Evaluation of water losses in distribution networks: Rammallah as a case study

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Abstract Water is one of the most valuable natural resources in Palestine. Therefore, it is very crucial for the Palestinians to achieve proper planning and management of their water resources to ensure proper usage of their water in the different sectors. Moreover, many of the Palestinian localities still lack the existence of water networks while many others suffer from the poor conditions and high losses in their networks that reach up to 50% of the input into the supply system. The paper will present a method to determine water losses from distribution networks and procedures of reducing it in a practical way. The method is based on three main steps: (1) tracing leaks of the supply districts or pipe sections by means of tightness tests and measuring minimum night flow; (2) pinpointing the leaks using the electro-acoustic techniques by DF Junior device and (3) repairing leaks. Consequently, the amount of leakage for the study area was largely reduced (from 5.6 L/sec to 0.16 L/sec).
Keywords Leakage detection; water conservation; water losses

Background

Palestine is composed of two separate areas, Gaza Strip and the West Bank. The eastern boundaries of the West Bank are the Jordan River and the Dead Sea, the western, northern and southern are Israel as shown in Figure 1. There are two clearly defined climatic seasons, a wet winter and a dry summer. The rainy season extends from mid-November to the end of April. Annual average rainfall in the West Bank is approximately 450 mm. Temperatures are relatively high and vary within the Palestinian Territories. January is the coldest month with average temperatures within the range 8 to 12°C, while August is the warmest month, with temperatures ranging between 22 and 34°C. The Jordan River system is the only surface water resource in the West Bank. There are two aquifers shared by Palestine and Israel: the Mountain Aquifer and the Coastal Aquifer (in Gaza).

The present problems that are related to water in Palestine are many and varied, and the disparity between water supply and demand is growing with time due to rapid population growth. This situation applies throughout the region, which is generally characterised by aridity and water scarcity (Lonergan and Brooks, 1994; Vajpeyi, 1998; Mimi and Smith, 2000). The dispute over shared water resources between Palestine and Israel has adversely affected the development of water resources. Israel and Palestine share aquifers and thus need to agree on their management. In addition, Israelis and Palestinians (together with other riparian parties) need to reach agreement regarding management of the Jordan River basin (Brooks, 1992; Naff, 1993; Medzini, 1996; Sawalhi and Mimi).

Water research studies for Palestine are urgently required to cater for existing requirements. Research goals include preservation and protection of aquifers, improving efficiency of water distribution and use, securing reliable sources of supply to meet future water demands, and development of centralised national data banks and trained national cadres in water resource science and technology. As an emergency measure, with the support of international aid donor agencies, several programmes and research studies have been initiated and are currently under implementation. Different actors are involved in

Water Science and Technology: Water Supply **Vol 4 No 3 pp 183–195** © IWA Publishing 2004

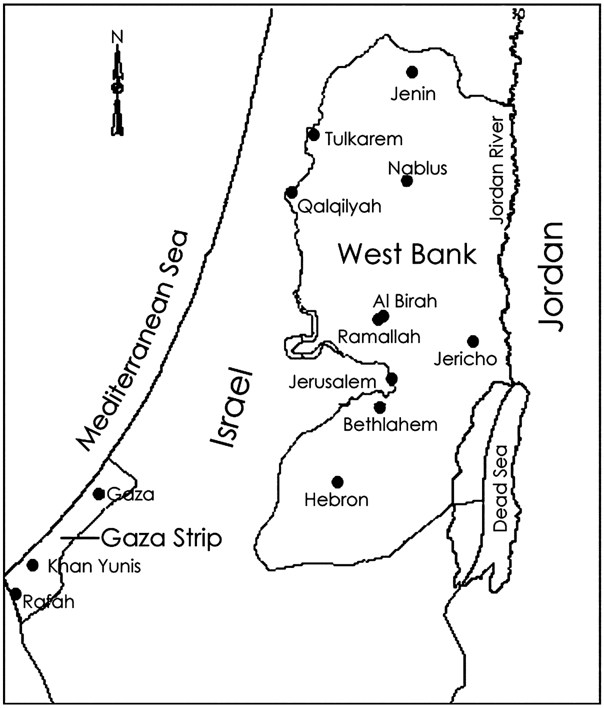

Figure 1 Study area location map

rebuilding and reshaping the Palestinian water sector, against the background of ongoing regional negotiations for sharing water resources.

Water is one of the most valuable natural resources in Palestine. Therefore, it is crucial for the Palestinians to achieve proper planning and management of their water resources to ensure proper usage of their water in the different sectors (domestic, agricultural, industrial, etc.). Moreover, many of the Palestinian localities still lack the existence of water networks while many others suffer from the poor conditions and high losses in their networks. Water losses are not acceptable from an ecological as well as from economic point of view. The water undertaking has to pay for lifting and treating drinking water; if the water is lost on the way to the customer, these expenses cannot be covered by water sales. The waterworks must additionally provide the amount of water lost through leakage, and so an additional extraction of raw groundwater or surface water is necessary to compensate these losses. Therefore, all possible efforts have to be made to avoid water losses (Mimi *et al.*, 2003).

Jerusalem Water Undertaking (JWU) provides water to the population of the southeastern part of Al-Bireh (the case study of this research) that is located in Rammallah District (Figure 1). The water supply network in Rammallah district consists of pipes connected in rings as a circulation system. At the end of 1995, the total length of the distribution system including all the different size of pipes was about 750 km. The water losses in the supply network are high and were estimated to be approximately 25% for the year 2000 which means a loss of approximately 2.6 million cubic metres (JWU, 2000). The main objectives of this paper are to study the leakage in the existing network for southeastern part of Al-Bireh and to suggest solutions to reduce leakage.

Water losses evaluation

In general there are many terms that can reflect water losses like non-revenue water or uncounted for water (UFW). Losses during distribution (Water Loss) comprises of both: (1) physical losses (known as leakage) which is the amount of water lost without being used due to failures and deficiencies in the distribution facilities (this includes leaking pipes, leaking pipe connections, leaking fittings, e.g. gate valves, hydrants, etc.) and (2) non-physical losses which is that amount of water that is not registered due to measurement errors or water theft.

Water losses can be evaluated by one of the following methods: (1) considering the difference between the cost of water that enters the system and the revenues and (2) measuring the volume of the water entering the system in comparison to the volume delivered to the consumers as measured by meters. Water losses are usually expressed as a percentage of input into the distribution system. The proportional characteristic loss (q_p) is derived from the ratio of water loss and input into the distribution system (Niemeyer *et al.*, 1996):

$$q_p = (Q_z - Q_A)/Q_z \times 100 \quad (1)$$

q_p = proportional characteristic loss (%)
Q_z = input into the distribution system (m^3/yr)
Q_A = consumption determined (m^3/yr)
Q_v = water loss ($Q_z - Q_A$)

Percentages give a small indication about the technical condition of a distribution system. They fail to take the most important parameter – the length of the distribution system – into account. In order to take the length of the distribution system into account, it is advisable to express water losses concerning a unit time and the length of the distribution system and refers to it as specific characteristic loss (Niemeyer *et al.*, 1996):

$$q_v = Q_v/(8760 \times L) \quad (2)$$

q_v = specific characteristic loss (m^3/hr/km)
Q_v = water loss (m^3/year)
L = length of the distribution system (km)
8,760 = 365 × 24 (hours/year)

Leakage is water uncontrollably escaping from any part of the distribution system, which may or may not be detectable with usual methods. Different methods of leak location have been developed, but they can only be put to reasonable use if the following data are available.

1. Pipe Documentation: The pipes are to be surveyed and entered into the documentation immediately after construction. Pipe documentation consists of maps, as well as additional data organized in files and lists (e.g. information about position, type, size, material and age of installation of the pipes and fittings). Without information about the position of the pipes, leak location is impossible.
2. Consumer Files: Consumer files should contain name of customer, identification of the connection (place, quarter, street, etc.), average annual water consumption and number of connections for each customer. This is needed for accounting and calculating the amount of water sold for the water balance.
3. Water Metering Records: Water meters should be installed at all points at which drinking water is put into the distribution system and at all delivery points, and try to keep them so accurate by continuous maintenance. This allows the input into the system to be compared with the total amount of water consumed.

Methods for leak location

There are two major steps in any systematic leakage control program. These are: (1) water audits for tracing leaks, and (2) pinpointing leaks (leak detection surveys). Water audits involve detailed accounting of water flow into and out of the distribution system. The audits help to identify areas having excessive leakage. Unfortunately, they do not provide information about the location of leaks. In order to locate leaks in areas that have been identified by water audits, pinpointing leaks must be undertaken.

Methods for tracing leaks

A. Continuous metering of the input into the supply districts. In this method, water flow in and out of the distribution system and water consumption is recorded in order to compare it with previous readings. Losses in the distribution system equals input minus consumption. The water balance for the whole supply system should be measured in regular intervals. If the supply system is subdivided into individual pressure zones or districts equipped with fixed flow meters, a water balance for each individual zone should also be measured.

B. Zero consumption measurements for small districts. In the case of the short-term measurements, the input during periods of suspected zero consumption or minimum consumption is metered. If zero consumption can be assumed the metered inflow equals leakage. Closing gate valves creates the measured district. With the help of input measurements over a short period, leaks can be traced to the shortest possible pipe section by successively closing valves. Mobile meters are usually used in this method.

C. Short-term measurements with the pressure feed method. In this method, leakage during a period of suspected zero consumption is measured while feeding water into a shut-off district under pressure. The district under consideration is isolated from the rest of the distribution system by closing the isolation valves. The mobile measuring unit is connected to service pipes (hydrants). The water tank of the vehicle is filled from the supply system. Then, the district under consideration is shut off from the rest of the distribution system by closing the isolation valves. Water is fed into the distribution system under normal service pressure with the pump in the mobile measuring unit. This allows the detection of possible foreign inputs into the district under consideration. During the operation of the pump, the input is registered on a recorder paper. It can be assumed that there are short periods of time during which no water is withdrawn from the distribution system by any consumer (zero consumption principle). Under this provision, the minimum feed equals the leakage from the shut-off district.

D. Minimum night flow. This method which will be applied in this research for the case study area is mainly based on minimum night flow. The measurements are taken in regular intervals using automatic data logging equipment. The minimum night flow should be compared with the estimated reference flow (ERF), if it is larger, this indicates the presence of leakage in the metered distribution system. The flow for large night consumers should be measured and added to the ERF. The estimated leakage (EL) is the difference between ERF and the average minimum night flow as shown in Figure 2.

The flow can be measured by using electronic equipment which are placed on the main water source pipeline that supplies the area. Flow is recorded for one week in order to ensure that the readings will repeat itself since it varies during days of the week. During this period, the large night consumption is recorded at night and it should be taken into account during data analysis. Fixed water meters and automatic data logging equipment are used in this method which include the following.

1. Aquaprobe: It comprises an electromagnetic sensing head mounted on the end of a support rod. This whole assembly can be installed in the existing pipelines without the need for major excavations. The Aquaprobe is designed for installation in the existing

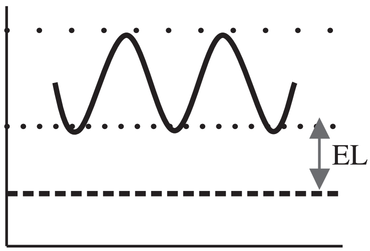

Figure 2 Estimation of leakage

pipelines by means of a small valved tapping. It is normally installed with the sensing head on the pipe centre, but may be located at a critical position of 1/8 of the diameter away from the wall, when flow is turbulent.

2. Aquamaster: It is a device that transmit the received data from Aquaprobe to the Loggermate. The transmitter provides a comprehensive display of all flow data including forward and reverse flow, flow rate, pressure, time/date etc. if all the data is not required, the transmitter is easily configured to display only the required values.
3. Loggermate: It is a recorder that takes the data from Aquamaster, and save it until uploading is done. All Loggermates use a magnetic probe sensor for local set up and downloading of stored data. This eliminates the need for cables and connectors and ensures quick and reliable data transfer. The magnetic probe sensor takes place through a sealed window in the outer case, using a probe connected to a data collection unit.
4. Clamp saddle: It is a clamp in the shape of saddle. It is fastened around the pipe, at the top of the clamp there is a ball valve from which the sensor of the aquaprobe should be inserted into the pipe.

Methods for pinpointing leaks

Electro-acoustic techniques. Water escaping from the leak produces noise, which propagates through a spherical volume of soil. The leak noise can be detected by means of a DF Junior device. Sounding on buried pipes can be easily done by means of a sensor that transmit waves and sounds to the DF Junior device. This device depends on the sound waves intensity; therefore, the leak is located by establishing the point of highest noise intensity. Since the sound waves are transmitted to the soil via the "pipe vibrations", the propagation of impact sound waves mainly depends on the material and mass of the pipe and its excitability. Steel pipes with small diameter, for example, are more excitable than steel pipes with large diameter. Consequently, the leak noise is detectable over greater distances. Plastic pipes are less conductive to sound waves than metallic pipes.

The leak is traced and pinpointed by sounding the surface above the pipe with a sensor. The pipeline is walked section by section and the sensor is shifted meter by meter. The intensities of the noise picked up are constantly compared. If the intensities increase and decreases again a few metres away, this gives an indication about the existence of a leak.

Leak location using correlator analysis (transit time method). In leak surveys, the water distribution system is checked for leaks by using acoustic equipment that detects the sound or vibration induced by water as it escapes from pipes under pressure. Acoustic equipment include listening devices such listening rods, headphones and leak noise correlators. These are modern computer-based instruments that have a simple field setup and work by measuring leak signals (sound or vibration) at two points that bracket a suspected leak. The position of the leak is then determined automatically based on the time shift between the leak signals calculated using the cross-correlation method.

In this method, two sensors are placed directly on a continuous pipe; the distance between the two sensors is usually taken 100 m, but it should not exceed 500 m. The position of the leak is calculated from the speed of sound that depends on the material pipe, the length of the pipe section between the sensors, and the difference in transmitting time to the sensors (Figure 3).The measurement results are independent of the subjective of leak noise by humans, therefore, this method is virtually unaffected by ambient noise. To determine the exact location of leakage, the following formula can be used:

$$a = (tv - L)/2 \tag{3}$$

a = unknown distance between leak and microphone A
v = speed of sound
L = pipe length between microphones A and B
t = difference in transit time = $(2a - L)/v$

Leak location can be carried out with an impact sound pick-up. This is done by placing impact sound sensors at accessible distribution system parts (fittings, excavated pipes, etc.). The impact pick-ups are connected to the test points on the pipes with adapters or magnets. This is especially important for plastic pipes, since they are characterized by a severe damping of longitudinal waves, due to their higher flexibility with respect to water sound waves. In the case of cast iron and steel pipes, impact sound sensors may well suffice.

The main equipment used in this method are: (1) Aquacorr – it has a screen that displays the results as a curve between the length of the pipe (between the two sensors) versus wave intensity – the location of the leak will be located precisely; (2) two microphone sensors are linked to two radio transmitters, which are connected to pipes by means of a magnet; and (3) radio transmitter for wireless signal transmission from the microphone sensor to the correlator.

The evaluation of the measurements has to be computer aided, since it requires a considerable amount of calculations. The internal computer of a modern correlator requires the following data: leak noise picked up by the sensors, pipe length between the two sensors measured by mean of a wheel, pipe material and pipe diameter.

After entering the necessary data to the Aquacorr, a curve between the length of the pipe between the two sensors versus the wave intensity is automatically drawn. If the curve was uniform, this means that there is no leakage. However, if there was a jump in the curve, this indicates the existence of the leakage or high consumption. To distinguish the high consumption from the leakage, the valves in the tested area should be closed. If the curve becomes uniform, this indicates that it was high consumption. However, if the jump remains the same, this indicates a leakage. The exact location of leakage is obtained from the curve.

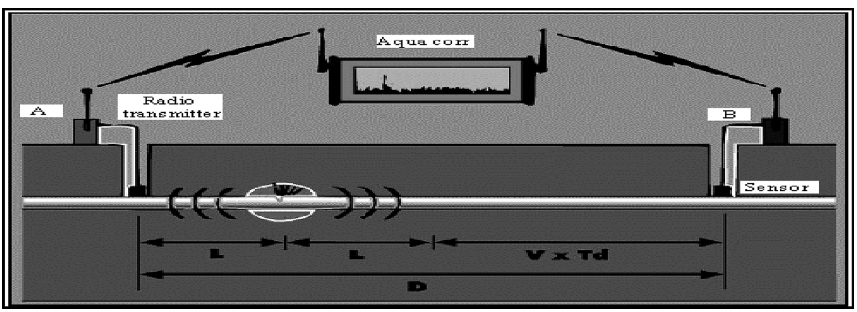

Figure 3 Principle of correlation method

The advantage of the correlator method over conventional electro-acoustic methods is the fact that measurements are objective and not subject to the subjective assessment of the locator. Since the method is virtually unaffected by ambient noise in the vicinity of the suspected leak (e.g. traffic noise), leak location need not be carried out during the quiet hours of the night, and can be performed during normal working hours. However, both the correlator and conventional electro-acoustic methods were applied for the case study area.

Leak location with the gas tracer technique. The gas tracer technique is suitable for locating very small leaks that can not be located with conventional techniques (acoustic methods) due to a lack of leak noise. Non-audible drip losses can be located with the gas tracer technique. The principle of the gas tracer technique is very simple. A gas that will either mix or dissolve in the water is injected into a shut-off pipe section. The gas escapes through the leak together with the water and can be detected with a gas tracer (detector). In other cases, the pipe is drained and filled with tracer gas.

Water losses in the case study area

The overall loss in Rammallah is about 25% of the total input in the distribution system; this percentage is high compared to normal losses. Table 1 shows water loss analysis for the years 1996–2000 for Rammallah District. Losses due to leaks in the distribution network constitute 55% of the total amount of losses in Rammallah network. These losses are relatively high when compared to international for losses in networks. The reason of this high percentage is the bad condition and aging of the old pipes, which were laid in the nineteen-fifties.

To trace the leakage, the study area has been divided into 7 separate areas (from A to G). The southeastern part of Al-Bireh (Part E) will be discussed here in detail for demonstration. This division has been based on isolating the water distribution network of each area, so that each area has its own water-supplying source. The aim of dividing and isolating areas is to make leak detection easier, by tracing and pinpointing leak in each sub-area rather than doing that for the whole system at the same time. The following steps were carried out for the study area.

1. *Data collection*. This includes locating the main water sources (inlet and outlet) for each separate area, and determining the network length. For the study area, it has two inlets (14.01 and PMD14.02) and one outlet (PMD22.01). The total length of the existing network is 31.5 km.
2. *Application of Pressure Zero Test (PZT)*. PZT was done to ensure that each separate area has its own water sources. The first step in doing the PZT was to install several gauge pressures at the consumers' connection points in the study area; meanwhile the pressure readings were recorded. The second step was closing the valves of the main inlet and outlet water sources, afterwards the pressure in the existing network started to drop. A few hours later, gauge pressure readings were taken; they were zero which means that there was not another water supplying source for the study area.

Table 1 Water loss analysis for the years 1996–2000

Description	1996	1997	1998	1999	2000
Total water supplied (m^3)	9051257	9630019	10646356	11289582	10987726
Water sold (m^3)	7029756	7577918	8344745	8624099	8304316
Uncounted for water (m^3)	2021501	2052101	2301619	2665483	2683410
Percentage (%)	22.33	21.31	21.61	23.61	24.42

Source: JWU (2000)

3. *Determination of large night consumption (LNC)*. LNC was determined by taking readings of water meters of large consumers (whose consumption exceeds 250 m^3/month) at night during a certain period of time. LNC for the study area was 0.5 L/s.
4. *Locating points of measurements*. The points of measurements are defined as the inlet and the outlet water sources for each isolated network. At the points of measurement, the flow must be laminar and this was achieved by placing the measuring devices at a minimum distance equals ten multiplied by the diameter of the pipe from the nearest valve, and a minimum distance of five multiplied by the diameter of the pipe from the nearest fitting (reducer, elbow, etc.).
5. *Excavation*. The pipelines were located exactly by using metal checking device. Thereafter, a hole was excavated (1.5 m × 1.5 m) with a depth of 20 cm below the invert level of the pipe. The pipeline covering materials such as asphalt coating within a width of 5 cm was taken off. The clamp saddle was tight well to ensure that the upper surface of the clamp saddle was perpendicular to the crown of the pipeline. The pipe wall thickness was penetrated using a manual drill.
6. *Inner diameter measurement*. A suitable rod was used to measure the pipe internal diameter to determine the exact position for the sensor which should be placed at the centerline of the pipe (insertion depth).
7. *Tracing leaks*. To trace the leaks Aquaprobe, Aquamaster and Loggermate were programmed using a computer software (winfluid). Internal diameter, direction of the flow, starting time, and the duration were entered in the software during the programming process. Thereafter, the data logging devices were installed on the points of measurement for a certain period of time. Flow and pressure readings were recorded and the data was uploaded from loggermate to the computer in site.
8. *Estimation of reference flow (ERF)*. For estimating the reference flow (ERF), the following points have been taken into consideration. (1) Water consumption during night – this value varies between 0.2 and 0.5 L/s/km considering development of area, number of persons per km^2, social habits of the people, and the season when the measurements are taken – for the study area, a value of 0.2 L/s/km was considered. (2) Value of the physical losses in the network: for the study area, a value of 0.05 L/s/km was assumed considering the small leaks in the network before the consumer's meters. These leaks cannot be found with the available equipment and it is not economically wise to search and repair it. (3) Value of significant consumption: readings of the large consumer's meters (hospitals, industries, etc.) will be taken during the night. For the study area, ERF was considered 0.25 L/s/km, which is the summation of water consumption during night and the physical losses in the network. Large night consumers must be taken into consideration in order to measure their flow and add it to ERF. Estimated leakage (EL) = Average minimum night flow – ERF.
9. *Flow and pressure recorded data were uploaded from the data logging equipment to computer (laptop), then it was saved*. Data were analyzed using winfluid software, the relationship between flow and time was drawn. Based on the flow curve, if the difference between peak consumption and minimum consumption was small, this indicated the presence of water losses. Furthermore the average minimum night flow obtained from the flow curve was compared with ERF which is 0.25 L/s/km in order to know the amount of leakage.
10. *The above equipment was placed at the inlet and outlet water source*. The devices were installed for 7 days to ensure that the curve of consumption will repeat itself since there were many variations in consumption in the study area. Meanwhile, the consumption of large consumers was determined by taking water meter readings between 12 and 4 am (measuring minimum night flow).

11. *Flow curves were drawn using Winfluid software*. The flow is obtained for each point of measurement separately; in order to study the whole area as one unit the net flow was calculated. The net flow curve presenting the consumption for the study area is shown in Figure 4. The net flow for the study area equals the flow at the two inlets minus the flow at the outlet. The flow readings were recorded for 6 days (from 31 Dec. until 5 Jan.) to ensure that the flow curve repeats itself since the consumption varies during the days of the week. It was noticed that water consumption on feasts and holidays is higher than the normal consumption in any other day. It was noticed also that on New Year's day (1 Jan.) and on Fridays (4 Jan.) the water consumption during the daytime is higher than the normal consumption in any other day since most people spend their time at home. Water consumption reached a value of 57.4 L/s on 1st of Jan., and reached a value of 54.6 L/s on Friday, whereas the water consumption in any normal day was around 40 L/s on any normal day. Table 2 shows the estimated leak in Area E.

Step testing

After estimating leakage in the study area, it is required to locate the leak points in the network. Consequently, the step testing was carried out as follows. Step testing is a night flow-based method of identifying leakage in a metered area. It is a method of narrowing down the position of a leak to a length of a pipe.

1. The hole area was divided into steps, the pipe length in each step ranges from 2 to 5 km, in order to locate the leak easier. The division was based on isolating the water pipes in each step from the whole network by closing its source valves tightly. As for the study area, the total length of the network is 31.5 km; hence, it is divided into 10 steps, each with 3 km approximately, in order to minimize and facilitate operating each part for inspection and to trace the leaks easily.
2. The pressure zero test (PZT) was applied for each step.
3. The flow was measured for each isolated step; this was done by installing the data logger equipment at the inlet and outlet water sources of the whole network. The total flow was measured in the whole network by keeping all the valves opened. Thereupon, the flow in a certain step was determined by isolating that step from the whole network by closing its valves tightly, then measuring the flow in the remaining steps excluding that step. The flow was recorded every one minute for a period of 15 minutes for each step. Step flow equalled the total flow before the step was separated minus the flow that was measured when that step was closed, and so on for all other steps. Subsequently, the

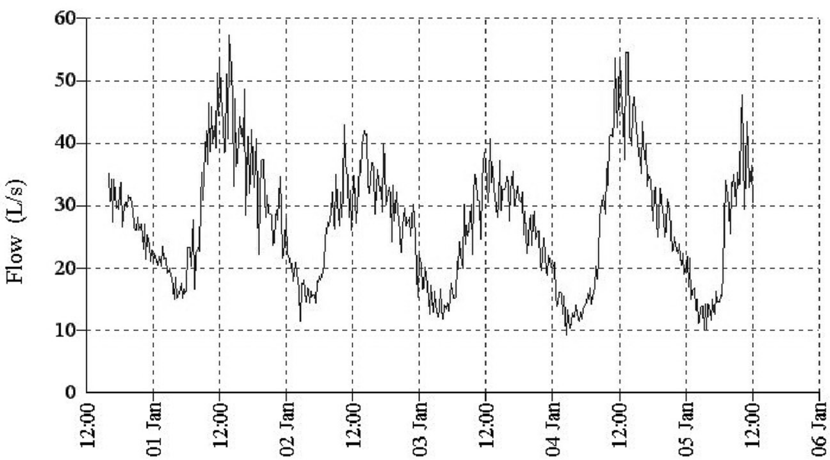

Figure 4 Net flow for part E

Table 2 Estimated leak in the study area (area E)

Length (km)	RNF [(1)] L/s	AMNF [(2)] (L/s)	LNC [(3)] (L/s)	NNF [(4)] (L/s)	Leak estimate [(5)] (L/s)	Percentage of leakage [(6)] (%)
31.5	7.9	14	0.5	13.5	5.6	20.5

(1) RNF = Reference Night Flow = L*(ERF) = 31. 5 Km * 0.25 L/s/km = 7.9 L/s.
(2) AMNF = The average minimum night flow is determined by taking an average minimum night flow for the whole period of measurements.
(3) LNC = Large night consumption can be determined by taking readings of water meters of large consumers at night during a certain period of time.
(4) NNF = Net Night Flow = AMNF – LNC = 13.5 L/s
(5) Estimated leakage = NNF – ERF = 5.6 L/s
(6) Percentage of leakage = (Estimated Leakage / Average Flow) * 100% = 20.5%

data was uploaded for each step. Finally, the steps was arranged according to priorities, which were based on the amount of estimated leakage for each step. Table 3 shows step flow and priorities.

Pinpointing and repairing leaks

After tracing the leaks using step-testing method, the steps were arranged according to priorities. Consequently in this stage, it was required to pinpoint the precise location of leaks using special devices such as Df-Junior and correlator which were discussed before. Leak pinpointing and repair were carried out on the step that has the highest amount of leakage.

For the study area, the step testing showed that there were seven steps that should be pinpointed and repaired. Accordingly, the correlation team started with Al-Amari camp (Step No. 2), since it occupies the first priority in the study area. However during pinpointing, it was found that the existing network is in a bad condition since it has large number of leak points. Moreover, many pipes were laid under houses, which make it difficult to pinpoint the leaks using a correlator or a Df-junior; hence these pipes cannot be pinpointed, repaired or replaced. Replacing most of the pipes in the camp would not be the optimal solution, in addition to the time and cost needed to pinpoint the leaks. Finally, the optimal solution was to design a new network for this camp in a systematic way that satisfies people demands with minimum losses.

As for the remaining steps, leak points were pinpointed and repaired. Most of the leaks were due to small damages and holes in pipes that were not discovered easily, in addition the old leaky fittings were changed in order to reduce amount of leakage.

Table 3 Step flow and priorities

Step #	Step length (km)	Step flow (L/s)	Step flow (L/s/km)[(1)& (2)]	Detection priority
1	4.40	0.62	0.14	No leakage
2	2.70	5.48	2.03	1
3	1.95	1.91	0.98	3
4	3.85	3.15	0.82	5
5	3.60	1.51	0.42	7
6	4.95	4.15	0.84	4
7	2.65	3.54	1.34	2
8	2.15	0.68	0.32	Acceptable
9	2.10	1.26	0.60	6
10	3.10	0.07	0.02	No leakage

(1)Step flow < 0.25 L/s/km → There no is leakage in that step
(2)Step flow > 0.25 L/s/km → There is leakage, it should be pinpointed

Flow measurement and data analysis after repair

The aim of this stage was to determine the amount and percentage of leakage after the maintenance actions were carried out. Thereupon, the data logging equipment was installed on the points of measurements; flow readings were recorded according to the assignment period of 15 minutes. The net flow curve represents the consumption for the study area is shown in Figure 5 from which the following can be concluded.

1. From 12 March till 13 March, it can be noticed that there was a big jump in the flow curve. The reason is that during these days, the Israelis were occupying Rammallah, and the 10” main pipeline that is the main source was damaged by the Israeli army during the curfew, resulting in a high amount of water losses. Therefore, PMD14.01 was the only inlet water source that supplied water to the whole study area since the other inlet water source was broken. It can be noticed that during these days, the behavior of the flow curve still remains the same, i.e. that the flow curve increases during daytime and gradually decreases during night. The reason is that there was little consumption for the areas that lies before the point of breakage of the 10” pipeline.
2. On 13 March at 5 pm, the valves were closed until the 10” pipeline was repaired to avoid additional amount of water loss. Therefore, PMD14.01 was the main inlet water source that supplies water to whole area.
3. On 15 March at 2.15 pm, the pipeline was finally repaired. Then the valves were opened which results in a high jump in the flow curve. This can be explained that most of the house tanks were almost empty for 4 days, and that after repair when the valves were opened, all the tanks started to be filled with water.
4. On 16 March from 1:45 pm till 2:30 pm., the valves that supplies the inlet water source PMD14.01 were closed for repair, which stopped supplying water to the area. It can be noticed that the flow values were negative, which mean that the direction of the flow was reversed and that PMD22.01 acts as an inlet water source instead of being an outlet water source during that period. Then after the repair actions, the valves were opened and the flow curve jumped suddenly and then returns to its normal state.

Thereupon a comparison study was done between the net flow before and after repair is shown in Figure 6. From Figure 6 it can be concluded that the difference between the peak and the minimum consumption was small before repair; this indicating that there was high percentage of leakage that is 20.5% as was mentioned before. After repair, the minimum night flow is largely reduced, while the maximum daily flow remains the same. This means that the difference between peak and minimum consumption after repair is wider than the

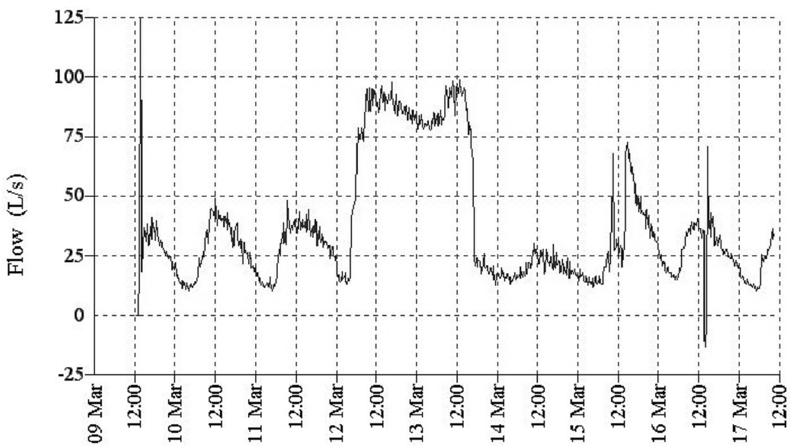

Figure 5 Net flow for part E after repair

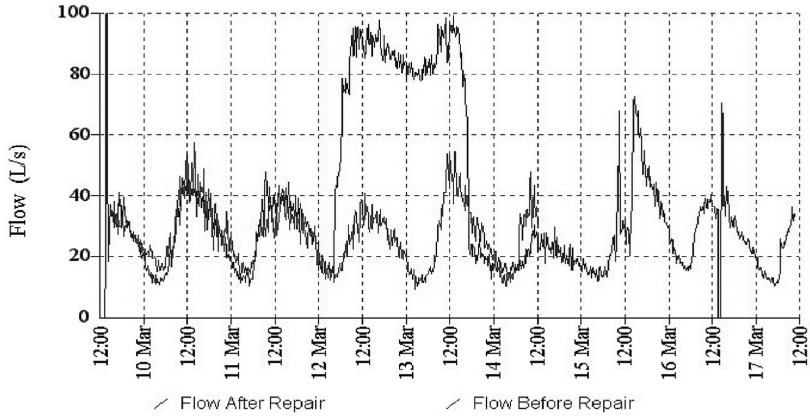

Figure 6 Net flow before and after repair

Table 4 Estimated leak in the study area (after repair)

Length (Km)	RNF L/s	AMNF (L/s)	LNC (L/s)	NNF (L/s)	Leak estimate (L/s)	Percentage of leakage (%)
31.5	7.9	11.3	0.5	10.8	3.0	8.0

difference that used to be before repair. This leads us to say that repairing actions results in reducing the minimum night flow, which results in reducing the amount of leakage. It is expected that the minimum night flow will be largely reduced after replacing the network of Amari camp. Table 4 presents the estimated leak in area E after repair.

As shown in Table 4, the amount of leakage was reduced from a value of 5.6 L/s (20.5%) before repair to 3.0 L/s (8%) after repair. The repairing actions were done for all the steps that needed that except step 2, which represents the Amari camp since it is recommended to design a new network. The amount of leakage after repair was 3L/s (8%) which represents the amount of leakage only in the Amari camp since all the leaks in the whole network was pinpointed and repaired. It is expected that after replacing the network of the Amari camp, the amount of leakage will drop largely to a value of 0.16 L/s.

Conclusion

- Leakage can be considered as one of the most important part of water losses in the distribution system. It forms about 50% of the total losses, therefore, leak detection must be given much attention from water undertakings, in order to reduce water losses and save money.
- There are many methods for leak detection; selection of the method depends on the percentage of leakage aimed at and the budget of the undertaking. In this paper, leak detection study was mainly based on the minimum night flow that is compared with the estimated reference flow in order to estimate the amount of leakage.
- As for the study area, the amount of leakage was found to be 176601.6 m^3/year. Pinpointing and maintenance actions were applied. Consequently, the amount of leakage was largely reduced (from 5.6 L/sec to 0.16 L/sec) i.e. $117,556 can is saved yearly. Which leads to say that this study was carried successfully. The network should be monitored continuously in order to detect leaks as soon as they occur.

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