Construction of delicate systems to manage water distribution systems and minimize water losses: endeavors and challenges in Beijing

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Abstract: The rapid population growth in Beijing exacerbates the contradiction between social and economic development and water resource shortage. The provision of sufficient and safe drinking water with reasonable pressure to local residents is the primary goal for Beijing Waterworks Group. The South-to-North Water Diversion Project is valuable to alleviate the water resource crisis in Beijing; however, it is of more importance to minimize water loss in distribution systems and to avoid water waste in daily life for residents. Beijing Waterworks Group has long dedicated to decreasing water loss by delicate management of water distribution systems, and the understanding of water loss composition is principal to optimize water-loss-control strategy. This paper analyzed the non-revenue water (NRW) composition in Beijing and the measurements taken to control the NRW. The results showed that Beijing Waterworks Group had made much progress in the NRW control.

Keywords: water losses; water distribution systems; non-revenue water control

1. Introduction

Water crisis has been a serious problem over the world, which attracted increasing attentions. As the capital of China, Beijing is one of the most water-lacking cities in the world, and water shortage has seriously limited its sustainable development. However, much water is wasted everyday, among which the non-revenue water (NRW) of the water distribution takes a large proportion. Reduction of excessive losses is very likely the next cheapest water source. A lot of work has been done in many countries, but water loss from distribution network is still widespread.

Being aware of the problem of different water balance formats, methods and leakage performance indicators, the International Water Association (IWA) has investigated water distribution networks of many countries and developed a standard international water balance structure and terminology, in which the components of system input water were defined. Water balance could reveal water imported, consumed and lost and provide a guide to calculate how much is lost as leakage from the network, and how much is due to metering inaccuracy. So far, water balance calculation has been carried out in many countries and used as the guideline of water losses control. In water balance calculation, NRW is defined as the difference between system input volume and billed authorised consumption [1]. NRW is predominantly caused by metering inaccuracy, leakage on pipes, illegal use, and free use [2]. In general, NRW reflects the

performance and management of distribution network. Component analysis of NRW could uncover where the largest components of water loss occur.

In recent years, the average NRW of Chinese cities has reached about 18 percent of the water produced. And in some cities, the proportion can be more than 25 percent, which is a serious problems for water supply efficiency. Therefore, the NRW management is an issue of great importance. Many water supply industries has recognized this point and invested heavily on the NRW control. As the water supplier of Beijing, Beijing Waterworks Group has enhanced the NRW management and obtained many achievements in recent years. The length of its distribution networks and the quantity of the registed customers has steeply increased with the continuously expanding of the city size. By 2010, the total length of the distribution networks in Beijing central district had reached 8100 km at a average annual growth of 200 km, while the registered customer number had reached 270.2million at a average annual growth of 20 million The components of NRW for the water distribution .system in Beijing were first analyzed and the Beijing's endeavors to control NRW were then reported.

2. NRW for Beijing water distribution system

NRW consists of unbilled authorised consumption and water losses[3]. In Beijing, unbilled authorised consumption includes some items such as fire demand, pipe maintenance etc. Water losses are the difference between system input volume and authorised consumption, and consist of apparent losses and real losses.

Apparent losses consist of unauthorised consumption (illegal and theft use) and metering inaccuracy. Its ratio to system input volume can range from almost 0 to 10% for different networks. Metering inaccuracy includes random error and measurement error of meters. Random errors are mainly from accounting procedures, such as misread meters, improper calculation, incorrect estimates of stopped meters etc. In fact, these random errors could offset each other. So in metering inaccuracy, the measurement error is the major part. Unauthorised consumption is related to management level of system, and in reasonably well managed systems it should not exceed 1% of system input volume. Unauthorised consumption is associated with misuse of fire hydrants and illeagal connections. Real losses of system are attributed to leakage on pipes and storage tanks.

The calculation of NRW usually uses "bottom-up" method or "top-down" water balance [4]. In "bottom-up" method, NRW is system input volume subtracting billed authorised water. In "top-down" water balance, every component is required to be calculated or estimated, and then the sum of them equals to NRW. In practice, it is suggested that two methods are applied to check reliability of data.

As for Beijing water distribution system, Figure 1 depicts that the ratio of NRW to system input volume gradually increased during 1990-2009. Especially in 2000-2002, NRW ratio sharply rose from 8% to 16%. One reasonable factor is that resident billing point changed from building meters to apartment meters. As a result, meter quantity dramatically increased from 260,000 to 1,400,000. Another probable reason is that customer meters have lower precision, leading to higher metering inaccuracy. So NRW ratio increased sharply.

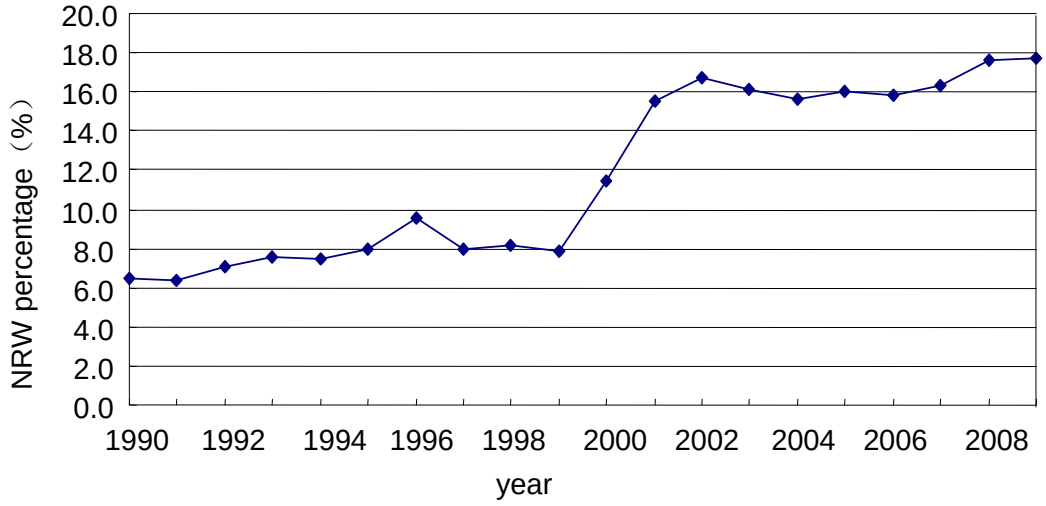

Figure 1 Beijing NRW percentage in system input volume during 1990-2009

From calculation of water balance in Beijing in 2009, the ratio of unbilled authorized consumption to system input volume was 0.498%. It is deduced that NRW was mainly water losses and the ratio of water losses to system input volume was 16.737%. In Beijing, water losses are due to real losses, metering inaccuracy and other factors.

3 Calculation of NRW components for Beijing

3.1 Calculation of real losses

Real losses are the leakages on main pipes (DN ≥ 300) and service pipes (DN < 300), designated as L_1 and L_2 respectively. They consist of reported leaks, unreported leaks and background leakage. Beijing maintenance record showed that real losses caused by reported leakage and detected unreported leakage are 4.3×10^4 and 2.02×10^6 m^3 respectively in 2009. All unreported leakages accounted for nearly 0.5% in system input volume.

Table 1 Unreported leakages detected in Beijing water distribution pipes in 2009.

Diameter （mm）	Number of unreported leaks detected	Number of reported leaks detected
DN ≥ 300	35	144
DN < 300	683	1801

L_2 includes unreported leakage (L_{21}) and background leakage (L_{22}). In 2009, real losses caused by unreported leakage accounted for nearly 2.368% in system input volume. The calculation of background leakage is based on minimum night flow [5]. The minimum flow of service pipes in Beijing was 0.64 $m^3/[h\bullet km]$, and L_{22} was accounted for nearly 3.457% in system input volume in 2009. From above, L_2 ratio to system input volume was 5.825%. The sum of L_1 and L_2 equals to real losses of water distribution network, namely its percentage to input volume was 6.325%.

3.2 Calculation of apparent losses caused by metering inaccuracy

In Beijing, metering inaccuracy is mainly from resident users and large consumers. Resident user meters have the average error of 14.36%, and their consumption was 2.3241×10^8 m^3 in 2009. So apparent losses caused by resident user metering inaccuracy (E_1) were 3.910 m^3. $\times10^7$. Large

consumers usually use C class meter, and their average error is 4.32%, and apparent losses caused by large consumer metering inaccuracy (E_2) were $2.155 \times 10^7 m^3$. The sum of E_1 and E_2 equals to apparent losses caused by metering inaccuracy, and its percentage in system input volume was 7.491%.

3.3 NRW caused by other factors

In addition, unbilled authorised consumption, theft use and hysteretic-registration of meter would also generate NRW. But how much water volume is caused by these factors is still unknown, so more detailed analysis of NRW is required. The percentage of each component was listed in Table 2.

Table 2 Components of NRW in 2007-2009.

Components of NRW	The percentage in system input volume		
	year 2007	year 2008	year 2009
Real losses of leakage on distribution pipes	1.35%	1.289%	0.501%
Real losses of leakage on services pipes	5.64%	5.598%	5.825%
Real losses	**6.99%**	**6.887%**	**6.326%**
Metering inaccuracies of resident users	4.56%	4.560%	4.787%
Metering inaccuracies of large consumers	2.53%	2.750%	2.643%
Metering inaccuracies	**7.15%**	**7.367%**	**7.485%**
Other losses	**2.15%**	**3.406%**	**3.419%**
Total	**16.29%**	**17.66%**	**17.23%**

4. Beijing's NRW management measures and application

Many strategies have been applied to control the Beijing's NRW in recent years. And according to the different components of the NRW, different measures have been taken.

4.1 Management of the metering error

Metering error is an important part of the NRW. It is mainly caused by the different precision of different level water meters and the decrease of their precision due to deterioration. The common approach to lower the metering error is to replace the water meters. On one hand, the metering of the water produced were enhanced by installing flowmeters on the water mains. In recent years, about 5 million RMB was spent on the installation of new flowmeters. Piping electromagnetic flowmeters with a precision of 0.5% were installed on all the water mains that conveyed the water from the water plants to the distribution pipe networks, and calibration was periodically conducted. On the other hand, the trade metering was also emphasized. Many measures such as meter reading quality control, meter calibration and replacement, big commercial and industrial customer metering analysis, high accuracy meter using .etc, have been adopted to improve metering quality.

4.2 Active water leakage control

Water leakage is another important contributor to the NRW, which is also the very part that is wasted directly. Therefore, water leakage control should be given a high priority in order to

control the NRW. According to Lambert[6], water leakage can be controlled in four aspects: active leakage detection, repaid and high-quality leak repair, water pressure regulation, and good water pipe network management. Beijing Waterworks Group has performed the leakage control from the abovementioned aspects and made many achievements. For example, 3116 leakage was reported in 2003, and in 2009 the number decreased to 2076. The drop of leakage numbers is 15% in average in the recent years.

4.2.1 Advanced leakage detection approaches applied

Traditionally, pipe leaks are found through listening to the sound of water leaking by a workman using a pole connected to the pipe. It is obvious that this method is inefficient. In order to improve the detection efficiency, Beijing Waterworks Group bought more than 3000 acoustical devices to record the acoustical signal of water leakage. The attenuation rule of the signal along the pipe was then investigated to help locate the leakage by the collaboration with Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences.[7]

Because the water pipe network of Beijing central district is very large, 3000 acoustical devices are still inadequate. In order to further improve the leakage detection efficiency, the two agencies worked together to develop leakage prediction models to decide the pipes' priorities to detect.[8,9] Figure 2 shows 20% pipes (highlighted) that should be detected first.

Figure 2 20% pipes that should be detected first (highlighted)

4.2.2 Enhanced leak repair work

Once leaks detected, the repair speed and quality become critical. In order to speed up the leak repair, Beijing Waterworks Group has enlarged the leak repair team and new leak repair stations have been built. From 2008, the number of leak repair station has increased from 9 to 13, and the average time between leakage reported and leakage fixed has been reduced from 2 hours to one hour,which apparently reduces the leaked water.

4.2.3 Exploration of the water pressure management mode

Water leakage amount and the new pipe breakage occurrence are positively related to the water pressure. Therefore, water pressure reduction facilitates the leakage control. According to calculation, the water leakage and electricity consumption can be reduced by 40,000 m^3 and 10,000 kWh respectively on every 1m drop of the water pressure. Beijing Waterworks Group has selected demonstration district to perform the water pressure task now.

4.2.4 DMA partition

District Metering Area (DMA) partition is a widely accepted method to control the leakage and manage the pipe network. In China this method has not been widely applied by now. Beijing Waterworks Group has studied the feasibility of this method to its pipe network and planed to partition its pipes inside the second-ring road into 120 DMAs.[10,11] Some of them have been successfully implemented. In the future, they will be implemented one by one and the whole large pipe network will be partition into many small ones. This activity will definitely help reduce the water leakage.

4.2.5 Replacement of the deteriorated pipes

Pipes deteriorate along the time. In old town area, there are some old castiron pipe and galvanized weld steel pipe, among of which nearly half of the leakage occurred. Thus, the reformation of pipe networks is imperative in those area. Beijing Waterworks Group has spent more than 676 million RMB on the pipe rehabilitation from 2003 on. And overall 1525 km pipes were rehabilitated. The pipe network's health has increasingly improved.

4.3 Establishment of the NRW management mode

Besides the engineering techniques, Beijing Waterworks Group also attached importance to the management mode establishment. For example, special department or company for leakage control was built up and related awarding system was established. The informationization management of the water pipe network was also emphasized on, which improve the group's capability to control NRW by a large margin.

4.4 Achievement of the Beijing's endeavors to control NRW

After several years of endeavors, the number of leaks on pipes decreased obviously. In Figure 3, it is shown that the leakage number decreased from 3258 to 2702 and the real losses ratio to system input volume gradually decreased during 2007-2009. Meanwhile, the water losses caused by metering inaccuracy increased (Figure 4) because of the significant increase of the resident meters. In future, there are more such users, which would lead to the further increase of NRW ratio

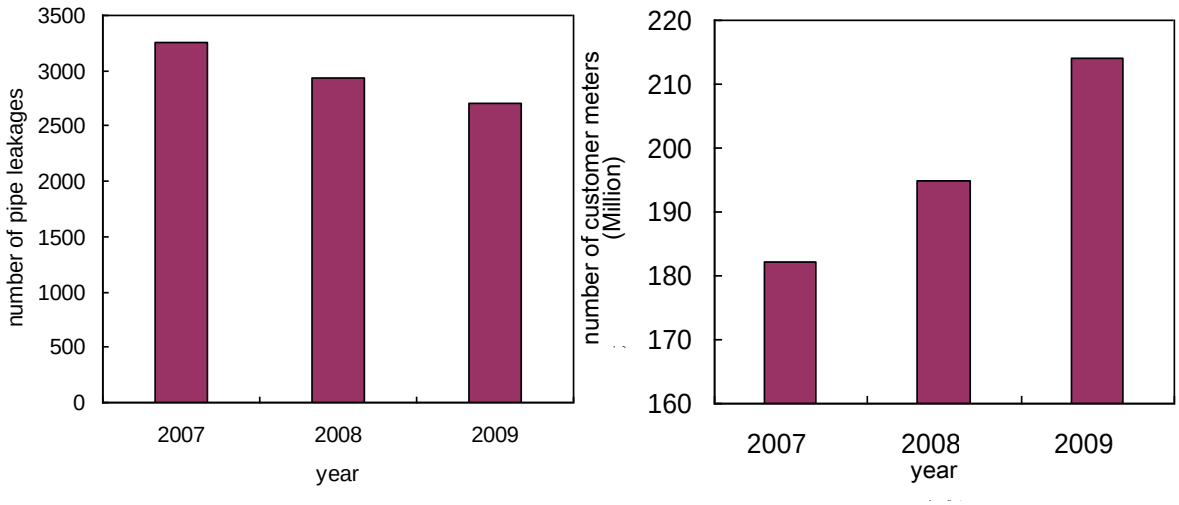

Figure 3 The number of pipe leakages and authorized customers in 2007-2009.

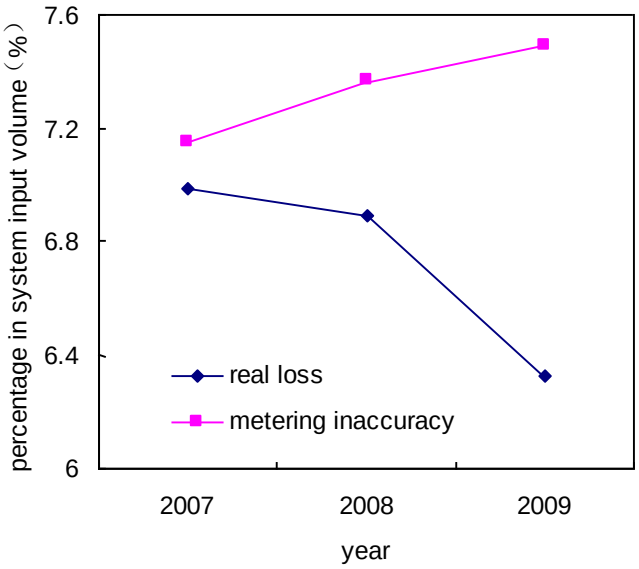

Figure 4 Ratio of real losses and metering inaccuracy to system input volume in 2007-2009.

5. Conclusions and prospect

From analysis of NRW, it is seen that NRW was mainly contributed by real losses on pipes and customer metering inaccuracies in Beijing. Therein, real losses are from service pipes and metering inaccuracies are from resident users and large consumers. Recently, Beijing Waterworks Group has achieved significant progress on the control of the NRW. In the future, the group will continue to improve in the following aspects.

(1) Adopting active strategies could effectively reduce leakage runtime. In the future, more pipe repair stations will be built and more resources will be used to leakage detection.

(2) Applying active leakage control method. DMA management would monitor leakage on service pipes and facilitate the pressure management of water supply system.

(3) Upgrading and checking customer meters, especially large consumers, could decrease the metering inaccuracies.

(4) Speeding up the pipe networks reformation. Beijing Waterworks Group plans to invest 2.4 billion RMB in the next five years to reform the deteriorated pipes. All the pipes to be

reformed total about 1969km long.

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