lack of proper measurement due to measurement error, reading, reading record, subscriber system, etc., the actual amount is not specified. The results show that different methods of water loss components are estimated differently by different methods. As a result, various waste reduction measures are planned and prioritized (Taha et al., 2020).

The apparent loss rate therefore includes the estimation of unmeasured costs as well as the correction of the measured costs taking into account the types of errors, and the actual loss includes the amount of leakage from the system (Ahopelto and Vahala, 2020).

Area of study

The area covered by Reservoir 91 is located in area one of Tehran Municipality (Figure 1). This area is bounded on the north by the mountains north of Tehran, on the east by Mina and Hosseini streets, on the west by Daneshjoo Boulevard and Shahid Beheshti University, and on the south by 19th Street and Daneshjoo Boulevard. According to the statistics obtained, the total population in the region in 1400 is equivalent to 13,457 people, an area of 125 hectares and therefore the density is equal to 108 people per hectare (obtained from the Statistics Center of Iran).

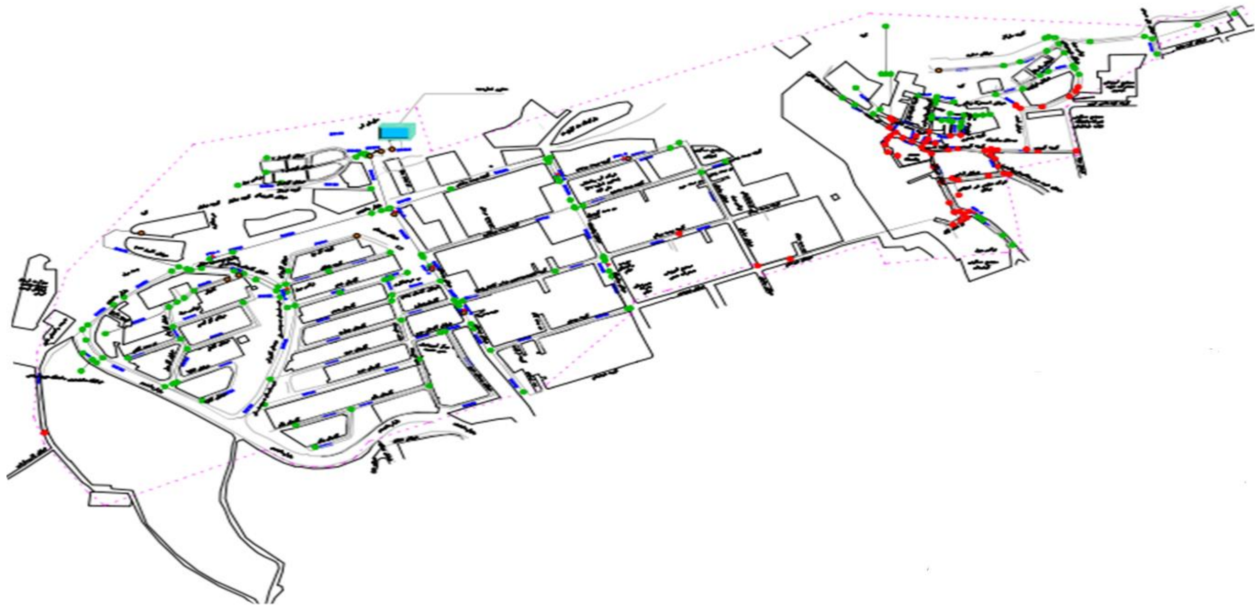

Figure 1. Area covered by Reservoir 91 Tehran

The texture of this area is mainly residential and the density in the eastern part of the region is slightly higher than the western part. The number of subscribers in this area is 760, which includes 711 residential subscribers, 7 public-administrative subscribers, 33 commercial subscribers and two subscriptions belonging to Tehran Municipality for green space consumption. The rest of the subscribers are not available in the subscriber affairs bank and do not have a specific user.

This reservoir with a volume of 12,000 cubic meters is located in the geographical coordinates of X: 535715 Y: 3963349. The outlet pipe of this reservoir is made of ductile iron and has a diameter of 400 mm. An ultrasonic meter is installed on the outlet of the reservoir and before the pumping station, which measures the output flow from this reservoir. The mentioned pumping station is in order to supply pressure in the streets adjacent to the reservoir. The length of distribution network lines is about 15294 meters, which are made of ductile iron, polyethylene and PVC.

1. Study method

According to the information of flow meters installed at the outlet of the reservoir and according to the statistics of water consumption and production, the amount of non-revenue water in the project area has been calculated. How to do this was that in the first step, the reading was measured in a time interval and with an interval of 15 minutes by the electromagnetic meter at the output of the reservoir; To consumption fluctuations in the network to determine the hourly fluctuations and also to determine the minimum consumption (in the early morning hours) to determine the amount and range of network leakage (major percentage of actual loss). In the second stage, by reading the inlet meters of the subscribers in the same reading period and the amount of water entering the area covered by the reservoir, it is compared with the number consumed in that particular period and finally its total losses are determined. Also, regarding night losses, due to the fact that the use of the project area is mainly residential, little harvest is done in the network, and this statistic can be calculated, especially in winter, by using meter reading information at the reservoirs outlet. According to the studies and analysis of the subscribers' affairs bank, the amount of hourly expenses was calculated separately for each subscriber according to the uses. The amount of water loss in the water distribution network depends on the quality of the network in terms of proper design, pipe life and how it is operated. According to the ultrasonic meters installed in the outlets of the reservoirs and the existence of their information during the year 2020-2021, it is possible to achieve the actual amount of losses by calculating the difference with the consumption statistics of the subscriber bank during the same period.

In order to model the network, first, the current status of the distribution network, including how the pipes are arranged, their diameter and manner of connection, the location of the shut-off and connection valves, and the pressure breaker, etc. were determined. Then the area covered by each pipe was calculated in ARC GIS software. According to the population of the reservoir area in 2020 and 2021 (obtained from the Statistics Center of Iran) and per capita water consumption (obtained from the Water and Sewerage Company of Tehran Province), the rate of flow rate of each pipe and finally the flow rate of network nodes were determined by considering the maximum daily and hourly coefficients. Finally, by establishing a connection between ARC GIS and Water Gems software, network analysis was started and the required corrections were made by the software (Systems, 2019) in order to adjust the pressure and speed in the network.

1-1. Water allowed with income

The amount of water with income consists of two parts:

A. Authorized expenditures measured by income
B. Permitted unmeasured expenditures with income (on account)

In order to calculate the volume of water with income, the report of the subscriber consumption statistics bank program has been used. The mentioned reports were received from November 2017 to the end of June 2021 from the Water and Sewerage Company of District One of Tehran. Due to the information in the output meters of the reservoir (in the measurement interval), the checks were performed in the same time period.

Due to the meter test operation, the required information of the subscriber affairs bank as well as the local survey, the required information was prepared and verified. Table 1 lists the number of subscribers read by uses and the diameter of their branches.

Table 1. Number of subscribers read by users and diameter of branches

user	Branch diameter (inches)						Total
	0.5	0.75	1	1.5	2	3	
Residential	420	191	80	20	_	_	711
Official	2	3	1	_	_	1	7
Commercial	29	3	1	_	_	_	33
green space	2	_	_	_	_	_	2
Total	453	197	82	20	_	1	753
Percentage	60.2	26.2	10.9	2.7	0.0	0.1	100

Table 2 shows the consumption of subscribers (measured and on account) separately for each of the available uses. Based on this table, it is determined that residential use has the highest amount of water consumption per day and green space use has the lowest amount of water consumption per day. It should be noted that the expenses mentioned in these tables are along with the expenses of the subscribers who have had obstacles for reading in some of the reading periods and their water prices have been considered as an account.

It is worth mentioning that the water allocated to the green space is by a separate well and in some cases where the municipality has a water share, it has been registered in the subscriber affairs bank and its cost has been received. Also, the constructions that are carried out in this area are either available in the subscriber bank (as a user under construction) or they buy water recharge in the form of volume meters; These items have also been added to the Subscriber Affairs Bank and have been calculated as revenue expenses. The subscriber statistics bank has been analyzed by SPSS, EXCEL, and ACCESS software for the statistical period years. In the analysis performed on the Subscriber Affairs Bank, the total numbers of subscribers covered by the reservoir and its consumption for different uses have been examined, which is mentioned in the table below.

Table 2. Consumer consumption (water with income) by user

user	Number of subscribers	Consumption (liters per day)	Consumption in the studied period (cubic meters)
Residential	711	3503830	2014702
Official	7	339556	195245
Commercial	33	118028	67866
green space	2	11306	6501
Total	753	3972720	2284314

1-2. Water without income or water is not counted

In general, the volume of non-revenue water can be examined in three sections:

1-2-1) Allowed expenses without income
1-2-2) Apparent loss (water is not considered non-physical)
1-2-3) Actual loss (water is not considered physical)

1-2-1. Allowed consumption without income

In general, the allowed non-revenue uses include the use of mosques, charities, fire and tanker water, reservoir washing, and distribution network. Within the scope of this plan, the cost of water used for mosques, charities, municipal fire water and tanker water will be collected; therefore, the allowable non-revenue uses in the reservoir area include washing the network and fire hydrants, and this amount has been inquired. It should be noted that the stop time is up to the end time and the average speed is equal to 0.7 meters per second. According to the pipe diameter, time and average speed, the total output flow rate is estimated at 187,000 liters.

From the total difference of non-revenue water in the studied period equal to 984628 cubic meters of allowable consumption without revenue equal to 187 cubic meters, the amount of waste is equal to 984441 cubic meters. The difference between non-revenue water and unaccounted for water is that in non-revenue water, the allowable consumption without unmeasured revenue is not considered a waste; but it is not considered in water, it is considered as an apparent waste. (Issue 556) Each of these components is examined below.

1-2-2. Apparent loss (water is not considered non-physical)

Subscriber information according to the meter test operations, subscriber affairs bank information as well as local navigation are mentioned in Table 3. On the other hand, a number of subscribers are not read in each period, which is usually a number of these subscribers are read in the next period; For this reason, the number of healthy meters is not the same as the number of subscribers read.

Table 3. Information about meters and their readings

Total number of subscribers	Number of subscribers read	Healthy meter	Faulty meter	No meter	Existence of reading barrier	unauthorized subscribers	Unread subscribers
760	753	754	6	0	23	0	7

The following error is examined in each of the following cases (issue 556):

A. New or old subscribers not notified to meter readers (management error)

New subscribers may be added to the list of water and sewage companies each month, or there may be subscribers generally who have files with water and wastewater companies; But it is not in the computer list or it is not in the file of water and sewage companies at all (subscriber left). In such a situation that the meter readers are not aware of, its common costs are not considered. Consumption related to these subscribers is equal to the average consumption in the reservoir area. Based on the research, the information of one subscriber was not informed to the meter readers that the consumption of this subscriber was calculated as 5225 liters per day, which was a total consumption of 3004 cubic meters during the study period.

B. Branches whose function is not registered (operation error)

Subscribers who have unregistered consumption during the study period are considered as operating errors. Based on the research, the information of 6 subscribers was not recorded that the consumption of each subscriber was calculated as 5225 liters per day, which was a total consumption of 18027 cubic meters during the study period. In general, branches that have no function or in general their function values are not registered in the subscriber affairs bank, are considered as the causes of operating error. These branches have been obtained by examining the subscriber affairs bank in the period under study and local survey, and their consumption has been calculated taking into account the average consumption.

C. Human error caused by the wrong reading of the meter

Due to the lack of proper training and lack of workload with the ability of personnel, there are always mistakes during the readings of the meters. Although, according to the mechanization of affairs by electronic machines, part of these errors has dropped compared to the past, but with these issues, such errors have not been completely eliminated. Based on the results of this study, the human error caused by the wrong meter reading was 5477 cubic meters in the study period. In a summer, this type of errors can be regarded as factors such as the following:

- The high workload of each meter, which inevitably decreases the reading time of each meter.
- Lack of standard sharing plaque
- The lack of joint presence in place
- Not to properly educate the affairs of each meter reader, so that the type of meters, its error, and repair and replacement of the meter.
- Failed to install correct meters
- Meters numbering status (broken glass, steamed, matted and ...)

D. An errors related to meter during consumption periods

Among the apparent errors in water pressure volume, there is a tool error that contains an error derived from meter. Home meters are mostly mechanical and turbine type; the base meter used in the meters of the subscriber test is the Contazara meter. The meter accurately measures the flow when its recording section is precisely calibrated. If there is a disturbance in the transmission speed of the turbine to the meter, the meter will not have the necessary accuracy and in this case the water flow will show less or more than its actual value. In the data collection method, the cluster sampling technique was used, in which each cluster contains 6 to 10 meters. In the reservoir range to select 8 random points from the total number of subscribers, the value of k is 94. The random number selected between (1 to 94) is equal to 60. Therefore, 8 points are selected by the following method.

$$60\,,60+\mathrm{K}\,,60+2\mathrm{K}\,,\cdots,60+(8-1)\mathrm{K}$$

After identifying the random points, the subscription number and address of the selected points must be extracted from the list. Then, regardless of the obtained point, 5 subscribers on the right and 5 subscribers on the left are considered as 10 meters of a cluster and the necessary tests are performed on it. For cases where the number of subscriptions specified for the test is not a factor of 10, one of the clusters is tested in a smaller number. By having a timely list of subscribers, including the subscription number, address and type of consumption of the study community, the selection of clusters is done systematically. To do this, if the total number of samples is n and the number of meters in each cluster is m, to select a random point systematically from the total number of pilot subscribers, first the parameter k is obtained as follows:

$$\mathrm{K} = \text{Total number of subscribers}/(\mathrm{n}/\mathrm{m})$$

Then, using a calculator, a random number between 1 and K is selected. The obtained parameters were calculated for clustering in the range of $\mathrm{K} = 94$ and $\mathrm{R} = 60$.

After listing the subscribers' expenses and reviewing the lists, the branches whose monthly consumption was less than a certain limit were determined. In this case, the meter shows the amount of common consumption is very small but greater than zero. Therefore, the uncalculated volume of water due to the measurement error of faulty meters was calculated by knowing the number of branches that consume less than a certain limit (for example, five cubic meters per month). With the expiration of the operating period of the currents before the start of the meter movement, the minimum current is not recorded or if it is recorded, they have a large error. According to the performed studies, it was observed that the diameters of 1.2 and 3.4 have a negative error. While one-inch diameters have a positive error (Figure 2).

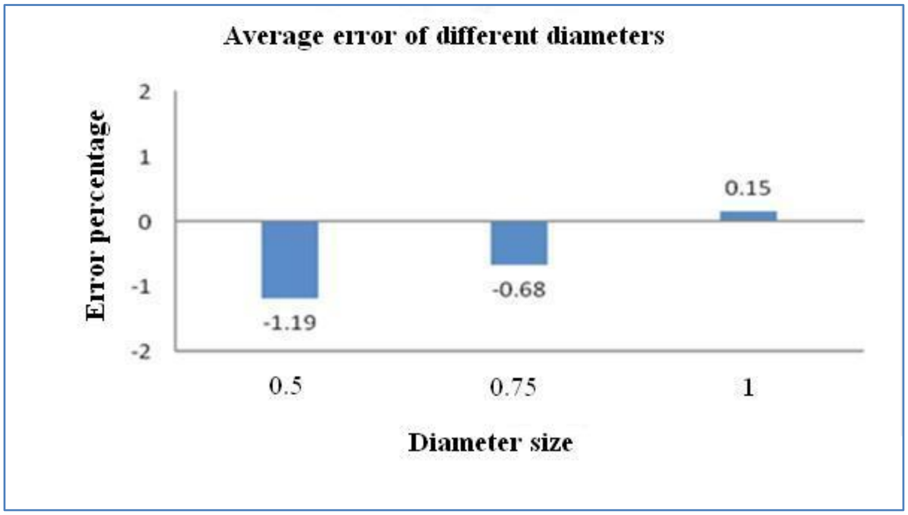

Figure 2. Mean error in different diameters

Finally, by applying the error coefficient obtained in each diameter, the volume error of the subscribers' meters was calculated (Table 4).

Table 4. Meter reading error

Branch diameter	Error ratio (percentage)	Consumption error (cubic meters in the study period)
0.5	-1.19	-6228
0.75	-0.68	-4751
1	0.15	956
Total		-10024

E. The expenses of unauthorized subscribers were determined in the review of the subscribers' affairs bank.

In apparent loss, part of it is related to unauthorized use. This type of consumption is related to the water consumption of those subscribers who are illegally using the water withdrawal network. This type of use can be identified by navigation operations. Unauthorized subscribers were not found by navigating the reservoir and using the information of their users.

1-2-3. Actual waste (water not counted physically)

Unaccounted for physical water (actual loss) covers a wide range of losses and is generally considered as a leak. In general, losses (leaks) in transmission lines, distribution network and branches can be divided into two main parts:

A. Visible leaks or accidents (reported fractures)
B. Invisible leakage (unreported fractures and background leakage)

Leakage and loss calculations in the reservoir area water distribution network were performed by three methods (Lambert and McKenzie, 2002).

1-2-3-1. Annual water balance method:

In calculating water losses from this method, the components of water balance must first be determined. Using this method, by calculating the volume of water entering the network, authorized consumption with revenue and without revenue and apparent losses, the total amount of real losses is obtained. Obviously, the accuracy of the number obtained depends on the accuracy of the calculations and estimates used to determine the other components of water balance.

According to the calculations made in the previous sections, the amount of authorized expenditures with income and without income and the amount of apparent loss has been determined. Given the volume of water entering the network, by subtracting the above, the actual amount of loss is obtained (Table 5).

Table 5. Actual wastage using the annual water balance method

Description	Cubic meters in the study period
Inlet water to the network	3268944
Authorized consumption with income	2284316
Authorized consumption without income	187
Apparent waste	36532
Real loss	947909

1-2-3-2. Leakage component estimation method:

This method is based on the theory of estimating wastes due to background leaks and bursts (visible leaks). It should be noted that there is no accurate method for estimating the components of distribution network wastes. In the current method, only the arithmetic difference between production and consumption represents the total wastes of the distribution network. However, even where all production and consumption are measured because measurements and calculations are prone to error; Analyzes show up to 50% uncertainty in calculating annual wastes (Journal 556). This method has been calculated in comparison with other methods.

A. Visible leaks (reported):

Part of the actual waste of water distribution networks occurs due to leaks caused by accidents and incidents. Fractures and leaks that become visible and recognizable without the need for active leak control are called reported fractures. Reported fractures have a higher discharge than background leaks and are usually reported very soon after occurrence, because they affect the consumption of subscribers or cause damage to homes, facilities and streets, and so on.

Familiarity with the amount of water wasted and its economic value reveals the importance of the accident phenomenon in the networks, and its calculation can determine some of the actual losses that have become visible. In order to determine the amount of water lost due to each accident, according to the hydraulic laws governing the flow, we need the burst cross section and network pressure at that time. The cross-section equivalent to fracture or crack was determined appropriately and accurately at the time of the accident and recorded in a special form; The amount of visible leakage was calculated only by knowing the network pressure at the scene of the accident and through the table related to the hole or crack (Journal of Accidents and Incidents of the Water Office without revenue of water supply system of the country). It should be noted that since the diameter of the hole or fracture in each of the events that occurred at the location is not exactly known; And according to the estimation that is used in equalizing the cross-sectional area of the fracture or hole and estimating the average network pressure and using the Orifice relation in calculating the leakage discharge, the calculated numbers are estimative but according to the available information, they are closest to reality. The average pressure of the distribution network at the scene of the accident is also considered according to the pressure measurements performed. Also, the average network pressure in the reservoir area is 49.5 meters of water.

Using the number of accidents, the average recovery time and the flow rate of fractures can be calculated the amount of leakage in the area covered by the reservoir.

The duration of fractures consists of three time periods, which are: time of awareness, time of positioning and reaching the place, time of repair. In the case of the study area, the reported fractures were from branches and tubes within the joint, which is 5 days of awareness and positioning. (Issue 556)

Due to the fact that the repair time can be extracted from the accident log file, it is used only for the time of knowing the publication 556 of the Program and Budget Organization. Repair time for branches, minor accidents and major accidents is 68 minutes, 118 minutes and 362 minutes, respectively, according to the inquiry made from the accident database.

In order to determine the leakage rate of the hole or fracture according to the pressure in the leakage range and the diameter of the crack or hole created on the pipe, the leakage rate is calculated. It should be noted that the diameter of the hole in the events of the branches is equal to 0.2 inches, in the minor events 0.5 inches and in the main events 1/1 inch. (Reference: Journal of Accidents and Incidents of the Office of Water without Revenue of water supply system of the Country)

The amount of leakage caused by accidents can be calculated based on the following formula:

Loss time (minutes) * Amount of water leakage through pipe holes and under different pressures (liters per minute) * Number of accidents

The number of accidents was reported according to the information received (33 in the study period). Loss time, which consists of a total of two fracture times and repair time, is 5 days and 68 minutes, respectively.

In order to calculate the amount of water leakage from pipe holes and under different pressures, by holding the hole diameter according to each of the types of accidents (main, secondary and branches) and also, the average network pressure of 49.5 meters of water (4.79 atmospheres) can calculate the amount of leakage caused by accidents (Journal of events and incidents of the water office without water supply system revenue of the country).

The volume of visible leakage caused by branching accidents during the study period:

$$33 \times 30.3 \times \big((5 \times 24 \times 60) + 68\big) = 7267273 \text{ (Liter)}$$

B. Unreported leaks:

Unreported fractures usually have a lower discharge than reported fractures, but their discharge is higher than the underlying leaks and can only be detected by active leak control operations. They can exist for a few days or operate in secret for years. Due to the lack of sufficient information to calculate the amount of unreported leaks, this volume of losses cannot be estimated.

C. Background leakage:

Almost all losses from fittings on main and secondary pipes (including all fire hydrants, water sources and tanks, etc.) and leaks from small pores are in the category of underlying leaks. Substrate losses are the cumulative leakage of all relatively small holes and leaks whose discharge is less than the threshold discharge between fracture and ground leakage. The threshold between fracture and ground leakage is not fixed and different figures have been reported in different countries. Generally, finding and repairing these leaks is not economically viable and will be eliminated with the reconstruction and renovation of pipes and other related facilities. In general, background leakage is divided into three components: background leakage from main and sub-lines, background leakage from branches, and background leakage from the common internal network.

It is difficult to calculate the amount of background leaks in a water distribution network due to their invisibility. In the Burst and Background Estimates method (BABE), the amount of leakage is determined using the estimated values of previous research. The background leakage of the main lines is calculated from the following equation:

$$\text{The main leak background lines} = \mathrm{Q_{Leak}} \times (\mathrm{p_{av}}/50)^{\mathrm{N}} \times \mathrm{L} \qquad (1)$$

$\mathrm{Q_{Leak}}$ is the leakage rate of the main lines in liters per kilometer per hour (issue 556), L are the length of the main pipeline in kilometers, N is the compressive strength for field fractures and $\mathrm{p_{av}}$ is the average network pressure in meters. The number 50 is the standard pressure at which the leakage rate values calculated at this pressure are proposed.

The ground leakage for the branches is calculated from the following equation:

$$\text{Branches for leakage grounds} = \mathrm{Q_{Leak}} \times (\mathrm{p_{av}}/50)^{\mathrm{N}} \times \mathrm{n} \qquad (2)$$

$\mathrm{Q_{Leak}}$ is the leakage rate of branching in liters versus branching per hour (Lambert and McKenzie, 2002) and n is the number of branching. Underground leakage for intra-joint pipes is obtained in the same way as for branching.

Considering the average infrastructure conditions in the region, the amount of field leakage from the distribution networks covered by the reservoir is given in Table 6.

Table 6. Field leakage

Network length (km)	Number of branches	Medium pressure (water meter)	Field leakage (cubic meters in the studied period)		
			Main distribution pipes	Subscriber branch pipes	Total
15.29	760	49.5	8356	31149	39505

1-2-3-3. Method of measuring and analyzing the minimum night flow:

This method is based on measuring the minimum input current to a separate (isolated) area at the time of minimum subscriber consumption and maximum amount of pressure and leakage and using the concepts of ground leakage (BABE) and Fixed and Variable Area Discharge paths (FAVAD). The method of analyzing the minimum night flow, especially when it is done continuously throughout the year, the calculations showed that this method has a higher accuracy than the water balance method.

Minimum overnight current refers to the amount of metered current in an area with a separate network at night and at a minimum interval of subscribers' consumption, which consists of the following three components: night use, background leakage and fracture. Table 7 shows the components of the minimum overnight flow.\

Table 7. Minimum overnight flow components

<table>
<tr><td rowspan="5">Minimum night flow (MNF)</td><td rowspan="2">Night use (NU)</td><td colspan="2">Long-term use (LU)</td></tr>
<tr><td colspan="2">Normal nigh use (NNU)</td></tr>
<tr><td rowspan="3">Leak (L MNF)</td><td>Visible</td><td>Reported fractures</td></tr>
<tr><td rowspan="2">Invisible</td><td>Unreported fractures</td></tr>
<tr><td>Field leakage</td></tr>
</table>

In order to calculate the leakage, the amount of night consumption should be deducted from the minimum amount of night flow.

$$L_{MNF} = MNF - NU \quad (3)$$

1-2-3-3-1.Minimum night flow (MNF):

Within the reservoir range, the minimum overnight current (MNF) is extracted from the output information of each meter over a period of time. The process was as follows: At first, after entering the output information of the meters, the minimum flow per day due to the large number of subscribers was obtained using SPSS software. Finally, the minimums were set in the desired time period. The minimum overnight flow (MNF) of the reservoir was calculated to be 1416156 cubic meters in the studied period.

Night Use (NU) includes consumption of regular subscribers and consumption of long-term use (LU).

A. Consumption of normal nigh use (NNU):

Indicates water consumed at home overnight in the community, which is determined by local research. Research in the UK shows that more than 6% of the population is inactive at night and each subscriber consumes about 10 liters of water per hour. Thus, overnight home consumption is simply estimated from the nocturnal active population over the study period (Lambert and McKenzie, 2002). The normal subscribers of the study area are 13457 people who consume 10 liters per hour per person. The total consumption of 111424 cubic meters in the study period was estimated.

B. Consumption of long-term use subscribers (LU):

In determining the long-term use (LU) subscribers, five times the average consumption is used as a basis. The reason for this is that initially the leakage rate was calculated as high-consumption subscribers based on the consumption conditions of subscribers whose consumption rate was more than ten times the average consumption, but the leakage rate in this case was more than 34%. This amount of leakage cannot be correct because the percentage of water with income that is documented in the Subscriber Affairs Bank accounts for about 70% of the water entering the network. This confirms that the consumption of high-consumption subscribers in this area is more than other areas. Therefore, the basis for calculating high-consumption subscribers in the reservoir area is five times the average consumption. The amount and speed of consumption of high-consumption subscribers are presented in Table 8.

Table 8. Subscribers with long-term use

Row	Consumption (liters per second)	Consumption (cubic meters in the study period)
1	0.64	32018
2	0.41	20440
3	0.44	21693
4	0.53	26472
5	0.41	20274
6	4.8	238464
Total	7.23	359361

By calculating the minimum night flow and the amount of night consumption of subscribers, both normal and high consumption, the actual loss rate of 945,371 cubic meters in the study period or 21.1% was calculated.

Finally, the values obtained from the three methods of annual water balance, component analysis and minimum overnight flow should be compared with each other. If the values obtained from all three methods are close to each other, the calculations and results are correct, otherwise the most logical value should be selected using engineering judgment (Journal 556). According to the calculations performed in the annual water balance methods and at least at night, it is observed that these two methods do not differ much in the actual loss rate (leakage), so the number obtained from the annual balance method is considered as the actual loss rate.

Results

According to the difference between inlet and outlet water and the studies performed, it was found that non-revenue water in the reservoir is as described in Table 9. According to this table, non-revenue water accounts for 30.12% of the total volume of inlet to the reservoir.

Table 9- Inlet water to the system and non-revenue water in the studied period

The volume of water entering the system	Unit (cubic meters)	Percent
Revenue water	2284314	69.88
No revenue water	984628	30.12
Total input volume (measured)	3268942	100

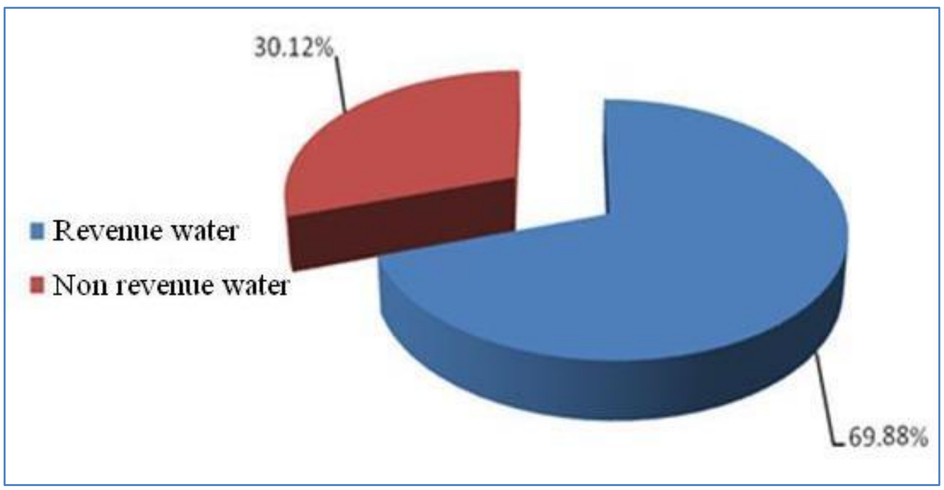

Figure 3. Percentage of water entering the system and revenue water of reservoir 91

Authorized non-revenue consumption within the scope of each reservoir includes washing the network and lines, which is measured at 187,000 liters. Table 10 shows the difference between the total non-revenue water from the authorized non-revenue consumption and the amount of loss. According to this table, 30.11% of the total water is wasted.

Table 10. All kinds of non-revenue water

All kinds of non-revenue water	Volume in the study period (cubic meters)	Percentage of non-revenue water	Percentage of total water
wasted	984441	99.9	30.11

Authorized non-revenue consumption	187	0.1	0.01
Total	984628	100	30.12

Finally, Table 11 presents the types of wastage.

Table 11. Types of wastage - cubic meters in the study period

<table>
<tr><td rowspan="10">Volume of water entering the system</td><td rowspan="10">3268944</td><td rowspan="2">revenue water</td><td rowspan="2">2284316</td><td>Revenue billed authorized consumption</td><td colspan="2">2214715</td><td rowspan="2">Revenue authorized consumption</td><td rowspan="2">2284316</td><td rowspan="4">authorized consumption</td><td rowspan="4">2284503</td></tr>
<tr><td>Revenue unbilled authorized consumption (on</td><td colspan="2">69602</td></tr>
<tr><td rowspan="8">non-revenue water</td><td rowspan="8">984628</td><td>Non-revenue billed authorized consumption</td><td colspan="2">0</td><td rowspan="2">Non-revenue authorized consum</td><td rowspan="2">187</td></tr>
<tr><td>Non-revenue unbilled authorized consumption</td><td colspan="2">187</td></tr>
<tr><td colspan="3">Leak</td><td>Real loss</td><td>947909</td><td rowspan="4">Water loss</td><td rowspan="4">984441</td></tr>
<tr><td>Branches whose function is not recorded</td><td>18027</td><td rowspan="3">Data and system management error</td><td rowspan="3">Apparent loss</td><td rowspan="3">36532</td></tr>
<tr><td>New or old subscribers who have not been notified to the meter readers</td><td>3004</td></tr>
<tr><td>Human error due to wrong meter reading</td><td>5477</td></tr>
<tr><td>Error of measuring equipment</td><td colspan="2">10024</td><td></td><td></td><td></td><td></td></tr>
<tr><td>billed unauthorized consumption</td><td colspan="2">0</td><td></td><td></td><td></td><td></td></tr>
</table>

Economic analysis

In order to economically analyze the proposed plans to reduce losses and create priority in network reform, the following tables are presented:

Water pressure is high in some parts of the network, which increases consumption and also increases the amount of leakage from the network. Therefore, in order to reduce the number of casualties in the region, these cases should be eliminated by modifying the network zoning and modifying some pipelines, as well as performing leak detection operations. It should be noted that each of the mentioned items has costs and revenues that are listed in Tables 12 and 13 separately (based on the price list of 2021 and price inquiries from manufacturers).

Table 12. Executive costs

Description	Total price (Rials)
Buy pipes	176,064,000
Piping operations with polyethylene pipes	86,912,000
Buy valves	202,515,000
Install valves	2,081,000
Construction of milk ponds	192,863,600
Earthworks and drilling strip repair	621,809,664
Transportation	20,007,773
Equipping and dismantling the workshop	52,090,121
Total	1,354,343,159

Pressure and consumption measurements show that for every 10 meters of water pressure reduction, network losses are reduced by 15 percent. Implementation of the correction plan reduces the pressure in the network from 49.5 meters of water to 41 meters of water, which means a reduction of 8.4 liters per second to reduce the consumption of subscribers.

Table 13. Revenues from pressure reduction in the network

Average consumption (l / s)	Percentage reduction of subscribers' consumption per 10 meters of pressure reduction	Pressure reduction after network correction (Water meters)	Consumption reduction rate (l / s)	Consumption reduction rate (Cubic meters per year)	Profitability in one year (Rials)
65.8	15%	8.5	8.4	264571	6,852,388,900

Reducing pressure reduces pressure-related costs (if direct pressure is used) and thus retrieving and storing resources, so reducing pressure can be an effective solution to control unwanted consumption. When the faucet is open, less water will be consumed at low pressure. The number of accidents and the amount of leakage from water distribution networks is directly related to the amount of water pressure in the network. For this reason, measuring and controlling the hydraulic pressure in urban water distribution networks can be an effective factor in measuring the condition of the distribution network and reducing leakage and accidents.

The cost of each cubic meter of water is equal to 37,000 Rails, of which 30% will be paid by the subscribers and the rest will be paid as a subsidy. Table 14 shows the revenue from leak reduction.

Table 14. Leakage Reduction Revenue

Network leakage (l / s)	Percentage reduction of subscribers' consumption per 10 meters of pressure reduction	Pressure reduction after network correction (Water meters)	Consumption reduction leakage (l / s)	Consumption reduction leakage (Cubic meters per year)	Profitability in one year (Rials)
13.83	15%	8.5	2.3	72938	2,698,707,391

The length of the network is 15.3 km. Based on 7,000,000 Rials per meter of leakage; the leakage cost of the entire network is calculated at 107,366,000 Rials. Leakage reduction of 9.07 liters per second has occurred, which is equal to 286032 cubic meters per year. This leads to a profitability of 10,583,166,240 Rials per year. 7 unread meters have 13478 cubic meters per year, which is 148,607,990 Rials per year. Table 15 shows the total expenses and revenues in a year.

Table 15. Total costs and revenues in a year

	Title	Costs per year (Rials)
Costs	Network modification costs	1,354,343,159
	Leakage cost	107,366,000
Total costs		1,461,709,159
	Title	Revenues in one year (Rials)
Revenues	Revenue from network pressure adjustment	9,551,096,291
	Revenue from leak fixing	10,583,166,240
	Revenue from unread meter readings	148,607,990
Total revenues		20,282,870,521

As can be seen from the table above, the amount of revenues is much more than the amount of expenses in a year, and this indicates the sensitivity of repairing and carrying out periodic improvements in the urban water distribution network due to water shortages.

Discussion

The results of this study indicate that residential use has the highest water consumption per day and green space use has the lowest water consumption per day. The normal subscribers of the study area are 13457 people whose consumption is 10 liters per person per hour. Information of 6 subscribers was not recorded that the consumption of each subscriber was calculated as 5225 liters per day, which was a total consumption of 18027 cubic meters during the study period. Also, the information of 1 subscriber was not informed to the meter readers that the consumption of this subscriber was calculated as 5225 liters per day, which was a total consumption of 3004 cubic meters during the study period. The amount of human error due to wrong meter reading was 5477 cubic meters during the study period. The leakage reported in this study is 7267.3 cubic meters in the study period. The length of the network is 15.3 km. Based on 7,000,000 Rials per meter of leakage; the leakage cost of the entire network is calculated at 107,366,000 Rials. Leakage reduction of 9.07 liters per second has occurred, which is equal to 286032 cubic meters per year. This leads to a profitability of 10,583,166,240 Rials per year. 7 unread meters have 13478 cubic meters per year, which is 148,607,990 Rials per year.

Non-revenue water accounts for 30.12% of the total volume entering the reservoir. In the study by Alkasseh et al., (Alkasseh et al., 2013) the average percentage of non-revenue water for the state of Perak in Malaysia was 29.4%, which led to financial losses, supply and major pressures, as well as excessive energy consumption. This rate is consistent with the results of the present study. In the study of Shushu et al. (Shushu et al., 2021) it was found that 50% of non-revenue water is present in the measurement area. This rate is 37% of the total network of the studied city. About 87% of non-revenue water was associated with actual losses in the measurement area, while about 52% of node connections had pressures above the recommended thresholds. High pressure caused leakage and bursting of the observed pipes in the measurement area. Therefore, the results of this study are relatively different from the present study. In the present study, 30.11% of the total water is wasted. Important results obtained from the Jabari study (Jabari, 2017) also showed that non-revenue water in Hebron was high and more than 30%. This finding is consistent with the present study. In the city of Hebron, the main factors that lead to the production of non-revenue water included the inaccuracy of the meter, unauthorized consumption and the method of estimating consumption through defective instruments. There is a policy of reducing non-revenue water in Palestine. However, it is clear that the number of qualified personnel available for leak detection activities is small; there are no suitable technologies to reduce water loss and maintain the system, which is needed to improve network performance and reduce the level of non-revenue water loss. In Iran, given the stable political situation compared to Palestine, it is expected that these problems will be resolved more quickly. Therefore, there is a need to employ professional personnel and new technologies to improve network performance and reduce the level of water loss without revenue. According to the findings of Tabesh et al. (Tabesh et al., 2018), poor management parameters such as increased apparent loss, poor training of workers and specialists, lack of timely replacement of devices and improper selection of pipes and devices have a higher priority in assessing the risk of non-revenue water. The findings of Lai et al. (Lai et al., 2017) showed that there is little public participation in the management of non-revenue water in Malaysia. Lack of knowledge and awareness about non-revenue water, excessive dependence on water services and government agencies in reducing non-revenue water rates and failure to report when observing pipe leaks are some of the problems of non-revenue water management in this country. The results of Lai et al. (Lai et al., 2017) according to the report of 7267.3

cubic meters of leakage at the time of investigation in this study do not correspond to the present study. According to the results of González-Gómez et al (González-Gómez et al., 2011), in the coming years there will be more water in the urban sector than in the rural sector. In this regard, reducing non-revenue water would be appropriate. Reducing non-revenue water helps develop cities. User dissatisfaction with water shortages or poor quality water can force city managers to improve services with a subsequent impact on non-revenue water. Lack of interest in this issue is due to the lack of awareness of people about the amount of non-revenue water and related costs in their cities. The minimum nocturnal flow (MNF) of the reservoir was equal to 1416156 cubic meters in the study period. By calculating the minimum night flow and the amount of night consumption of subscribers, both normal and high consumption, the actual loss rate of 945,371 cubic meters in the study period or 21.1% was calculated. Lee et al. (Lee et al., 2010) concluded that nocturnal flow and background water loss in indoor piping systems show large differences for each region, which is highly influenced by water use characteristics and scale of facilities.

Conclusion

In order to reduce the apparent and real loss in the area, the following measures are suggested:

1. Necessary measures in reducing the apparent loss

In order to reduce the apparent loss, which includes instrumental, human and managerial errors, it is necessary to perform the following series of measures:

- Replacement of broken meters
- Increasing the software capability in calculating unaccounted for water losses in the management and operation sector
- Installing a subscription plate for all subscribers.
- Preparing an updated map of the coding of subscribers' places
- Establishment of meter testing workshop
- Repair the connection areas of the meters so that the following set of defects is corrected:
    - Install the shut-off valve before the meter for all subscribers.
    - Removing valve after the meter of all subscribers.
    - One-way valve service for all subscribers.
    - Leakage and repositioning of meters by proper installation in relation to the subscribers identified in the survey
- Organizing the reading route of meter readers and creating retraining courses for them.
- Inspecting different places and eliminating their violations.

2. Necessary measures in the field of reducing real waste

In order to reduce the actual loss related to leaks from the distribution network and transmission lines and reservoirs, the following series of measures need to be taken:

- Network pressure management
- Replacement of worn sub-network pipes to new pipes.

- Maintenance and repair of some valves and valves related to the main lines.
- Continuous leakage of distribution network and branches

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