

CIVIL ENGINEERING

Losses in Riyadh Water Distribution Network

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Abstract. This article demonstrates a practical and more reliable approach for assessment of leakage from Riyadh water distribution network. It presents the methodology and discusses the result of the field study of ten selected areas of the city. The average leakage of the ten areas was found to be about 34 percent. Assuming the selection of the ten areas were fairly representative, the average leakage of Riyadh city based on total consumption may be taken as 34 percent. However, during field study it was noticed that most of the leakage was at or near house connections. Based on the ratio of house connections of the ten areas and Riyadh city, the average leakage for the city was of the order of 22 percent.

Introduction

Although some quantities of water are always lost from distribution system, sometimes this can represent a significant financial loss. There is no absolute figure which can be taken worldwide as the acceptable limit of water losses through a distribution network. This limit mainly depends on the economics of leak detection and control versus the water cost. If the sources of water are limited and the cost of production of water is high, in countries like Saudi Arabia, it becomes more necessary and economical to introduce leak detection and control program. Waste in water distribution networks around the world usually ranges between 10% to 50% of the water supplied, though in some places the figure is even higher. The Manual of Water Supply Practices of Indian Water Works Association [1] reported the percentage of waste ranged between 19% to 36% for seven Indian cities, and between 26.5% to 51% for eleven cities in developing countries in Asia. According to Water Authorities Association [2] the amount of leakage in U.K. ranged between 10 to 50 percent of the total water supplied and the average was of the order of 24 percent. Many authors such as Sulivon [3], Moyer [4], Babcock [5], Orr [6], American Water Works Association [7], Kempe and Liston [8], Preece [9] and Hock [10], reported water losses between 2 and 50 percent in various U.S. cities. Bremner [11] reported about 18% loss for the city of Toronto and American Water Works Association [12]

reported leak levels for selected Quebec municipalities in Canada to be in the order between 34 to 50%. Swedish Water Authority [13] reported unaccounted for water in the range of 5 to 40% for various cities in Sweden. Wheadon *et al* [14] reported from seven years investigation in Moscow (USSR) water system that the average leakage was about 0.6 to 0.7 cubic meters per hour per km length of pipe 14.4 to 16.8 m³/day/km).

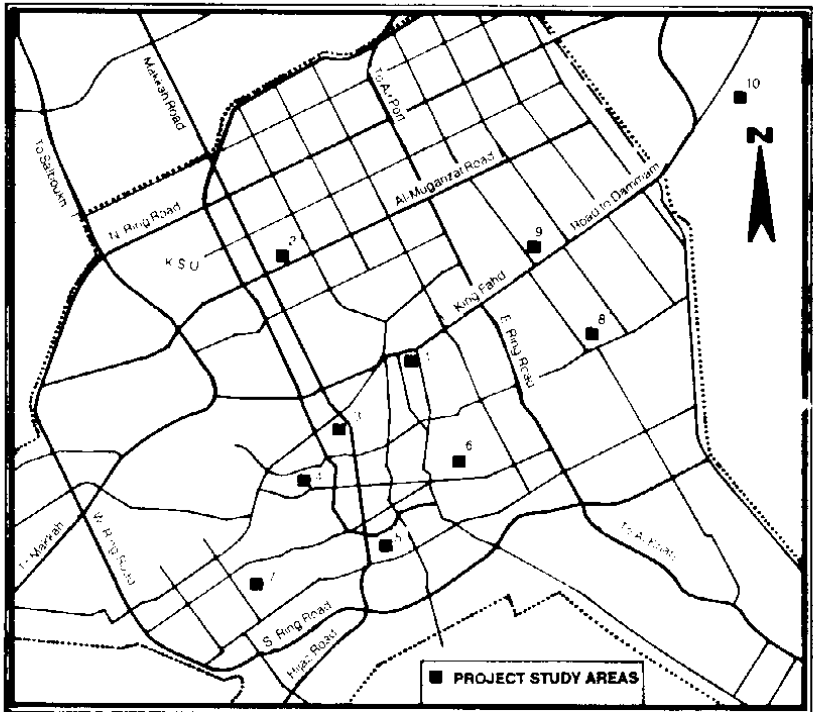
Guidance to utilities on acceptable level of water losses is provided in India by the Manual of Water Supply and Treatment [15]. 5 to 10% is a low waste level, unsatisfactory conditions exist at 10 to 20% with action advisable and beyond 20% remedial action is urgent. The American Water Works Association [7] suggested that a system having 10 to 20% are considered reasonable. From the worldwide experience reported by various authors, some of them mentioned above, it is quite evident that losses up to 15% are usually tolerated and depending on the benefit cost ratio of water and leak detection and control, a leakage level of 5% may be achieved for a well managed water supply system.

Al-Salem [16] in his M.S. thesis submitted to Loughborough University predicted from the statistical analysis of water consumption in ten areas of Riyadh city that the loss varies between 23 to 73%. In his study the water consumption in each area was estimated from meter readings of only a limited number of houses. The amount of water supplied in each area was not measured but estimated. Arriyadh Development Authority [17] reported from their study on the effect of ground water fluctuation in Riyadh City, that the estimated leakage from the network is about 16%. Their estimate is based on the study of five areas of Riyadh City. In their study quantification of losses were done by pressurizing isolated pipe stretches (suspected of leaking by use of electronic leak detector) and measuring the losses in those stretches only. Average water consumption was estimated from meter readings of only 30 houses in each area. Al-Ghamdi [18] from actual measurement over nine month period supply and consumption from an area of 1.5 km² in Riyadh city found 31.5% as the average amount of water loss. Projecting his study result to the entire area of Riyadh city, he is of the opinion that Riyadh water distribution network loss may range between 30 and 50%. From the above discussion it is quite clear that there is significant variation of the estimate of the losses from Riyadh water distribution network depending on the method used for its determination.

The purpose of this study is to obtain a more reliable estimate of losses from Riyadh water distribution network by measuring actual supply and consumption in ten selected areas of the city. This article demonstrates a practical and more reliable approach for assessment of leakage. It represents the methodology and discusses the results of the field study.

Extent and Locations of Study Areas

The most significant factors responsible for selecting study areas and their size were: pressure, age, network density, number of reported leakage from different areas and of course time and budget available for this study. Ten study sites were selected after due consideration of above factors, so that the average result of these ten areas may reasonably represent average losses of the whole city. The general location of the study areas are shown in Fig. 1.



- | | |
|--------------------|-----------------|
| 1 Al-Malaz | 6 Al-Khaldiyyah |
| 2 Al-Malik Fahad | 7 Al-Swaidi |
| 3 Al-Namodhajiyyah | 8 Al-Salam |
| 4 Al-Shimaisi | 9 Al-Roudah |
| 5 Mantuha | 10 Al-Nadheem |

Fig. 1. Selected locations of study areas

After obtaining the as-built general location drawings of the network from Riyadh Region Water and Sanitary Drainage Authority (RRWSDA), the plans were studied in detail and the sites were visited and inspected. The existence of all valves, hydrants, pipes and house connections as indicated by the drawings were checked. Any discrepancy was noted and corrections incorporated in the drawings. The final position and boundaries of each area were based on the following practical considerations.

1. Workable size of area not to exceed 0.25 km^2 (IWWA [1]) to 0.4 km^2 (Borrows and Broomfield [19]).
2. The locations and operating conditions of valves should be such that the area could be isolated and consequently be supplied through a single feed point via a bypass flowmeter.
3. The isolation should not adversely affect the pressure distribution and water supply within and outside the study area.
4. Number of house connections or property meters in the area not to exceed 350 (Raman [20], IWWA [1]) to 500 (Di Michele et al [21]).
5. Length of pipe in the area not to be more than 6 km (Cole [22], AWWA [12]) to 8 km (AWWA [12]).
6. Total water demand of the area not to exceed 950 l/min (AWWA [12]).

If due to any discrepancy the area could not be isolated and supplied by a bypass water meter, or if the test program could not be conducted on the area due to some other reasons, then the boundary of the area was readjusted until it was satisfactory. The general problem encountered in the selection of area was the proper isolation of the area due to damaged or improper closing of isolating valves. The size and characteristics of the ten study areas are shown in Table 1.

Preparatory works before field testing

Before starting any field testing program in a selected area, the following preparatory works were necessary.

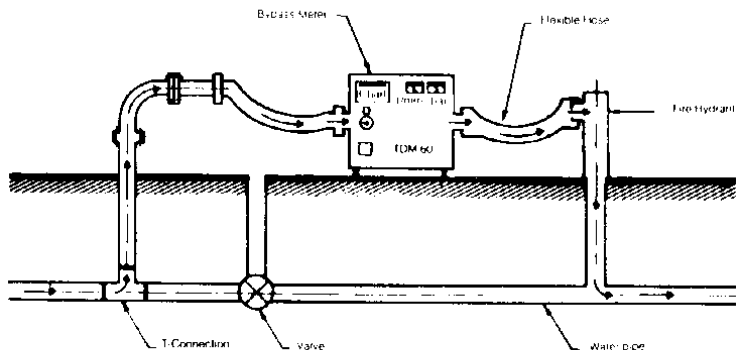
1. All boundary valves, hydrants, and house connections appurtenances of the selected area were checked for water tightness and repaired whenever necessary.
2. All house water meters connections of the study area were checked, so that water supply to the property can be completely stopped during net night flow measurement (as discussed later). Any water meter found buried underground or under

Table 1. Area, number of house connections and pipe characteristics of the study area

Parameter/Area	1	2	3	4	5	6	7	8	9	10	Total
Gross area (km ²)	0.26	0.35	0.20	0.19	0.14	0.23	0.45	0.22	0.28	0.74	3.06
No. of connected properties	330	360	101	115	306	113	191	201	197	287	2281
Pipe length (m)											
50 mm		-	350	746	986		50		190		2352
100 mm	6323	7600	5235	3435	3856	5965	8610	3056	1600	3145	47825
150 mm	577	574	710	-		1431	2897	1616	430	2165	10160
Total pipe length (m)	6900	8174	4295	4181	4842	5396	11557	4732	5220	5310	60647
Age (years)	16	9	9	20	14	5	9	5	8	7	
Materials	All main lines are of PVC. House connections are mostly polyethylene except for some area where it was of PVC										

pavement was uncovered and checked for its proper functioning to supply/shut off valve.

3. A bypass system was then installed on the site in order to supply the area from one point through a bypass water meter. The arrangement is shown in Fig. 2. A T-connection was constructed on the feeder main to divert the flow through the bypass meter. The outflow from the meter was then fed to the area via a fire hydrant or vice versa. The bypass of flow was accomplished by closing the intermediate valve between the T-connection and the hydrant as well as all other boundary valves in the study area. Entrapped air was removed by operating the fire hydrant in the isolated

**Fig. 2. Bypass flow measuring system.**

area. Prior to its use the bypass water meter was calibrated in the hydraulics laboratory at the College of Engineering of King Saud University.

Inflow and minimum night flow to the area

After proper isolation of the study area the water flow fed into each area was monitored and continuously recorded over a period of seven days via a bypass water meter [23]. Hourly flows, minimum and maximum flows read from the recorded carts were tabulated and entered into a computerized database for storage and analysis.

Estimation of leakage from water network by measuring minimum night flow rates is a method based on the assumption that the minimum water flow which occurs during the late night and early morning hours will indicate the rate of leakage. The accuracy of this method is usually improved by calculating the net night flow from the difference between minimum night flow and an assumed water consumption by properties during the same period. Both the above mentioned methods were found inappropriate for application to water supply system such as the one for Riyadh, where almost every property has a large ground water storage tank in addition to a roof water tank. The resulting effect is the damping of flow variations, balancing water supply and demand and obtaining more uniform water supply rates throughout the day and night. At night when the pressure in the line is high, roof tanks fill up when actually there is no consumption. Therefore a different method of measurement of net night flow rate (NNF) or leakage rate was adopted in this study. At the completion of the one week period for flow monitoring, as mentioned above, all valves on property connections in the area were closed overnight for a period of 16 hours, from 4 pm to 8 am of the next day. This time was selected in order to avoid inconvenience to the consumers. Hence, the measured flow during this closure period would accurately represent NNF or the actual leakage rate in the isolated area at the recorded operational pressure.

Results and Discussion

Table 2 shows the flow and pressure characteristics and Table 3 shows the leakage characteristics of each area under study. The relative small variations of daily flow rates are expected because of the widespread use of underground water storage tanks in buildings and villas in Riyadh. It is therefore quite evident from the results of Table 2 and 3 that the minimum flow cannot be taken as an indication of leakage level in Riyadh city. For example when the ratio of minimum to average flow in area No. 6 was 0.96, the leakage was only 3%. The newly constructed areas showed a low rate of leakage, as low as 2% in Area No. 10, whereas older areas showed very high leakage rate, as high as 80% in area No. 4.

Table 2. Flow and pressure characteristics of the study areas

Parameter/Area	1	2	3	4	5	6	7	8	9	10	Total	Average
Flow rates (l/min)												
Average	865	786	474	854	733	695	825	370	544	518	6563	
Minimum	833	643	244	810	704	669	739	178	310	246	5376	
Maximum	894	903	510	902	766	733	884	555	720	718	7585	
Ratio of min. to average rate	0.96	0.82	0.65	0.95	0.96	0.96	0.90	0.48	0.57	0.47		0.82
Ratio of max. to average rate	1.03	1.15	1.37	1.06	1.05	1.05	1.07	1.50	1.32	1.39		1.16
Pressure (bars)												
Average	2.1	1.5	3.7	1.1	2.4	2.0	2.7	1.9	2.8	3.3		2.35
Minimum	1.4	1.0	2.5	0.8	2.0	1.6	2.2	1.4	1.3	1.6		1.58
Maximum	2.9	2.7	5.2	1.4	3.1	2.4	3.5	2.5	4.6	5.4		3.37

Table 3. Leakage characteristics of the study areas

Parameter/Area	1	2	3	4	5	6	7	8	9	10	Total	Average
Net night flow rate												
l/min	580	70	95	686	432	24	282	25	40	12	2246	
m ³ /day	835	101	137	988	622	35	406	36	58	17	3235	
l/H C/hour	109	12	56	358	66	13	89	8	12	3		59
l/km/hour	5044	514	1327	9845	5353	267	1464	317	460	136		2224
% of Av. flow	67	9	25	80	60	3	34	7	7	2		34

$$\% \text{ of Av. flow} = \frac{\text{Net night flow rate l/min}}{\text{Average flow rates l/min}} \times 100$$

The average inflow and the total losses in the ten areas were 6563 l/min (9451 m³/day) and 2246 l/min (3234 m³/day) respectively representing average leakage of about 34% of the daily average inflow into the areas. The average daily supply of Riyadh city in 1991 was 1,200,000 m³/day. Assuming the average loss in the ten study areas represents the average loss of the whole city (that is 34%), the total loss in Riyadh city comes to 408,000 m³/day in the year 1991. The various leakage rate in the cities around the world are discussed in the introduction section. The average leakage rate of 2,224 l/km/hr or 59 l/house connection/hr or 34% of total inflow for Riyadh city fall in the higher range of leakage rates.

During leak detection and repair program of the ten study areas it was observed that most of the leakage was located on or near the house connections. Therefore it is more realistic to make the projection of losses for the whole city on the basis of number of house connections. The total number of house connections in the ten study areas and in the whole Riyadh city (according to the figure available in 1991) was 2281 and 187,635 respectively. Therefore the total loss in whole Riyadh city based on house connection ratio is $(3234 \times 187,635)/2281 = 266,029 \text{ m}^3/\text{day}$ that is about 22% of the total supply.

About 70% of the water supply of Riyadh city is obtained from Jubail desalination plant. Remaining 30% are obtained from deep wells of Minjur and Wasia. The cost of desalinated water is about 8.00 Saudi Riyals/ m^3 (Al-Salem [16]). The average cost of well water is about 3.00 Saudi Riyal/ m^3 (personal communication with water authority). This gives the average cost of water supplied to Riyadh city about S.R. 6.50/ m^3 . Even if we take the conservative estimate of 22% leakage from Riyadh water supply network, the loss amounted to more than 600 million Saudi Riyal in the year 1991 alone.

Conclusions

A detailed field study was undertaken to assess the extent of leakage in water distribution network in Riyadh city. It was estimated that net leakage of the city in 1991 is of the order of 22 to 34 percent, which is in the higher range of leakage rate reported by many authors around the world. The minimum flow rate at night or early morning cannot be taken as an indication of leakage for Riyadh city because of the widespread use of underground tank in addition to overhead tank in most of the houses. It was observed that the highest level of leakage belonged to the oldest part of the network and achievable leakage can be as low as 2%. It is encouraging to note that the Riyadh water authority has realized the importance of the leak detection and control program of the water distribution network and has established a separate division responsible for this purpose. The division has already finished the first phase of leak detection and repair works and was able to reduce the leakage substantially in the areas taken up during the first phase. It is recommended that the water authority should concentrate their efforts first in the older parts and gradually extend the program to all other parts of the network. Periodical checking should be continued in all parts of the city turn by turn once a reasonable level of leakage has been achieved.

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الفاقد في شبكة مياه الرياض

علي أآتر قرش و آالء آمء الضوابع

قسم الهندسة المدنية، كلية الهندسة، جامعة الملك سعود، ص.ب ٨٠٠،

الرياض ١١٤٣١، المملكة العربية السعودية

(اسألم في ١٧/١١/١٩٩١م؛ قبل للنشر في ٦/٧/١٩٩٢م)

ملخص البحث. هذه الورقة توضح طريقة عملية وموثوقة لتقويم التسربات من شبكة مياه الرياض. تبين هذه الورقة تفاصيل الطريقة وتناقش نتائج الدراسات الحقلية لعشر مناطق في المدينة. متوسط التسربات للعشر مناطق يقدر ب ٣٤ بالمائة. على فرض أن العشر مناطق المختارة تمثل واقع الشبكة فإنه يمكن تقدير التسربات لمدينة الرياض ب ٣٤ بالمائة من الاستهلاك الكلي. ولقد لوحظ أثناء الدراسة الحقلية بأن معظم التسربات كانت في التوصيلات المنزلية أو قريبة منها. بناء على نسبة عدد التوصيلات المنزلية في العشر مناطق إلى عدد التوصيلات بمدينة الرياض فإن متوسط التسربات في المدينة كان في حدود ٢٢ بالمائة.