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Centre for Water Systems
College of Engineering, Mathematics, and Physical Sciences

Development of a Leakage Target Setting Approach for South Korea based on Economic Level of Leakage

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Euijeong Lim

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I certify that all material in this thesis which is not my own work has been identified and that no material has previously been submitted and approved for the award of a degree by this or any other University.

Signature: …………………………………………

ABSTRACT

Leakage has become a crucial issue that needs to be addressed effectively by the water suppliers in terms of economic management of the water system. Leakage management costs such as pipe replacement, pressure management, detection and repair costs have been steadily increasing. These costs have a direct effect on the financial performance of water suppliers. Hence, they have to continuously do their best to reduce leakage. However, a large number of water systems are operated by small local government operators who are not well funded and lack the necessary expertise. Consequently, a large volume of water is being lost due to leaving on-going leakage unrepaired. In order to resolve these problems, South Korea has been promoting the Non-Revenue Water (NRW) reduction project of local water supplies in which the authorized organization, specializing in water management would operate facilities on behalf of struggling local government. K-water, the public water company in South Korea, has been operating and managing 22 NRW reduction projects instead of local government since 2004.

In this thesis, a target setting method based on the Economic Level of Leakage (ELL) calculation is proposed. The methodology applied is developed specifically for the South Korean context to select a minimum achievable level of NRW. In addition, the thesis will examine the appropriateness of the current target within existing financial constraints by using limited available data. This approach is focused on the derivation of the NRW control cost curve by using the newly developed cumulative method that minimizes data fluctuation and enhances the cost curve reliability. This has been applied to a case study by using data collected from the water supplier information system. The results obtained from the case study show significant outcomes in respect of both identification of an economically optimal target and prevention of unnecessary investment to meet this aim. This advance in leakage management allows water suppliers to select a rational target and manage their system economically and efficiently.

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LIST OF ABBREVIATIONS

ALC	Active Leakage Control
CARL	Current Annual Volume of Real Losses
CI	Cost of Intervention
CV	Variable cost of Water
DMA	District Metered Area
ELL	Economic Level of Leakage
FAVAD	Fixed and Variable Area Discharge
GIS	Geographic Information System
GPR	Ground Penetrating Radar
ILI	Infrastructure Leakage Index
IWA	International Water Association
LNC	Leak Noise Correlator
NRW	Non-Revenue Water
OFWAT	Water Services Regulation Authority
PI	Performance Indicator
PLC	Passive Leakage Control
PMA	Pig Mounted Acoustic
PRV	Pressure Reducing Valve
RR	Rate of Rise of unreported leakage
SCADA	supervisory control and data acquisition
SELL	Sustainable Economic Level of Leakage
TGT	Tracer Gas Technique
UARL	Unavoidable Annual Real Losses
WDSs	Water Distribution Systems
WLSG	Water Loss Specialist Group

LIST OF SYMBOLS

Lm mains length (km)

Nc number of service connections

Lp total length of private pipe, property boundary to customer meter (km)

P average pressure (metres).

L_0, L_1 the leaks flow rate before and after change in pressure

P_0, P_1 pressures before and after change in pressure

L level of leakage(m^3/connection/year)

C cost of leakage control (£ /connection/year)

L_a actual level of leakage for the area(m^3/connection/yea)

C_a actual cost of leakage control for the area(£ /connection/year)

L_b base level of leakage for the area(m^3/connection/year)

L_p passive level of leakage for the area(m^3/connection/year)

R^2 coefficient of determination

CHAPTER 1 INTRODUCTION

1.1 Background

Industrialization, environmental pollution, climate change, aging infrastructure and increasing level of customer expectations have made huge changes in water supply (Levin et al., 2002). The changes require various types of investments such as reinforcement and expansion of facilities, the introduction of advanced water treatment facilities, and strengthening risk management (i.e. climate change resilience and strengthening preparations). This has become a serious burden on the water suppliers economically.

According to a recent World Bank publication, the annual volume of Non-Revenue Water (NRW) was estimated to be approximately 50 billion cubic meters globally and the losses were equivalent to at least US $15 billion per year (Frauendorfer and Liemberger, 2010). Similarly, a large amount of water in South Korea is disappearing through leakage every year. The annual volume and lost revenue in 2013 were 656 million m^3 and $753 million (Environment, 2014), respectively. In spite of continuous investment and efforts to reduce NRW, its management cost continues to increase rapidly. The costs have nearly doubled in the last 10 years (Koo et al., 2011). However, owing to a lack of expertise and aging and deteriorated infrastructure of local waterworks, a large volume of water is still being lost due to leaving on-going leakage unrepaired.

In order to resolve these problems, South Korea has been promoting the NRW reduction project of local water supplies in which an authorized organization, specializing in water management would operate facilities on behalf of struggling local governments. As a result, K-water, the public water company in South Korea, has been operating and managing 22 NRW reduction projects, instead of local governments, since 2004.

When it comes to the project target, the aim is to achieve 20% NRW within 5 years from the beginning of each respective project, including infrastructure installations and maintaining this level until the end of the project life cycle, typically 20 years (K-water, 2014). This NRW rate has been established as a performance indicator for a long time in South Korea. This has been the case despite the problem with changes in the level of consumption. In addition, NRW rate does not consider the operating environments such as finances, water use patterns and topographic conditions of the individual areas (Koo et al., 2011).

Since 2004, identical target setting has created problems because regional characteristics, financial conditions and water use scale were not considered. Specifically, the efficiency of NRW reduction shows variation in NRW control cost such as leakage repair, pipe replacement, and pressure management. Some projects with a budget shortage may have difficulty managing their water system for the remaining period. Therefore, it is necessary to introduce an economic principle for achieving and maintaining the NRW target efficiently with the limited budget to the K-water projects. This introduction of an economic framework will allow water suppliers to manage their water system economically and efficiently. The research carried out in this thesis addressed the issues mentioned above. The verified method in the UK and newly developed calculation model, cumulative cost-benefit analysis, are proposed.

1.2 Aim and Objectives of Research

The overall aim of this research is to contribute to the development of the economic level of NRW calculation model and target setting method. The specific objectives are:

1. To introduce and develop an economic level of NRW calculation model for South Korean water systems. Given the condition of rising operation and management costs in water supply systems, it is required to introduce and develop cost-effective NRW management strategy from an economical perspective in South Korea.
2. To identify an acceptable NRW level within the budgetary constraints. Most water suppliers in South Korea regard NRW level of developed countries as

10%, and they try to achieve this as an ultimate objective. However, different NRW levels should be set, which can be achievable and maintainable by every water supplier.

3. To assess whether application of uniform NRW target to K-water projects is appropriate and reasonable. Water suppliers have various operating conditions such as financial status, labour force, infrastructure deterioration, geographical conditions, and political and social demand.

4. To test, verify and demonstrate the applicability of developed methodologies for economic level of NRW calculation. This economic level of NRW calculation is a newly attempted method in South Korea. It can be used for a range of purposes (i.e. as a system performance indicator, budget allocations, and project target setting).

1.3 Thesis structure

The thesis is organized into five chapters showing the process and result of the research. A specific description of each chapter is introduced below:

- Current chapter 1 presents the motivation and background. It also explains the aims and objective of this study. Additionally, the thesis structure is outlined.

- Chapter 2 provides a literature review and is divided into two sections: general water loss management and Economic Level of Leakage (ELL) concept. The former gives a wide range of overview about water loss assessment, target setting and four water loss management methods. The latter is focused on economic leakage management informed by previous research.

- Chapter 3 sequentially introduces economic level of NRW calculation and target setting procedure, required data collecting and processing, and calculation methods. When it comes to methods, two methods are presented: (1) Marginal cost Analysis and (2) Cumulative cost-benefit analysis. The first method is generally used in the UK. The second method is a newly developed method in this research.

- Chapter 4 shows a case study with discussed methodology from Chapter 3. Firstly, the background of the case study area selection is presented. Secondly, in order to decide the most suitable method, a reliability check of the NRW control cost curve is carried out. Thirdly, the economic level of NRW of the case study area is estimated with a chosen method. Fourthly, a sensitivity analysis is presented with the purpose of finding the most influential factor on the economic NRW level. Lastly, the evaluated economic NRW level is compared with the current level and the most efficient and economic target is suggested.

- Chapter 5 includes an overall summary of this thesis and related contributions are briefly summarized. The conclusion of this research emphasizes the discussed methodology in chapter 4, followed by required future research work which could strengthen and extend the methodology.

CHAPTER 2 LITERATURE REVIEW

2.1. Introduction

Leakage in water distribution systems (WDSs) represents lost water through pipes, joints, fittings and reservoirs (Trow and Farley, 2004). These losses have been taking place since the WDSs have been installed and they are common events which we can notice in our everyday lives. However, recognition of leakage has changed over time. The interruption in the water supply in the past mainly created customer inconvenience; however, today it leads to social and economic effects such as traffic congestion, flooding, interruptions in factory operations and customer inconvenience. However, the complete removal of leakage in a water distribution system is impossible and expensive (Stephens, 2003). As leakage reduction activities follow the law of diminishing returns, there comes a tipping point at which costs increases outweigh benefits of leakage reduction. Therefore, finding and managing at the most economical level is required in terms of efficient use of budgets (Pearson and Trow, 2005).

Research related to the economic efficiency of leakage has been performed since the eighties. Particularly in the UK, economic management methods in WDSs have been developed and all the water companies have adopted the Economic Level of Leakage (ELL) methodology. Water Services Regulation Authority (Ofwat), which is an organization that regulates the performance of the water companies, evaluates their annual reports on a regular basis. With this effort, most companies are now operating at the high efficiency level. "The optimal level of leakage is the point at which the cost of reducing leakage is equal to the benefit gained from further leakage reductions" (Ofwat, 2002). In other words, it is better to stop reducing water leakage at the point where costs and benefits meet.

The focus of water supply utilities in South Korea has not been on operational and economic management because they have concentrated on the development and expansion of infrastructure (Koo et al., 2011). Recently, they also showed interest in the economic leakage management by reducing both leakage and high maintenance costs due to the rise in the cost of water production. However, this work on saving costs in water companies has been performed only at a basic level. It still requires much effort to systematize the data store and its acquisition.

The purpose of this research is to find advantages and disadvantages identified in previous studies, especially in the UK, related to the Economic Level of Leakage (ELL). Its aim is to develop an appropriate methodology which can be applied to water supply systems in South Korea. This literature review was performed with this particular aim in mind. This literature review is largely composed of two main parts. The first part explains the overall water loss management concept and the other presents ELL methodologies and previous research efforts.

2.2. Water loss management

Despite the global effort to reduce water loss, a large amount of water is being lost through leakage. According to the World Bank discussion paper No.8 (2006), 32billion m^3 of water disappears every year. For the efficient use of limited water resources and its conservation, it is necessary to understand the cause of water loss and to attempt to reduce this by using the techniques (described below in section 2.2.6).

Farley and Liemberger (2005) stated that why water loss occurs in the WDSs mainly occurs because of poor infrastructure, bad operation and management. Specifically, it can happen for various reasons such as the complexity of water pipe networks, shortage of operators and equipment, and a lack of professionalism, insufficient repair/replacement and faulty customer meters.

Water loss has many economic and social repercussions. Firstly, water lost is directly linked to water company profitability since it generates additional costs such as treatment, sludge disposal and electricity. Secondly, water loss leads to customer dissatisfaction and damages the company’s image, since disruption of supply and low water pressure has an important effect on customer satisfaction. Lastly, water loss can reduce available water resources (ABB Limited, 2011).

2.2.1 Water loss assessment

Analysis of annual water balance is very important to understand its components and calculate its quantities, while considering optimal strategy establishment and management (Lambert, 2003). The portion of volume of each component compared to the system input volume represents a good measure that could be used to decide the direction for water loss management. Therefore, the starting point is to calculate the water balance. The components of water balance can be seen Table 1.

Table 1 : International Water Association(IWA) standard international water balance and terminology(Trow and Farley, 2004)

<table>
<tr><td rowspan="9">System Input Volume (corrected for known errors)</td><td rowspan="4">Authorised Consumption</td><td rowspan="2">Billed Authorised Consumption</td><td>Billed Metered Consumption (including water exported)</td><td rowspan="2">Revenue Water</td></tr>
<tr><td>Billed Unmetered Consumption</td></tr>
<tr><td rowspan="2">Unbilled Authorised Consumption</td><td>Unbilled Metered Consumption</td><td rowspan="7">Non-Revenue Water (NRW)</td></tr>
<tr><td>Unbilled Unmetered Consumption</td></tr>
<tr><td rowspan="5">Water Losses</td><td rowspan="2">Apparent Losses</td><td>Unauthorised Consumption</td></tr>
<tr><td>Customer Metering Inaccuracies</td></tr>
<tr><td rowspan="3">Real Losses</td><td>Leakage on Transmission and/or Distribution Mains</td></tr>
<tr><td>Leakage and Overflows at Utility’s Storage Tanks</td></tr>
<tr><td>Leakage on Service Connections up to point of Customer metering</td></tr>
</table>

The most representative terms, which are widely used in WDS, are water losses and NRW (Wu, 2011). Water losses consist of apparent and real losses and NRW is made up of water losses and unbilled authorized consumption, such as public purpose uses. NRW also expressed the difference between system input volume and revenue water.

High level of water losses and NRW means huge financial losses and waste of limited water resources. In order to prevent these losses, it is very important to understand the reasons and factors which affect water loss and NRW. Trow and Farley (2004) explain that the most important issue in a water loss management strategy is deciding the leakage target and assessing current leakage level precisely. Currently three methods are widely used by the water companies to calculate water losses: (1) Total integrated flow analysis(Top-down), (2) Minimum night flow analysis (Bottom-up) and. (3) Component analysis (Thornton et al., 2008).

2.2.2 Water loss Assessment methods

Significant practical efforts to address leakage in the WDS have been made since the Burst And Background Estimate (BABE) methodology was developed in the mid-1990s (Lambert, 1994). In order to reduce controversy about measuring water losses, IWA (2000) introduced standard terminology and performance measures for water balance calculations. Unavoidable annual real losses (UARL) which is the lowest attainable annual real losses under the current leakage control policy was made based on the BABE concept (Lambert, 2003). This can be used for comparisons of technical leakage performance within a water system with current annual real losses (CARL). The specific explanation is described in Section 2.2.3.

2.2.2.1 Total integrated flow analysis (Top-down method)

A ‘best-practice’ standard water balance, as shown in Table 1, is a common terminology originally introduced by International Water Association Task Forces (IWATF) to unify various formats and relevant definitions. This method has been most widely used by water companies because of its easy and simple to use technique (Lambert, 2003). Using the data presented in Table 1(described in section 2.2.1), water losses are easily calculated by deducting authorised consumption comprising of billed and unbilled authorised consumption from system input. However, as its quantity cannot be calculated directly, it can only be assessed by evaluating other components. In this respect, it is important to note that the water loss volume can be affected by errors and/or uncertainties associated with other components (Weimer, 2001).

Generally, unbilled authorised consumption and apparent losses are considered having high errors and uncertainty. In terms of unbilled authorised consumption, water is used for public purposes, such as flushing distribution main, street cleaning, fire fighting and frost protection, and is not subjected to exact metering. According to a recent paper published by the IWA Water Loss Specialist Group (WLSG), unbilled authorised consumption is estimated to contribute to the billed metered consumption by 0.5%(Lambert et al., 2015). Even though this is a small portion of water balance, the used water volume should nonetheless be recorded for precise assessment (Weimer, 2001). With respect to apparent losses arising from unauthorised consumption (theft and illegal use) and metering errors, these are estimated to account for 4.5% of the System Input Volume in South Korea, based on figures pertaining to other countries. The quantity is still significant and must be addressed (Weimer, 2001).

However, it must be noted that obtaining information about real losses and separating the individual components is extremely difficult, if not impossible. Besides, since the total integrated flow method is normally used on a yearly basis, there are some limitations to water suppliers for using this method as an alert system, especially if the aim is to detect new leaks and bursts. For these reasons, it is necessary to utilise it in conjunction with two additional assessment methods described in the subsequent sections.

2.2.2.2 Minimum night flow analysis (Bottom-up method)

Minimum night flow analysis (Bottom-up method) was first developed in the UK and is based on night flow measurements and flow-pressure relationship. Thus, real losses are calculated by subtracting customer night time use from minimum night flow, which is measured between 2 and 4 AM. However, this approach should also incorporate the Night-Day-Factor to convert the results into daily volume of real losses in order to account for diurnal variation of the pressured distribution system

(Wu, 2011). Nonetheless, this method is useful for checking the real losses of Top-down calculations, whereby the gap between top-down and bottom-up should be within 5% for precise estimation. Normally, if its gap exceeds 5%, water suppliers are recommended to repeat the procedure. Although this is a complementary assessment method which can supplement the top-down method, it is required to verify average customer night use for applying to the South Korea situation. The reason is average values for calculation of customer night use need to be adjusted because of different per capita consumption, lpcd (litres per capita per day), between approximately 150 lpcd in UK and approximately 330 lpcd in South Korea. Since different water use habits and patterns exist between the two countries, investigation of customer night use needs to be done in advance. Otherwise, volume of leakage is likely to be overestimated.

There is another opinion about minimum night flow analysis. Handy (2011) reported that it is difficult for a water distribution system having high water losses to adapt this method. This is because WDSs having high water losses usually have poor finances, inaccurate water meters and unauthorized consumption; eventually these bring about huge and unmanageable uncertainties in water balance analysis.

2.2.2.3 Component analysis

Understanding the various components of water balance is important to remove leakage. Component analysis is very helpful to find specific reasons for the leakage and the volume of losses in the WDS. Lambert (2003) reported that loss volume from each leakage location is affected by flow rate and leakage run-time until the leaks is repaired. This is the BABE concept, which was first developed and calibrated in order to understand the factors involved in water balance in the UK. This method uses numbers, average flow rate and average run-times of leaks and bursts to estimate annual real losses in each part of distribution infrastructure such as mains lengths, number of connections, and private pipes from boundary to meter. If all data are produced by water suppliers correctly, this method allows water suppliers to establish the most suitable real losses reduction strategy. This is significant in terms of efficient water loss management for achieving economic level of leakage(Thornton et al., 2008).

It is very important to develop a water loss management strategy because this makes water suppliers invest their budgets efficiently. However, in case sufficient data is not available, many assumptions such as flow rate are needed for the analysis. Therefore, systematic data management in analysis of water losses is very important. The best way to evaluate water losses is the combination of three methods (top-down, bottom-up and component analysis) in order to get reliable results. (Wu, 2011)

2.2.3 Performance Indicators

Performance indicators (PIs) are used to compare performance across the country, benchmark best practice for water loss management and to set targets. Until now, when it comes to evaluate performances of NRW and water losses, the most widely used PI are ‘percentage by volume’. It has traditionally been widely used as a PI even though it has huge potential for misinterpretation and manipulation. The reason is that it is affected by consumption scales and changes (McKenzie, 2002). Alegre et al. (2000) also announced that it is not suitable for assessing operational management of real losses. In order to resolve this matter, Alegre and Association (2006) explained PIs based on the IWA’s Manual of Best Practice as seen in Table 2.

Table 2 : Recommended indicators for physical losses and NRW (Alegre and Association, 2006)

Function	Level	Performance Indicator	Comments
Financial: NRW by volume	1 (Basic)	Volume of NRW [% of System Input Volume]	Can be calculated from simple water balance, but not too meaningful
Operational: Physical Losses	1 (Basic)	[Litres/service connection/day] Or	Best of the simple 'traditional' performance indicators, useful for target setting, limited use for comparisons between systems
		[Litres/km of mains/day] (only if service connection density is <20km)	
Operational: Physical Losses	2 (Interimed)	[Litres/service connection/day/m pressure] Or	Easy to calculate indicator if the ILI is not known yet, useful for comparisons between systems
		[Litres/km of mains /day/m pressure] (only if service connection density is <20km)	
Financial: NRW by cost	3 (Detailed)	Value of NRW [% of annual cost of running system]	Allows different unit costs for NRW component, good financial indicator
Operational: Physical Losses	3 (Detailed)	Infrastructure Leakage Index(ILI)	Ratio of current annual physical losses to unavoidable annual real losses, most powerful indicator for comparisons between systems

From among these, the infrastructure leakage index (ILI) is considered the most appropriate performance indicator (PI). This is a measure of how well distribution system is managed and maintained in terms of reducing real losses. It is the ratio of Current Annual volume of Real Losses (CARL) to Unavoidable Annual Real Losses (UARL). This indicator has no units so it is very effective for comparing between countries that use different units. (Wu, 2011)
The formula can be seen below:

$$\text{ILI} = \text{CARL} / \text{UARL} \tag{2.1}$$

UARL (litres/day) = (18 x Lm + 0.8 x Nc + 25 x Lp) x P

- where Lm = mains length (km); Nc = number of service connections;
- Lp = total length of private pipe, property boundary to customer meter (km);
- P = average pressure (metres).

By the way, three coefficients used in the above UARL calculation formula are highly uncertain and need to be developed separately for each system. Because the three coefficients were derived from component-based approach, those values can be varied with different system conditions such as infrastructure condition, intensity of leakage control, and quick and effective leak/burst repair. Thus even though above formula is being used internationally, it needs to be assured whether the coefficients are reasonable values to each water system.

To return, ILI values close to 1.0 represents that the CARL is managing and operating at a technical minimum. However, it does not mean that such low ILI values are economical in leakage management. This is because ILI is a technical performance indicator without considering the economic aspects (McKenzie, 2002). Pearson (2002) announced that ILI of the 34 demand zones of United Utilities in UK showed scope between 1.13 and 3.2, its average and median value were respectively 2.38 and 2.21. This means most demand zones are well managed and operated by water companies. Moreover, their infrastructures are maintained under the favourable conditions. Figure 1 shows the ILI value of each demand zones.

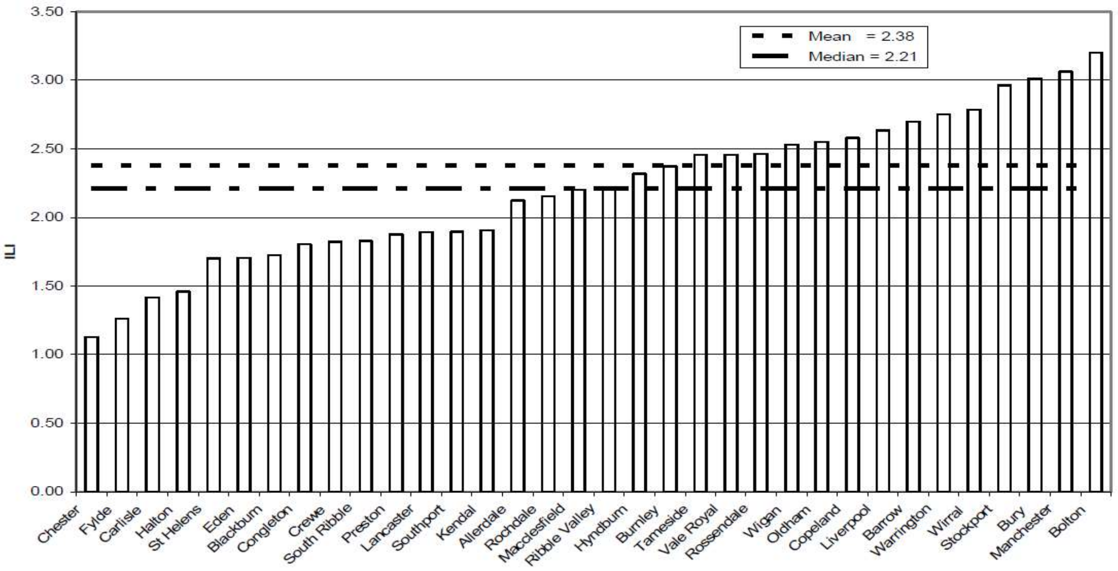


Figure 1 : ILIs of 34 Demand Zones in North West England (Pearson, 2002)

In contrast, the ILI value of K-water, (the Korean Water Resources Corporation) was much higher than the UK results. The range of ILI values are spread from 1.74 to 27.86. The average and median value was 7.99 and 6.21 (Environment, 2012) . Specific ILI value can be seen in Figure 2.

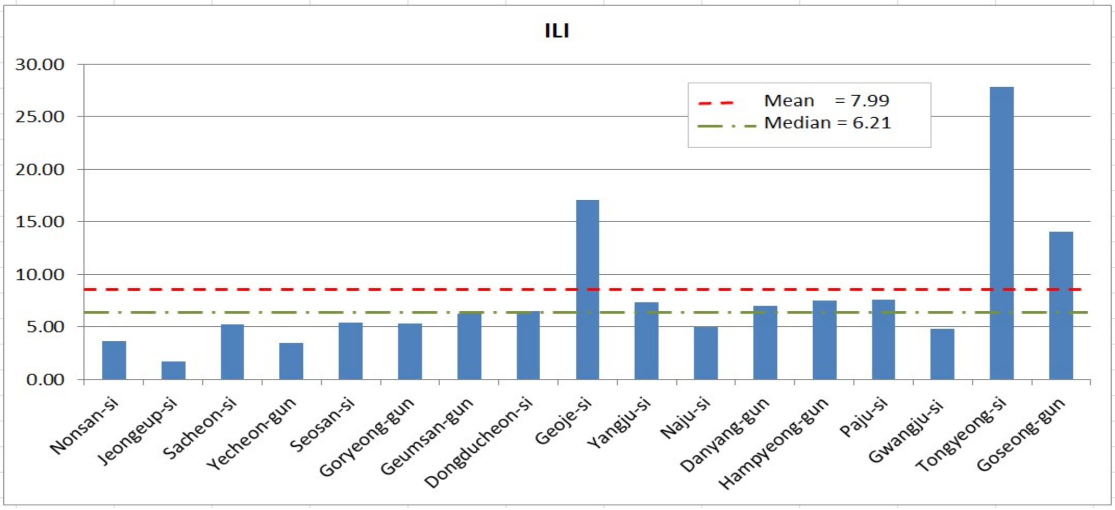


Figure 2 : K-water O&M 17 cities (Environment, 2012)

There is another opinion about using ILI as a performance indicator. Liemberger et al. (2007) pointed out that assessing ILI identifies a problem with data reliability in developing countries. This is because they do not manage or record important data such as network length, number of service connections and pressure and real losses. This causes different result with the current operation environment. However, until the present, there have been no suitable performance indicators which can replace ILI and it is still the best indicator to describe the level of real losses of a system.

2.2.4 Leakage target setting

It is crucial to establish an accurate water losses target along with the calculation of the precise volume of water loss. Exact target setting allows water suppliers to use limited water resource efficiently and it prevents unnecessary investment such as water pipes replacement, construction of reservoirs and water treatment facilities. PIs presented in the table 2 are good indicators as a water loss target setting. Therefore, many water suppliers use them widely for comparing and benchmarking their performances with others (Fanner et al., 2007).

In South Korea, the ‘percentage by volume’ method has been used as an indicator to set a goal for a long time despite the problem with changes in the level of consumption by customers. Their indicator is NRW rate (%) which is calculated by dividing volume of NRW with the volume of total water produced in the treatment facilities. In general, policy makers and water suppliers think the optimal NRW rate is approximately 20 percent, the national average NRW rate in South Korea. However, it does not consider various options such as financial, water use pattern and topographic conditions of the individual areas. Recently, K-water got interested in the ELL, which is UK’s economic framework in water loss management. The idea is that it will enable water suppliers to manage their water loss economically. Furthermore, it can suggest with limited budgets and current manpower structure, which NRW level is the maximum achievable. This is first objective of this study along with adapting the ELL methodology for the South Korean water system.

In the UK, the ELL methodology has been used for setting leakage targets since 1990s. ELL calculations involve finding the tipping point between the costs and benefits of water loss management (Ofwat, 2002). Ofwat decides economic level by using ELL methodology and manages water loss accordingly. It is based on mega litres per day (Ml/day) units. More details about the ELL methodology will be presented in the section 2.3.

2.2.5 Leakage detection methods

Leakage detection has been the basic approach to find and locate leaks in the WDSs. Regardless of equipment, it can be classified with localization and pinpointing (Pilcher, 2003, Fanner et al., 2007, Puust et al., 2010).

2.2.5.1 Leakage localization methods

Leakage localization is a procedure aimed at identifying and prioritizing areas within the system, in order to discover leaks faster and easier (Pilcher, 2003). Typically, step-testing, acoustic logging, ground motion sensors and ground penetrating radars are employed (Puust et al., 2010). Step-test examines changes in the water flow data during the period of minimum night flow by closing valves systematically to identify suspected areas. However, owing to the difficulties associated with planning and working at night, in the 1990s, this method was replaced with acoustic logging (Pilcher, 2003). Elaborate equipment, such as vibration sensors or hydrophones that can collect leak signals during night times, used in acoustic logging approach, make leakage localization easier and simpler than in the step-test. The data collected in this manner can be analysed statistically using computer software. However, experts skilled in this type of analysis are required, and the problem of background noise interfering with sound collection still needs to be addressed (Puust et al., 2010). Lastly, ground penetrating radar (GPR) is a non-destructive method enabling analysis of both cross-section and surface features. Owing to the technological advances, scanning speed of up to 15-30 km/h is now possible, making this approach extremely efficient. Nevertheless, it can yield false conclusions, when metal objects are detected or pipes are buried deep in the ground (Puust et al., 2010).

2.2.5.2 Leakage pinpointing methods

Leakage pinpointing in contrast to leakage localisation is elaborate process because this can directly affect an excavation costs and amount of labour necessary to repair leaks. Three widely used methods are described in this section: (a) leak noise correlators; (b) gas injection; (c) pig-mounted acoustic sensing (Puust et al., 2010).

Leak noise correlators (LNC) are employed in order to find a leak point by comparing the arriving time of sound from one correlator to another. The accuracy of this method depends on pipe materials. While it can locate a leak within 1 metre in case of metal pipes, its utility is questionable when applied to plastic pipes.

Tracer gas technique (TGT) is another method used in this field, which can detect a leak point by using gas, such as helium or hydrogen. After injecting gas into the pipe, operator traces its distribution using a highly sensitive gas detector. Although this is a highly accurate method, it is very costly. Furthermore, it might adversely affect the operating water network, as it can cause a water pipe to burst if the gas is injected at high pressure (Puust et al., 2010).

Lastly, pig-mounted acoustic (PMA) technique is based on placing a microphone into the main to record the leak position and noise. It is a highly accurate approach because, by passing through the water pipe, the microphone can collect information that can provide the exact distance and transmit the leak sound. However, it cannot be applied to old pipes due to heavy corrosion. In addition, it may be affected by water quality, since pigs are in direct contact with the inner pipe (Puust et al., 2010).

2.2.6 Water loss management methods

After setting a specific leakage target, adopting the most suitable leakage management methods that can accomplish the optimal level effectively and efficiently is significant because various types of leakage occur in spite of continuous leakage reduction activities. Moreover, the leak volume varies with the water use patterns, geographic conditions and facilities condition. According to IWA (2000), the following four representative leakage management methods have been shown as most effective: (1) pressure management, (2) active leakage control, (3) speed and quality of repairs and (4) pipeline asset management, maintenance, and renewal. This can be seen in Figure 3.

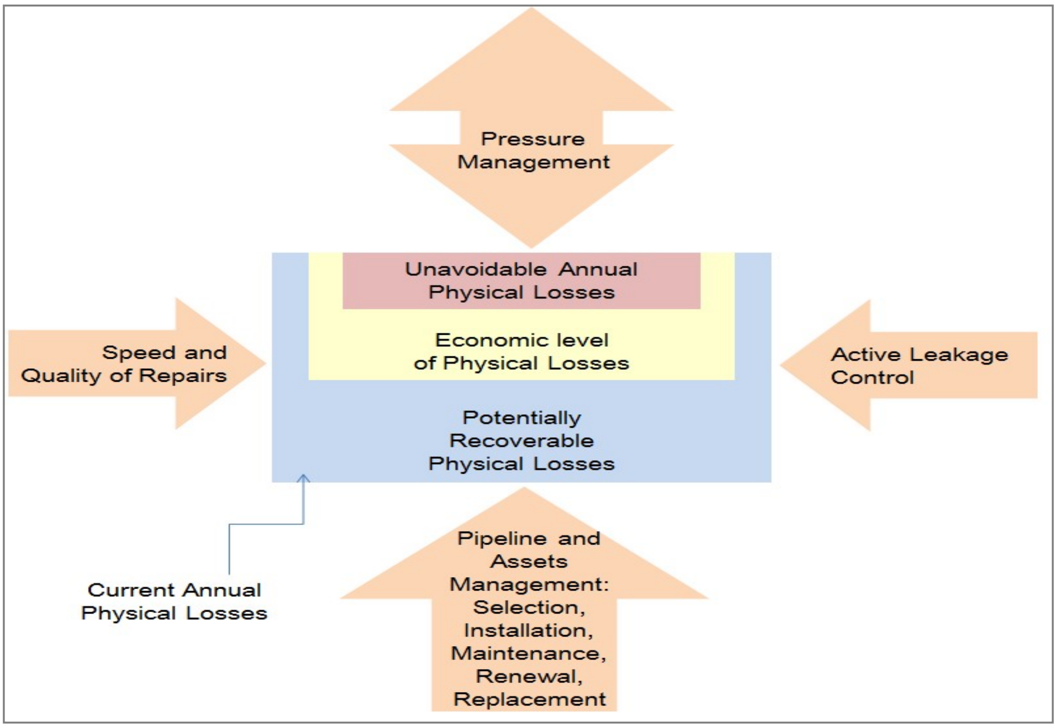


Figure 3 : The four pillars of a successful leakage management strategy (Force, 2003)

In Figure 3, the large rectangle represents the current annual volume of real losses. If the four methods mentioned above are not applied effectively, the volume of real losses will slowly increase. The smaller inner rectangle - Unavoidable Annual Real Losses (UARL) which stands for the lowest achievable level – can be obtainable only if the water system is well managed and maintained. However, achieving this level entails huge investment (Liemberger et al., 2007). The Economic level of Real Losses is the point of balance and should be targeted by water suppliers.

2.2.6.1 Active leakage control (ALC)

Severn Trent Water (2009) stated that active leakage control process consists of proactively seeking out or detecting leaks for repair. There are two types of leakage control according to the response to the leak. One is passive leakage control (PLC) and the other is active leakage control (ALC). PLC assumes that water suppliers react only when water comes up to the surface or when their customers complain about low pressure (Thornton et al., 2008). ALC is one of the most rapid response leakage reduction methods today and its process consists of leakage monitoring and regular surveys. The leakage monitoring is finding changes of flow rate by comparing flow entering into the water supply zone to quantify leakage and deciding the priority for the leakage survey. Regular surveys are an activity that identifies and locates the leaks periodically through listening for leaks on pipes, fittings, valves and water meters, and by using leakage detection equipment (Farley and Liemberger, 2005). With the development of computational management techniques, desk-based studies have also been made possible.

2.2.6.2 Pressure management

Pressure management is the most cost-efficient and rapid method of the leakage reduction techniques since it is possible to decrease leakage by reducing pressure instead of detection, repair and pipe replacement through the whole distribution area. Moreover, this method has many advantages such as reducing the number of leaks and bursts, extension of infrastructure life, and decreasing surge impacts (Fanner et al., 2007). Koo et al. (2011) stated that if utility managers reduce over-pressure by 10%, they can save as much as 10% in the volume of leakage. Therefore, understanding the relationship between pressure and leakage is very important in pressure management because the volume of water losses varies along with pressure.

2.2.6.2.1 Fixed and Variable Area Discharge (FAVAD) concept

May (1994) define the concept of Fixed and Variable Area Discharge (FAVAD), which is the most widely, used equation showing the relationship between pressure and leakage. The following is the FAVAD equation.

$$\text{L Varies with} \quad P^{N1} \quad \text{and} \quad \frac{L_1}{L_0} = \left(\frac{P_1}{P_0}\right)^{N1} \tag{2.2}$$

Where L_0, L_1 : the leaks flow rate before and after change in pressure

P_0, P_1 : pressures before and after change in pressure

Equation (2.2) describes how Leakage Rate varies with Pressure P to the power N1. N1 is the controlling factor to explain different type of pipes and stature of the distribution network (Wu, 2011). N1 value varies from 0.5 for fixed area such as metal pipes to 2.5 for variable area such as non-metallic pipes. In the case of large systems, which have mixed pipe material, N1 can be assumed to be 1.0 (Fanner et al., 2007). N1 value can be decided by using pressure-leakage relationship curves. These curves can be seen in Figure 4.

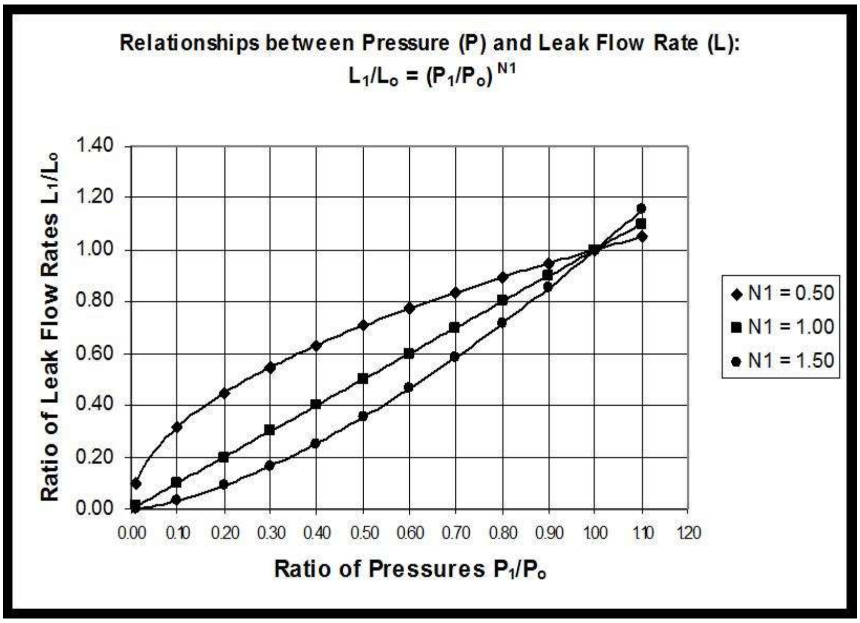


Figure 4 : Ration of Pressures (Force and Thornton, 2003)

This N1 value can be calculated by a pressure step test conducted at night. If there is no specific information, N1 can be assumed to be 1.0. And IWA WLTF developed a more empirical equation:

$$N1 = 1.5 - (1 - 0.65/ILI) \times p/100 \quad (2.3)$$

Where ILI is the Infrastructure Leakage Index and p is the percentage of detectable leakage on rigid pipes.

2.2.6.2.2 Type of Pressure Management

Pressure management can be divided into three types: (1) Sectorization, (2) Pump control, (3) Pressure reducing valve control.

Firstly, the most basic form of pressure management is sectorization. This method divides large area into the small sectors naturally according to the topography, ground level and water pressure. Otherwise, the area can be divided by installing boundary valve artificially. This is simple and cost-effective way but not sufficient to control pressure perfectly. It is more effective when using with the pressure reducing valve and controller (Thornton et al., 2008).

Secondly, pump control can be a method of pressure management. This control pump head to maintain proper water pressure at the critical point and average zone pressure point of a pressure management area. In case of using variable speed pump to meet a change in flow and pressure, this can lead to waste of energy due to the frequent pump operation. This methodology needs to be used carefully (Thornton et al., 2008).

Lastly, the most widely used method is using pressure reducing valves (PRV). PRVs reduce or maintain the pressure from a set point to the customer irrespectively of the upstream pressure or changes in flow rate (Wu, 2011). There are three types of PRV operation: fixed outlet control; time-modulated control; flow modulated control. A brief introduction of these methods can be seen in Table 3.

Table 3 : Comparison of three PRV operation types (McKenzie and Wegelin 2010)

Types	Characteristic	Advantages	Disadvantages
Fixed outlet	● Control Maximum pressure from inlet point	● Simple control ● No additional equipment ● Cheap installation	● Difficult to control surplus pressure
Time-modulated	● Control operating time with the pressure changes at the critical point	● Provide further reduction during the off-pick period	● Cannot react to water demand change ● More expensive than Fixed outlet
Flow-modulated	● Control the flow of the inlet point and react to the pressure of the critical point	● Most effective of the Three types	● The most expensive ● Require high level of operation skill

Each type of pressure management has own advantages and disadvantages. McKenzie and Wegelin (2010) emphasized that operator should consider selecting appropriate form of pressure control type rather than the valve types by comparing variables such as budget, expected savings and operational skill in pressure control.

2.2.6.3 Speed and quality of repairs

Volume of water losses consists of large and small losses. Large leaks like those on water mains normally last for a short time while small leaks could last much longer as they are difficult to detect. In order to control these leaks, it is vital to understand three elements of leakage runtime (Thornton et al., 2008). The volume of lost water from leaks is function of time which consists of awareness time, location time and repair time (Trow and Farley, 2004):

- Awareness time: The average time from start of leak to aware of its existence.
- Location time: The average time to find the location of the leak.
- Repair time: The average time to repair the leak.

Water suppliers should reduce leakage runtime for the fast repair of leaks. In terms of awareness time, frequent customer opinions gathering about the water pressure, real time monitoring of district metered areas (DMA) and increased leakage detection efforts have an effect on reducing overall awareness time. Location time can be reduced by positive leakage detection campaign of well-trained detection team members. At the same time, appropriate usage of leakage detection equipment is also an important way. Another way of locating pipe bursts is using a decision support methodology. Good quality of repairs also have an effect on decreasing the repair time (Thornton et al., 2008). For example, when a small pin hole happens in a cast iron pipe, the network operators have to decide how to repair the leak and whether to replace the leaking section with new pipes or to repair the pipe with a clamp. This decision also can reduce repair time.

2.2.6.4 Pipeline and assets management

If the target area has a high burst frequency and a high level of background leakage, the replacement of water pipes can reduce this (Trow and Farley, 2004). In addition, this is the most effective method to eliminate background leakage along with pressure management. However, since water pipe replacement follows a law of diminishing returns, making an accurate diagnosis can minimize unnecessary pipe replacement. Currently, this has been made possible along with the development of technology, such as internal inspection with robot or elaborate camera (Thornton et al., 2008). Within this context, various trenchless technologies are considered when making a decision about pipe replacement. (The advantages and disadvantages of representative techniques are described in the Table 4)

Table 4 : Water pipe replacement and rehabilitation techniques (Thornton et al. (2008)

Techniques		Advantages	Disadvantages
Replacement	replacement	● Exact replacement ● Remove background leakage ● Improving water Quality	● Traffic congestion ● Pedestrian inconvenience
	Slip lining	● Simple and fast construction ● Long length can be achieved ● Improving water quality	● Reduction of cross sectional area ● Difficult to find leak
	Pipe cracking or pipe bursting	● Fast construction ● Improving water quality	● Difficult to remove old pipe
Rehabilitation	Epoxy	● Fast renewal without excavating service connections ● Improving water quality	● Lining peel off ● Pipe to be clean before lining
	Cement	● Structural enhancement ● Flow is improved ● Provide long term protection ● Improving water quality	● Long setting time ● Reduced hydraulic capacity ● Impossible for small pipes

2.3. Economic Level of Leakage

Due to the need to extend the existing water system, to mitigate climate change impacts and to meet customers' expectations, management costs of water system are rapidly increasing. In the field of leakage management, there is an increasing need for investment to reduce leakage. This is due to the detection costs of finding remaining smaller leakage which is much higher than for the bursts that can be found easily. Recently, these rising costs have imposed a burden on water suppliers in terms of the difficulty of securing a budget and achieving a low leakage level. For this reason, water suppliers were forced to increase their interest in economic water production and distribution. In South Korea, K-water which is the public water company has developed an interest in economic leakage management and tries to adapt ELL methodology.

ELL research first started in the UK in the 1980s. A number of water companies began to use this concept while going through severe drought in 1995/1996. The continuous effort of water companies and Ofwat regulation led to considerable reduction in leakage levels from 5,112Ml/d in 1994-95 to 3,576Ml/d in 2005-06 (Ofwat, 2007). Currently, most UK water companies manage their leakage level close to the ELL. In order to develop an applicable methodology for South Korea, the following are described in this section: ELL definition, components for calculating ELL and recent research trends on economic leakage management.

2.3.1 Definition of ELL

UKWIR (1994) used the term "Optimum level of leakage" which is "the level of leakage where the marginal cost of active leakage control equals the marginal cost of the leaking water". Ofwat (2002) defined "Economic level of leakage (ELL)" as a same concept as optimum level of leakage. That is "the point at which the cost of reducing leakage is equal to the benefit gained from further leakage reductions" (Ofwat, 2002). In other words, when achieving the ELL it is possible to minimize the total costs for supplying water to the customer and to operate the water system most efficiently (Stephens, 2003).

Eventually, ELL is the level that water suppliers should achieve within their financial constraints. The concept of ELL is expressed in Figure 5.

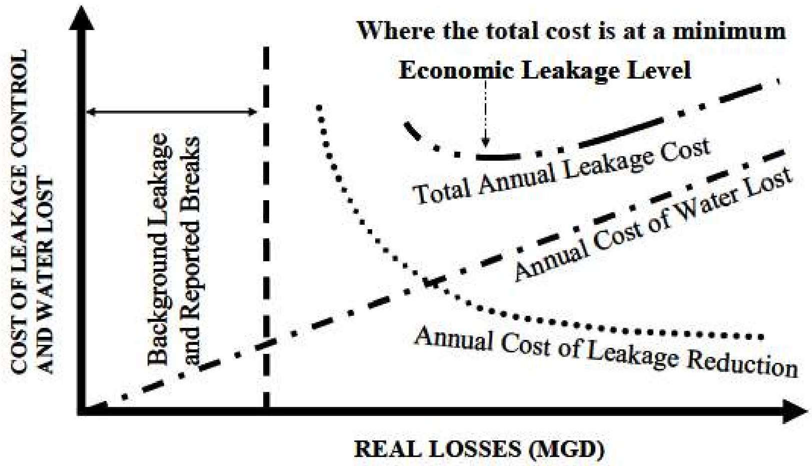


Figure 5 : Economic level of leakage calculation(Fanner et al., 2007)

The X-axis is the level of real losses and the Y-axis is the cost of leakage control and lost water through leakage. Annual cost of leakage reduction refers to the cost of all leakage reduction activities which follow the law of diminishing returns. For example, the more reduction in real losses required, the more cost compared to the low level of real losses. If the current real losses are reduced to the background leakage level, the costs of leakage reduction increase exponentially. Regarding the annual cost of water lost shown in the graph, this refers to the sum of production and distribution costs which varies according to the volume of lost water. This can be saved directly by producing less water through leakage reduction. The overall Economic Leakage Level is calculated by the sum of the annual cost of leakage reduction and the annual cost of water lost. On this curve, the minimum point is the economic leakage level. (Smout et al., 2010)

2.3.2 Time frames of ELL

An economic level of leakage has, according to the capital investment, both short and long run time frame. The former only considers operational cost, without capital expenditures. The latter evaluates life cycles and decision making. As mentioned above (See section 2.2.6), of the four primary components of leakage management, active leakage control and speed and quality of repairs refer to the short run ELL. Pressure management and infrastructure that requires significant investment decision is considered ELL in the long run (Pearson and Trow, 2005). Recently, the upgraded concept of "Sustainable economic level of leakage (SELL)" was introduced. SELL considers externalities such as social and environmental cost and benefits. (Beal et al., 2012)

2.3.3 ELL target setting process and the components

2.3.3.1 ELL target setting process

Ofwat (2002) presented an ELL target setting process map. It can be seen in Figure 6.

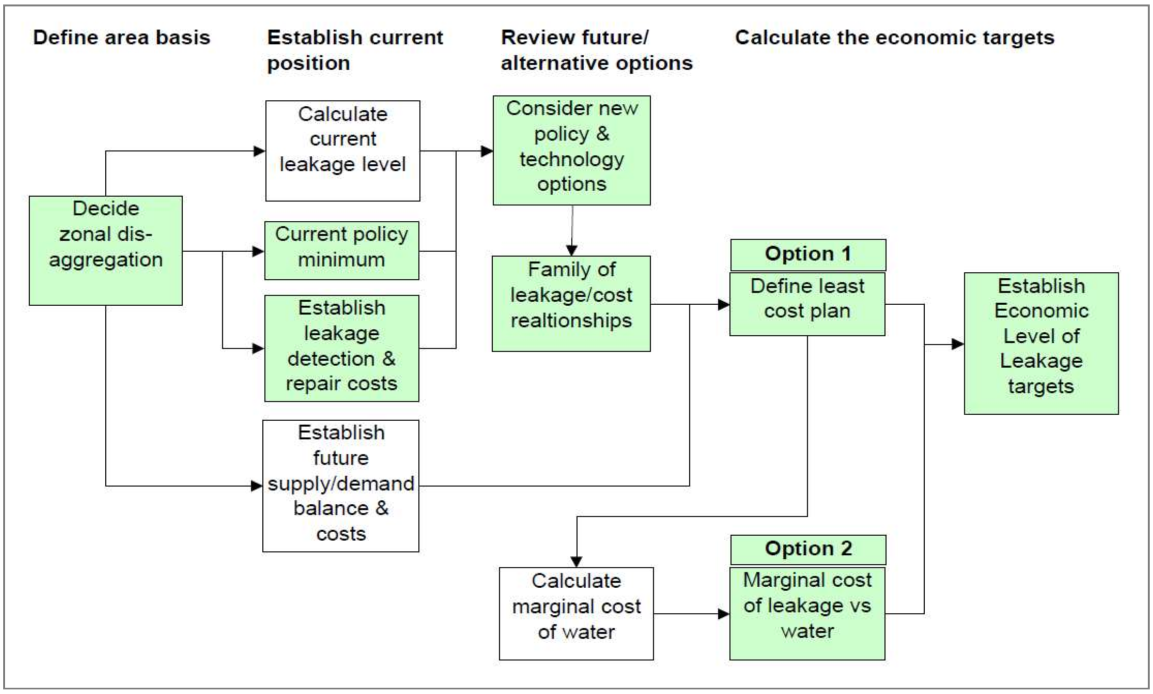


Figure 6 : ELL target setting process map (Ofwat, 2002)

The start of ELL target setting is deciding the area of analysis which requires selecting a smaller geographical zone for more accurate results. Next, the current policy minimum needs to be set on the basis of current leakage levels which are estimated from the bottom-up and top-down water balances referred to in the above chapter (See section 2.2.2). At the same time, leakage detection and repair costs should be calculated. After this process, decision makers have to consider new policies and technical options to ensure further reduction in leakage in the future. Then, the relationship of leakage level and costs need to be reviewed for greater efficiency and better financial savings. Finally, decision makers can choice appropriate options among Option 1 and Option 2 and estimate a suitable leakage target. (Ofwat, 2002)

2.3.4 Calculating Economic Level of Leakage

2.3.4.1 Policy minimum

Policy minimum is defined as a lowest achievable level of leakage at every DMA with current leakage control methods, equipment and reasonable effort (Ofwat, 2002). It consists of reported leaks and un-detectable leaks under the current ALC operation and whether theoretical or practical levels of leakage are achievable. Therefore, deciding on the policy minimum is an important process, since it is the lowest level which can be achieved under the current leakage control strategy. In other words, in order to achieve a lower level than the current policy minimum, another leakage control policy needs to be introduced. Trow (2006) also explained that “policy minimum is a level of background losses which results from an optimized entry and exit policy for DMA management, or exit policies for regular survey”.

Policy minimum can be calculated as follows. First, intensive sounding and noise logging throughout DMA should be performed and all leaks should be repaired within the target periods. The next is analysing minimum night flow and calculates the average minimum nightline values. At this moment, the average size of DMA should be within between 900 properties and 2000 properties. Lastly, the current policy minimum should be compared to the historical value (Ofwat, 2002). According to the data from the Water UK leakage managers, the average background leakage is about 51% of total leakage (Beal et al., 2012).

Estimation of policy minimum is currently impossible in South Korea, since minimum night flow analysis has not yet been applied to the water system. Therefore, as an alternative, indirect, comparative analysis with the UK's average rate of background leakage and the UARL indicator will be employed in Chapter 4.

2.3.4.2 Least cost planning approach (Option 1)

The least cost planning approach is used when setting a long-term plan (basically 25 to 30 years) for managing the supply-demand balance. This approach aims at minimizing a net present value of the cost related to the supply-demand investment (operating, capital, social and environmental costs). Leakage is a factor that affects supply-demand balance. The leakage profile that leads to the lowest net present value of costs, is precisely the economic level of leakage profile (Ofwat, 2002).

While this is similar to the method of calculating the marginal cost of water, it is a more comprehensive concept because the least cost planning deals with all options, related to supply-demand policy, based on supply-demand forecasts (Ofwat, 2002, Beal et al., 2012). Furthermore, this approach gives more accurate results compared to the marginal cost method due to applying various options. Hence, many water companies take advantage of marginal cost approach to establish the base line leakage level, and then use a least cost planning approach to decide if further leakage reductions are economic (Beal et al., 2012).

However, taking into consideration of the current data level, the marginal cost approach is more suitable for the South Korea water system. This is because many assumptions should be made for ELL calculation due to the complexity of assessment and data-intensive structure of the least cost planning approach. Therefore, the marginal cost approach was used as a method for ELL calculation in this study. The marginal cost approach is presented in more detail than the least cost planning in the following section.

2.3.4.3 Marginal cost approach (Option 2)

The marginal cost approach determines the ELL as the relationship between marginal cost of leakage control and marginal cost of water form the next resource scheme. If the marginal cost of leakage control for saving additional water is less than that for development of next resource to meet the demand, it will be cost effective to increase leakage control. On the contrary to this, the new resource should be developed. Accordingly, ELL is defined as a level which “the marginal cost of leakage control equals the marginal cost of water from the next resource” (Ofwat, 2002).

The marginal cost approach only considers the balance between leakage control and resource/treatment costs, this is relatively simple and more transparent than the least cost planning (Ofwat, 2002). For this reason, even though regulators suggest water companies use least cost planning, significant numbers of water companies are more likely to use a marginal cost analysis. Especially, if there is no deficit in the water supply, 83% of the water companies without a deficit used this marginal cost approach (Beal et al., 2012).

However, because the least cost planning deals with full modelling of the supply-demand balance, it is recommended to develop the SELL by using a least cost plan.

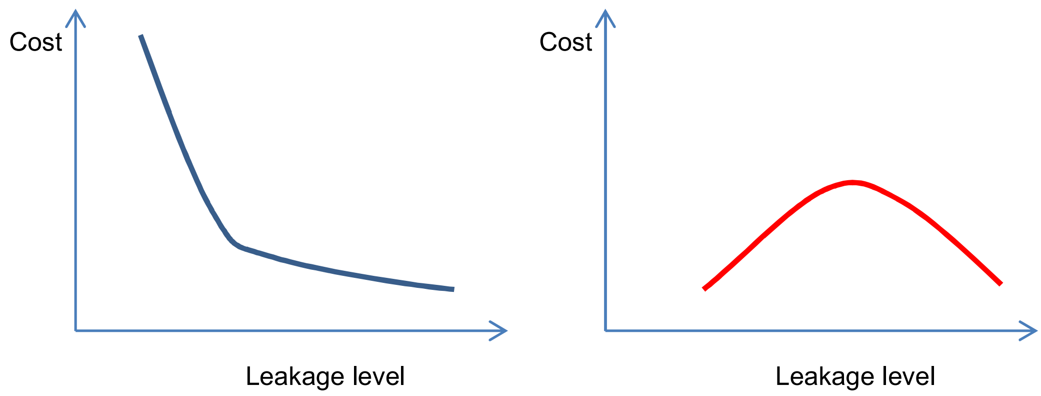
As noted above, though the least cost planning is more powerful than marginal cost approach, the former will be used in this research. Key components of marginal cost approach, marginal cost of leakage control and marginal cost of water, are explained as follows:

1) Marginal cost of leakage control

As with the marginal cost of water, the marginal cost of leakage control is an important factor in the ELL calculation. This is additional cost in order to reduce leakage from the current level to a lower leakage level. The greater the leakage reduction, the more money is required when the current level approaches the policy minimum (UKWIR, 1994). Hence, from the economic point of view, it is critical to forecast associated costs depending on leakage levels. There are two methodologies for estimating the cost of leakage control, and these will now be outlined.

The first methodology draws a regression curve using the actual investment costs. Whilst this method is highly reliable, it requires much effort to acquire data and process because it is based on actual operating data. After completing the data processing, it is possible to draw the leakage control cost curve similar to the exponential or logarithmic function shown in Figure 5.

The leakage control cost curve drawn according to the South Korea situation is a different form of the UK's shape. In order to compare the form of the curve, two types of graph are shown in Figure 7.



(1) Typical costs curve of UK

(2) Costs curve of South Korea

Figure 7 : Leakage control costs curve

The left graph shown in Figure 7 is the typical leakage control cost curve in UK. The right graph which is obtained from K-water, highlights to the Annual Investment Plan of Water Efficiency Improving Project, which is operated by K-water in South Korea. The main reason for these differences is attributed to the investment policy. An average of approximately 40% of investment, such as establishing DMAs, pressure management and pipe replacement/rehabilitation, is being made by K-water within 5 years (Koo et al., 2011). Then, during the remaining period of the project, (2013~2027), it is anticipated that investment will be on average 4% of the total. These projected figures can be seen in Table 5.

Table 5 : Annual investment plan of Danyang Gun (K-water, 2008)

(Unit: ￡)

Total	2008	2009	2010	2011	2012	2008~12	2013~27
	1 year	2 year	3 year	4 year	5 year	5years	15years
11,813,746	751,067	1,685,485	747,538	1,033,796	715,196	4,933,082	6,880,665
-	6%	14%	6%	9%	6%	42%	58%

Therefore, the development of the cost curve derivation method, allowing for this investment structure of the K-water project, is the crucial point for the ELL calculation. This specific process will be addressed and explained in the Chapter 3. The alternative method is adopting the modelling approach introduced by UKWIR/WRc in 1994. The method is represented by following Equation (UKWIR, 1994).

$$\text{Total cost} = C = C_a \frac{\ln\{\frac{L-L_b}{L_p-L_b}\}}{\ln\{\frac{L_a-L_b}{L_p-L_b}\}} \qquad : (2.4)$$

L= level of leakage, m^3/connection/year

C = cost of leakage control, ￡/connection/year

L_a = actual level of leakage for the area, m^3/connection/yea

C_a = actual cost of leakage control for the area, ￡/connection/year

L_b = base level of leakage for the area, m^3/connection/year
L_p = passive level of leakage for the area, m^3/connection/year

Once each component mentioned above is calculated, the cost curve can be easily derived from the equation.

2) Marginal cost of water

The marginal cost of water is an additional expense which is required for water production and distribution in each water resource zone. There are largely three types of costs: (1) Marginal operating costs, (2) Marginal capital costs and (3) externalities (social and environmental) costs.

Firstly, marginal operating costs are comprised of pumping costs (with the objective of abstraction, production and distribution), treatment chemical costs, sludge disposal costs, and raw water withdrawing or purchasing costs (Fanner et al., 2007). These costs directly link to the cost savings when leakage is reduced and water does not need to be produced in order to meet the increasing demand. Secondly, marginal capital costs occur when water suppliers cannot provide sufficient quantities of water into the supply zone. Expenses are also incurred in the construction of new facilities, which are planned due to the increase in demand. This marginal capital costs can be saved by deferring future capital investment plans (Fanner et al., 2007). Lastly, social and environmental costs, (which is the last marginal cost of water effect on leakage reduction), should be considered in the ELL calculation. This is because changes in leakage levels influence financial considerations. It can save money via a decrease in water abstractions and less purchasing of bulk water. Also, it can incur expenses such as inconvenience for pedestrians and delay of vehicles. Therefore, it is necessary to develop an ELL calculation by considering these costs for water suppliers, customers, society and environment (Ofwat, 2008).

Nevertheless, there is no typical guideline about social and environmental costs. Even though an example calculation with default/typical values was introduced in

2012, they are still specific to each area (Beal et al., 2012). Thus, it is necessary to apply this to the externalities of the South Korea water system, but only after further research has been undertaken.

2.3.5 Previous research on Economic Level of Leakage

The research on economic leakage management starts from questions: How much money should be invested for leakage reduction? Additionally according to the investment, what benefits we can get from the investment? (Lambert et al., 2015). Various researches on ELL have been performed in UK since first report has been published in 1994.

The purpose of the first trial was to develop an economic model for evaluating leakage in South Africa. This model allows water suppliers to decide the economic ALC intervention frequency, every 6, 12 and 24 months, by comparing the costs (McKenzie and Lambert, 2002).

Lambert and Fantozzi (2005) introduced a model which can assess leakage intervention frequency based on regular surveys. This method requires only three parameters for calculations: Cost of intervention (CI), Variable cost of Water (CV), Rate of Rise of Unreported leakage (RR). These required parameters, when calculated exactly, offer a variety of applications: operators can easily confirm economic intervention frequency, the time of next intervention, required annual budget and economic annual volume of unreported real losses. However, most countries with a different data management system to the UK would have a problem calculating these factors.

The other huge change in estimating economic level of leakage is the inclusion of externalities such as social and environmental costs and benefits. This is the concept of sustainable economic level of leakage (SELL). If the existing concept of economic level of leakage is made for water companies, the SELL is optimal for both customers and society, by considering social and environmental impacts such as reduction abstraction charges, carbon emissions and costs of traffic disruption

(Ofwat, 2008). Munoz-Trochez (2012) introduced how energy externalities associated with ALC can be estimated and included in the ELL calculation.

Islam and Babel (2012) adapted the ELL concept to find the optimal ALC costs for the Bangkok water distribution system in Thailand. While the methodology used in this research followed previously published equations, this research also introduced more user friendly elements. Those included not only how to calculate ELL quickly and estimate optimal ALC costs, but also how operating pressure and marginal cost of water can affect the ALC cost and ELL. This is a significant advancement for water distribution system managers who want to analyse and operate ELL as a management tool.

Finally, Cho (2013) stated that most research on economic leakage management have focused on individual activities such as leakage detection, pressure management and mains renewal rather than on overall activities for leakage reduction and setting operational targets. In terms of long term economic level of leakage, it is difficult to make accurate economic predictions due to the change in costs and development of leakage detection technologies. Therefore, verification of the long term leakage targets should be checked at least every 5 years.

2.4. Summary

Large and small leaks occur continuously in any water distribution network. The process for reducing leakage has not changed much over time, but the related costs such as labour, material and maintaining costs have increased dramatically. Koo et al. (2011) stated that the costs for raising the revenue water rate by one percent have increased 1.5 times compared to the early 2000s in South Korea. In order to use limited budgets efficiently and manage leakage systematically, economic leakage management methods should be introduced. However, due to the differences of data management methods and systems, it is difficult for the South Korean water system to apply the UK's methodology. Therefore, in order to resolve these problems, the following two tasks are considered fundamentally important:

- Based on the water loss management literature review, accurate volume of water losses should be calculated.
- Required information and method of collecting data need to be identified for continuous ELL analysis.

The key requirements for calculating the ELL falls mainly into three categories. The first is estimating leakage control costs and benefits according to the leakage level. The second is developing procedures of cost curve derivation by considering the investment structure of the project. The last is simplifying the complex UK-based ELL calculation process as data management systems and the variable quality levels differ in South Korea. There is a requirement to develop a methodology that can easily evaluate ELL with limited South Korea data:

- Exact costs and benefits resulting from leakage reduction should be worked out.
- Cost curve derivation procedure which is suitable for the business structure of K-water projects have to be made.
- Simple and easy methodology which can adapt with current operation data should be included.

In the next chapter, specific methodology and process will be presented by focusing on the difference between the UK and the South Korea.

CHAPTER 3 METHODOLOGY FOR ASSESSING ECONOMIC LEVEL OF NON-REVENUE WATER

3.1. Introduction

The first local waterworks operational efficiency projects were promoted by K-water in South Korea in 2004. Given the remaining project period (i.e., approximately 10 to 15 years), it is necessary to review the results of NRW reduction and suitability of uniform NRW goals applied to all projects. Having has this background, this study aims to conduct this review and suggests reasonable NRW target.

Currently, there are no serious discussions about an evaluation method related to economical leakage management in South Korea. Only the NRW rate has been used as an indicator to compare the level with another local waterworks' and national average NRW. However, this indicator is unable to take into account the economical leakage management (Cho, 2013, Koo et al., 2011). In addition, this indicator overlooks some variables in the network such as regional characteristics, water use pattern and scale, and infrastructure deterioration status. These variables can have a significant impact on the NRW level and budget security. Meanwhile, approaching the same objectives and NRW reduction strategies, without considering these variables, has shown a huge difference in the reduction of NRW unit costs (i.e., more than 5 times) (K-water, 2013).

The literature review was conducted in order to understand the water loss management concepts and economic target setting method, and guide the development of the leakage target setting approach for South Korea. In light of this, ELL calculation model of the UK, (reviewed in Chapter 2), is the optimal model to examine the appropriateness of the K-water projects' target. However, the direct application of UK's model to K-water projects is problematic. The main reason is that data acquisition and processing, analytical procedures and method definitions need to be modified to reflect the South Korea business environment.

In chapter 3, the applicable methodology for the South Korea context, based on the ELL used in the UK, is developed and described. In section 3.2, the target setting process of the economic level of NRW is illustrated. In the next section (3.3), components of the economic level of NRW, data collecting and methods and two approaches for economic NRW target setting are explained. In addition, section 3.4 presents how the economic level of NRW is applied to the target setting. Next, section 3.5 describes sensitivity analysis of the key parameters. Finally, conclusions are drawn in section 3.5.

3.2. Economic level of NRW target setting process

The economic level of NRW target setting flow chart can be seen in Figure 8.

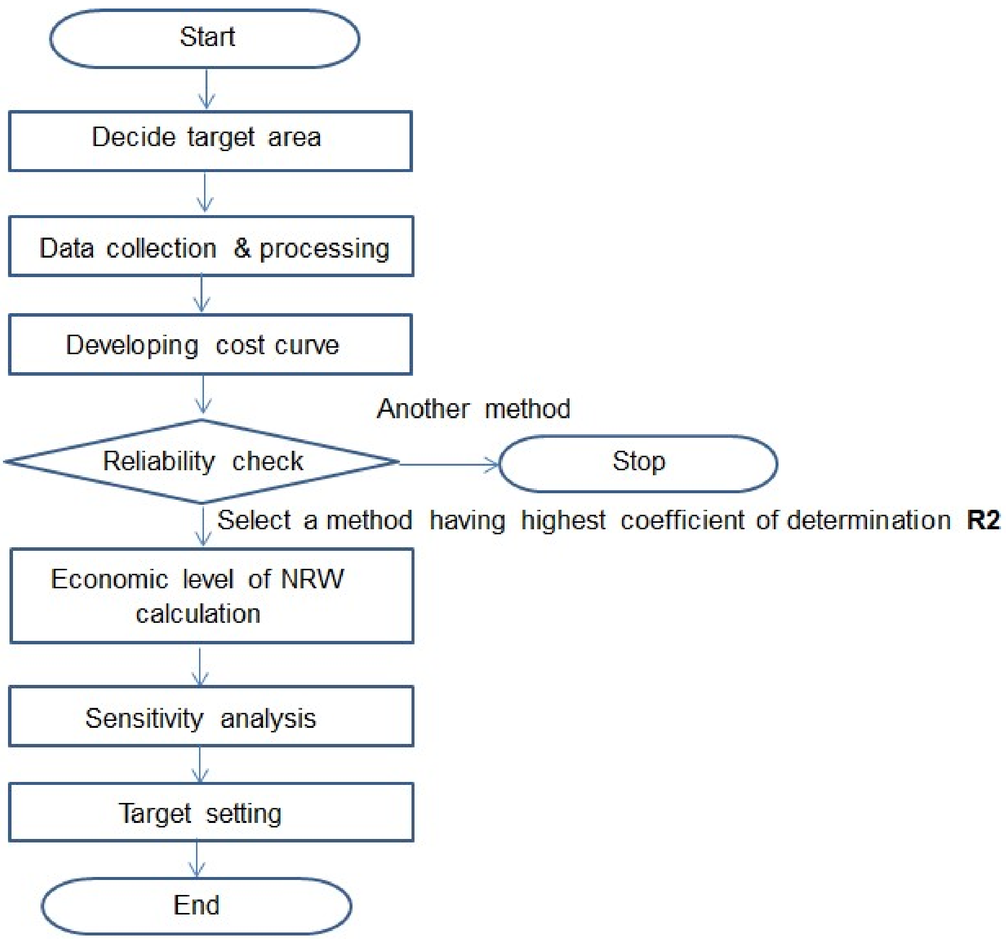


Figure 8 : Economic level of NRW target setting approach

The first step is to decide a target area having at least 5 year operating data of DMAs, due to the acquisition of minimum available data. Next, the current level of NRW and policy minimum need to be estimated which is referred to in the above chapter (See section 2.2.2). The UARL would be employed instead of minimum achievable background leakage. At the same time, costs data should be collected from the company information system. After this process, the NRW control cost curve would be developed by using two approaches respectively (Ofwat, 2002). After that, it is possible to determine the most reliable approach for this study by comparing derived cost curves fitting. The method showing highest coefficient of determination R^2 is used for economic level of NRW calculation. The other method having low coefficient of determination R^2 will not be considered in this thesis. Then, the economic NRW level is estimated by using the selected method. Through this process, decision makers can identify economic level and decide a project target, by considering these financial constraints, social and political request.

3.3. Economic level of NRW Calculation

3.3.1 Deciding Target Area

Ofwat (2007) recommended that the analysis period for calculating ELL should be a minimum of five to ten years. This means the target area should have operation data during the same period. These data must be automatically and periodically collected by the supervisory control and data acquisition (SCADA) system. Taking into account the above explanation, the current 12 of 20 projects operated by K-water can be selected for target area as only 12 has established DMAs and has been monitored for at least 5 years after the installation of DMAs. In order to decide a suitable target area, the following various factors are comprehensively considered: 1) the scale of water supply, 2) presence of own water resource and bulk water imports, 3) completion of DMA installation and water pipe replacement, and finally 4) sufficient operating data. Having accounted for these factors, a project is selected and analysed as a target area since it have managed operating data systematically and have shown outstanding data accuracy due to the recent establishment of a Geographic Information System (GIS).

3.3.2 Data collection

Munoz-Trochez (2012) stated that quality of data have a major impact on the reliability of ELL calculation. All the data used in this research are collected based on various statistics and information systems. The sources of data are shown in Table 6 and details about required data can be found in Appendix A.

Table 6 : Source of collected data for ELL calculation

Sources	Managing body	Main contents
Water statistics	Country, Local government	Water supply status, water facilities information, revenue water rate etc.
Annual report	K-water	Water supply status, water facilities information, operation data etc.
Information system	K-water	NRW rate, accounting, customer service, water pipe network operation system etc.
Technical Report	K-water	Annual investment plan of development of DMA and water distribution system maintenance
Future maintenance strategy	Local Government	Water facility expansion plan including pumping and booster stations, water treatment, service reservoirs and water pipe expansion

3.3.2.1 Policy minimum

Policy minimum data consists of the number of connections and properties, the length of water mains and communication pipes with average pressure of each DMA, and the performance indicator values. Connection and property information can be collected from the Customer Information System. Length of water pipes and pressure values are collected by DMA units and those values are recorded at one-minute intervals from the SCADA system. Lastly, performance indicator values can be assessed through various calculations, such as CARL, the length of the water pipes, the number of connections and the average pressure. In this study, UARL divided by connection numbers, will be used as a policy minimum.

3.3.2.2 Current NRW

NRW data, estimated by total integrated flow analysis, can be obtained from annual and monthly reports that are submitted to the general work system by local office managers of waterworks systems. This consists of two types of data according to the size of the target area. The two forms of data collection can be seen in Appendix A.

3.3.2.3 Costs data

There are largely two types of costs data, NRW control costs and cost of lost water. The NRW control costs are classified as expenses such as pipe replacement, installing DMAs, valves and pressure equipment, repair costs and leakage detection. These data are recorded on an individual basis by K-water accounting information system and can be collected in a simple and easy manner. Specific contents are described in Appendix A.

The cost of lost water is a function of marginal costs (i.e. production, distribution and capital investment associated with future upgrades to meet the increasing demand) and level of NRW. The more NRW increases, the cost of lost water is higher. On the other hand, the cost of lost water can be regarded as a benefit due to the amount of water saving as a result of NRW reduction by the water utilities. That is, the benefit is the reduced costs associated with the volume of water reduced by NRW control. Therefore, the costs of production and distribution, such as bulk water purchase costs, pumping or boosting costs, and water and sludge treatment costs, usage charges of dam water, expansion of pipe diameter and construction of reservoir, can be an important component the in economic level of NRW calculation. These data will be linked to the benefit calculation, can be collected through national and local government statistics, annual reports and various information systems.

3.3.3 Policy minimum

The Policy minimum is the lowest achievable level of leakage which is calculated through the night flow analysis and it is called background leakage (Ofwat, 2002). Moreover, it is impossible to estimate this under the South Korea data management system because there is no standard for estimating night use. Even though it is possible to estimate with the UK's average night use values, it is necessary to verify the UK's night use value by comparing the result of total integrated approach. Mckenzie (1999) presented a simple calculation process, which uses default loss parameters derived from night flow analysis. This makes it possible to calculate background leakage very quickly. However, when considering the different water supply environment and status of infrastructure, the reliability of value needs to be checked. Therefore, as an alternative, the UARL indicator will be employed as a policy minimum in Chapter 4 (Beal et al., 2012).

3.3.4 Current NRW level

NRW is defined as the difference between the system input volume and the amount of authorised consumption (Pilcher, 2003). The system input volume is managed by water suppliers in real-time. It is easy to acquire the volume of system input data. When it comes to authorized consumption, water meter reading is carried out at every month and the accurate volume of authorized consumption is estimated. This NRW can be calculated by IWA standard international water balance (described in section 2.2.1)

3.3.5 Economic level of NRW calculation methods

Once current NRW and policy minimum are estimated, economic level of NRW can be calculated by analysing relationship between costs and benefits. In this thesis, two types of methods are employed to estimate the optimal level of NRW by comparing costs and benefits; (1) Marginal cost analysis and (2) Cumulative costs-benefits analysis. The first method is generally used in the UK (UKWIR, 1994). The second method is the newly developed method specifically suited for South Korean situation. All methods will be applied to a selected case study area. In order to select the most appropriate methodology for the South Korea business environment, a comparative analysis based on the reliability of each cost curve will be performed. After that, the economic level of NRW will be estimated by the preferred method.

3.3.5.1 Method 1: Marginal cost approach

This approach finds an intersection point between the marginal (unit) cost of NRW control and the marginal cost of water. Both the marginal (unit) cost of NRW control and the marginal cost of water curve can be drawn, as in Figure. 9. In this graph, the intersection point of both curves is the most economic NRW level (UKWIR, 1994) .

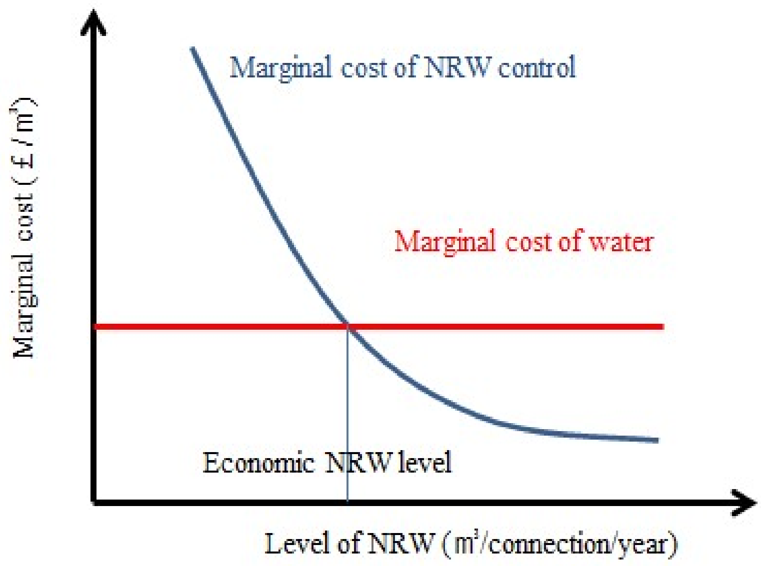


Figure 9 : Marginal cost curve

1) Marginal cost of NRW control

The marginal (unit) cost of NRW control means additional cost for further 1m³ of NRW reduction. This cost can be calculated by dividing the annual volume of NRW reduction over the previous year into the annual cost of NRW control, which consists of various activities such as water pipe replacement/rehabilitation, pressure management, water meter replacement, and leakage detection/ repair (UKWIR, 1994).

2) Marginal cost of water

The marginal cost of water can be estimated by adding marginal operating costs, marginal capital costs, and social and environmental costs (UKWIR, 1994). However, the social and environmental costs will not be included in this research due to the difficulty and uncertainty in exact calculation. The marginal operating costs are based on production and distribution costs such as power, chemical, bulk purchase, and abstraction. The marginal capital costs can be affected by NRW reduction. A reduction in the level of NRW may allow to change the size of a project or to postpone its plan. These two costs are explained as follows.

(1) Marginal operating costs can be calculated by dividing annual variable costs such as bulk water purchase, pumping and pump boosting, water treatment, sludge treatment and usage charges of dam water into total annual volume of water provided into the distribution network (UKWIR, 1994). This can be estimated by Equation (3.1).

$$\text{Marginal operating costs} = \frac{\text{Pumping and Boosting costs} + \text{Wate} \quad \text{treatment costs} + \text{Sludge treatment costs}}{\text{Annual volume of production}} + \frac{\text{Usage charges of Dam water}}{\text{Annual volume of dam water}} + \frac{\text{Bulk water purchase costs}}{\text{Annual volume of purchased bulk water}} \quad (3.1)$$

(2) Marginal capital costs occur when capital expenditure is decreased or postponed due to the NRW reduction. Therefore, all the items which can be affected by NRW reduction such as water resource works, treatment works, pumping and boosting stations, service reservoirs and distribution main replacement and rehabilitation should be considered (UKWIR, 1994).

UKWIR (1994) introduced two methods: The method 1 is dividing the present value of the planned investment programme by the present value of the growth in water demand over the same period. The present value of the growth in water demand is difference between demand considering increase rate in water demand of the future and demand without increase rate. The present value of demand related investment is changed future capital cost by applying discount rate to planned investment according to the future maintenance strategy. The method 2 is dividing the difference in the present value of investment expenditures by the present value of the demand reduction. The difference between method 1 and method 2 considers the changes of planned investment projects according to the leakage reduction.

It is important to note that both methods can be adapted under the assumption that future demand increases during the project period. Since expecting the exact timing of capital expenditure is not easy under the current K-water business environment and data management system, marginal capital costs would be calculated by method 1. If the demand decreases or maintains constant level, the marginal capital costs will not be adapted. In this study, marginal capital costs can be calculate with the following equation (3.2)

Marginal capital costs

$$= \frac{\text{Sum of present value of demand related investment}}{\text{Present value of the growth in water demand}} \tag{3.2}$$

3.3.5.2 Method 2: Cumulative cost-benefit analysis approach

Unlike the previous method, the cumulative cost-benefit method is a newly developed approach taking into account the particular operating conditions in South Korea. The economic level of NRW can be identified by analysing the relationship between the cumulative cost of NRW control and the cumulative benefit of NRW reduction. Based on the data collected from the water supplier billing system, the cumulative costs of NRW control are estimated. The cumulative benefits are represented as the aggregated value of annual benefits of NRW reduction. The annual benefits of NRW reduction are calculated by multiplying both volume of NRW reduction over previous and marginal cost of water. With this data, the cumulative benefits of NRW reduction can be estimated in the same way as the cumulative costs of NRW reduction. The cumulative cost curve can be identified by using both data worked out through the above process. The cumulative cost and benefit curves are illustrated by two forms in Figures 10 and 11 against the cumulative volume of NRW reduction and the annual level of NRW per connection, respectively.

In Figure 10, the cumulative benefit curve (the red line) shows that the cumulative benefit increases over time due to the continuous NRW reduction. However, the rate of increase diminishes over time. On the contrary, the slope of cost curve, (the blue line), shows an initial linear increase before growing exponentially beyond the economic point. Once the graph is developed, the intersection point of both curves is the most economically optimal NRW level. Though Figure 10 suggests an optimum cumulative volume of NRW, it has a disadvantage in indicating the best NRW level represented by "m^3/connection/year". Therefore, the cumulative cost-NRW level curve is used in conjunction with Figure 10 to help calculate the optimal NRW level. This is illustrated in Figure 11.

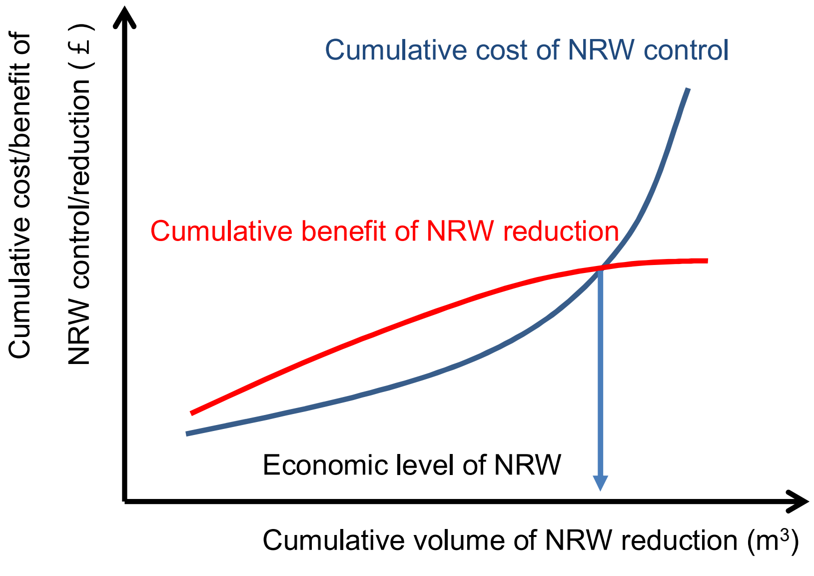


Figure 10 : Cumulative cost-benefit curve A

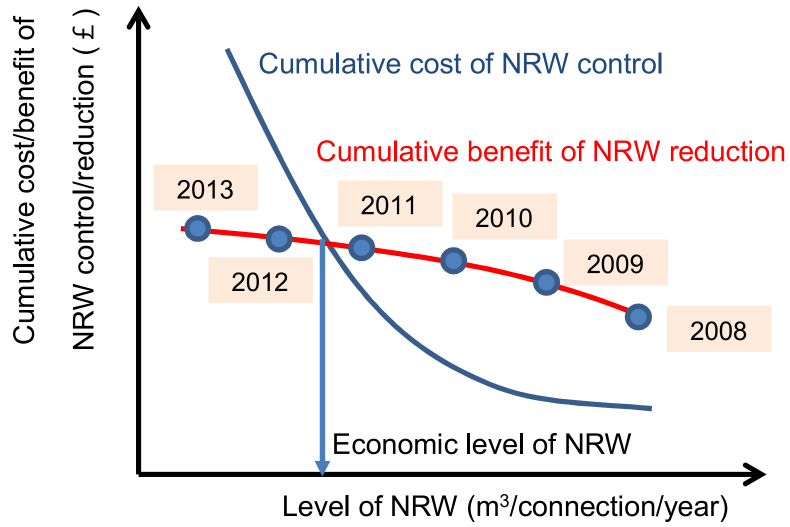


Figure 11 : Cumulative cost-benefit curve B

In Figure 11, when NRW level moves from high(right) to low(left), the cumulative benefit of NRW reduction increases only slightly because of the difficulty associated with reducing NRW to a low level. In other words, the cumulative benefit of NRW reduction increases over time due to the continuous NRW reduction. However, the rate of increase diminishes over time. On the contrary, the cumulative cost of NRW control rises rapidly. Due to all these reasons leakage reduction activities follow the law of diminishing returns.

3.4. Economic Level of NRW target setting

The long-term goal of the South Korean government, in line with public opinion, is to achieve 20% NRW. Most of the NRW reduction projects, which have promoted by K-water, are designed to achieve that level. Under the current status, though estimated NRW from this study is the most economically appropriate target, it is difficult to modify the current NRW target, in a short time. Therefore, in this study, the estimated economic NRW level through the discussed approaches would be suggested as an optimal target by comparing both current and historical NRW levels.

3.5. Sensitivity analysis

The economic NRW level is determined using a variety of variables that are subject to uncertainty. The representative variables applied to this study are volume of NRW, NRW control costs, marginal cost of water, and number of connections. The sensitivity analysis will be performed to investigate which factor has the most influence on and how a change in the parameter causes a change in economic level of NRW value. The sensitivity will be tested by applying +/-5%, +/-10%, and +/-15% to each variable.

3.6. Summary

The Economic Level of Leakage calculation model developed in the UK has provided water suppliers with economically useful information for the operation and maintenance of WDSs. This chapter has presented the economic level of NRW calculation methodology with detailed reference to the UK model. In this chapter, two methods for calculating the Economic level of NRW were discussed: (1) Marginal cost analysis and (2) Cumulative costs-benefits analysis.

The first approach is well known method in the UK. The second Cumulative cost-benefits approach is newly developed method in the economic level of NRW calculation. It uses both cumulative costs and benefits for the economic level of NRW calculation. This is advantageous for minimizing data fluctuations resulting from an application to the project having a short period of operating data.

In Chapter 4, two methods will be applied to a case study involving K-water projects. In order to select the most appropriate methodology for South Korea business environment, a comparative analysis of the reliability of each cost curve will be made. After that, the economic level of NRW will be estimated by the chosen methodology.

CHAPTER 4 CASE STUDY

4.1. Introduction

In this chapter, two methods for estimating economic level of NRW are applied to a K-water case study. The project area has just completed infrastructure improvement such as DMA instalment, water pipe replacement and rehabilitation. The case study presented in this chapter employed empirical data collected from the project management system. The objective of this chapter is to find an optimal NRW level based on the real data. Then, through comparison with the current project target, a reasonable NRW target will be decided.

This chapter is outlined as follows. After this introduction, Sections 4.2 and 4.3 present how the economic NRW level is estimated with the most appropriate method. Then a sensitivity check in section 4.4 was made for identifying the most influential factors affecting optimal NRW levels. Finally, Section 4.5 includes the chapter summary and presents conclusions.

4.2. CASE 1: NRW Reducing Stage (Danyang-gun)

4.2.1 Description of study Area

The Danyang-gun water system has been operated by K-water since they were contracted to operate and manage the system in 2008. One of the main goals is to achieve 20% NRW rate by 2014 starting from 52% NRW in 2008. In 2013, the recorded NRW rate was recorded 21%.

Danyang-gun is a small city which is located in the north-east of South Korea covering a total area of 780.65 km². The location of the case study area is shown in the Figure 12.

By the end of 2013, out of a total population of 31,390, 22,433 people, (71.5%) use treated water from the K-water. The remainder of the population is using a small-scale water supply system based on ground water (Ministry of Environment, 2013).

Three water treatment facilities have been providing water to this case study area. The average volume of this supplied water was 8,149m^3/day. Recently, it has been increasing due to the attraction of businesses as well as tourists.

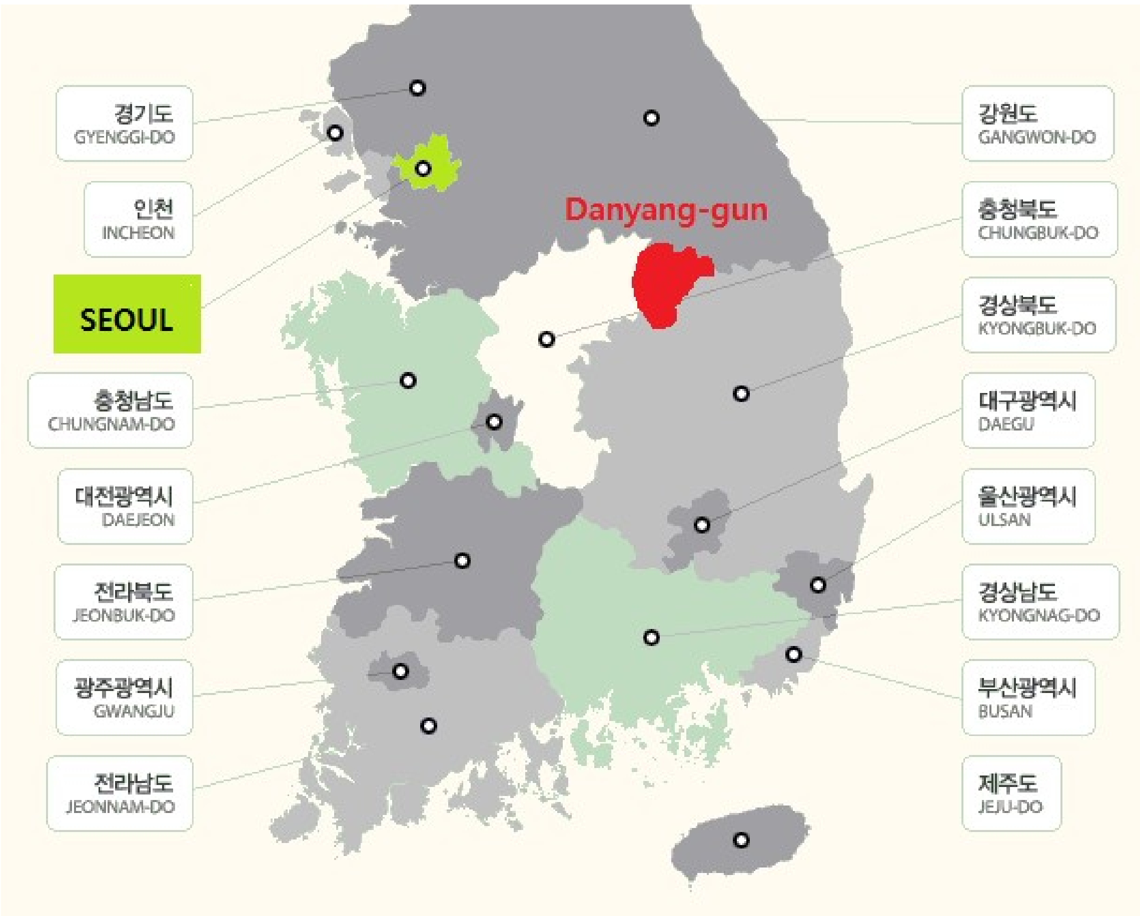


Figure 12 : Location of Danyang-gun in South Korea

The Danyang-gun DMAs were allocated by region. The location and name of DMA are described in Figure 13.

The rest of the Danyang-gun area, except for Danyangeup and Maepoeup is small and geographically far apart. The status of each DMA is explained in Table 7.

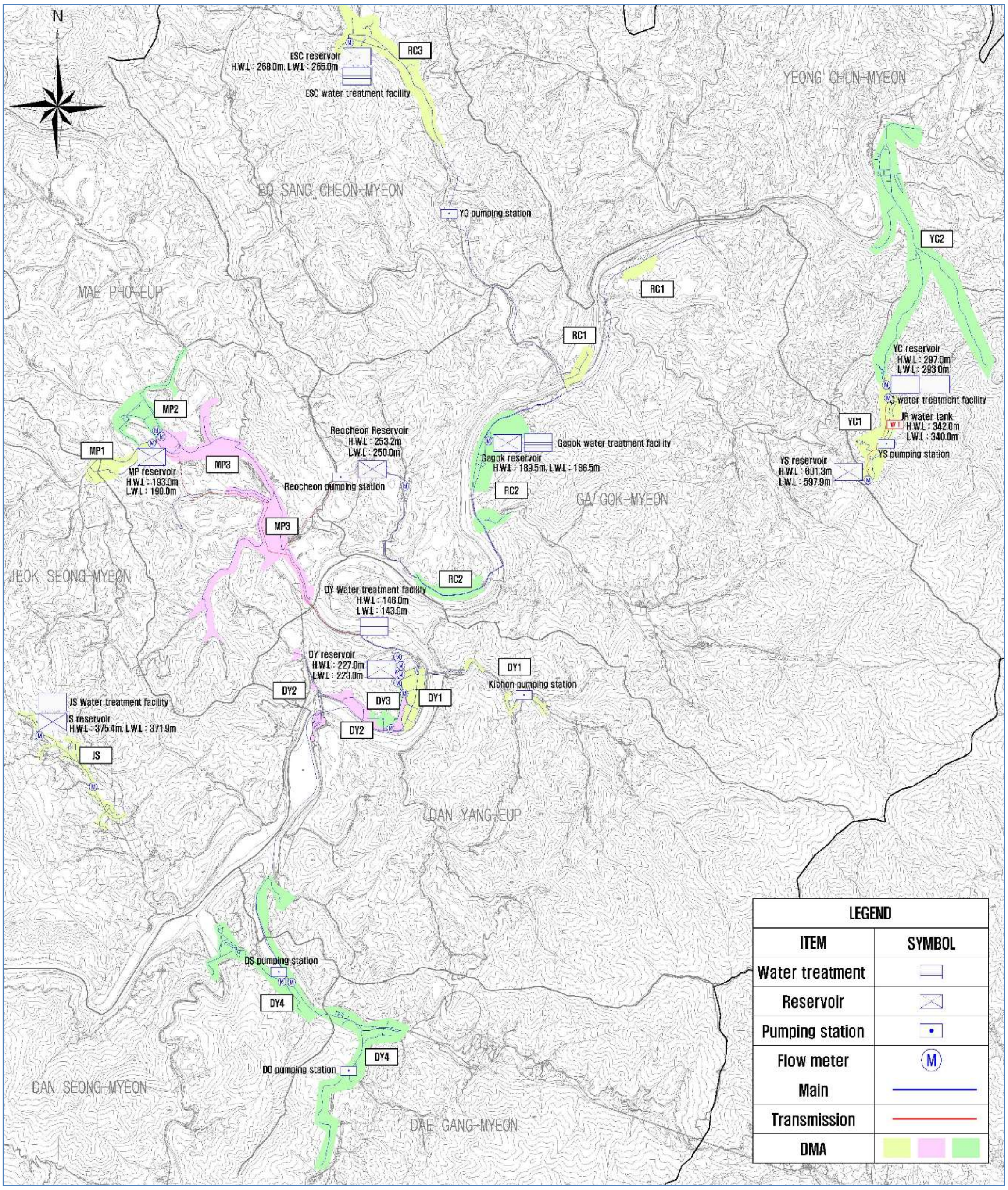


Figure 13 : Location of Danyang-gun and DMAs

Table 7 : Year 2013 statuses of connection, property and population

Large DMA	Medium DMA	Small DMA	Number of connections (-)	Average water use (m^3/d)	Water pipe length (Km)		
					Total	Mains	Communication pipe
Total			6,414	8,149	348.5	255.4	93.1
DY	DY	DY1	1,456	2013	48.8	35.6	13.2
		DY2	587	725	21.1	16.8	4.3
		DY3	65	973	3.0	2.6	0.4
		DY4	1,073	850	48.0	30.5	17.5
	MP	MP1	41	60	6.1	4.7	1.4
		MP2	1,041	984	27.0	17.9	9.1
		MP3	373	961	37.8	31	6.8
	RC	RC1	169	77	14.5	9.8	4.7
		RC2	554	899	50.8	40.9	9.9
		RC3	351	154	34.4	25.1	9.3
YC	YC	YC1	552	351	41.7	29.8	11.9
		YC2	3	34			
JS	JS	JS	149	68	15.3	10.7	4.6

4.2.2 Data collection and analysis

4.2.2.1 Connection, property and population

Connections, property and population were obtained from the K-water billing system and Danyang-gun statistical yearbooks. Table 8 shows that they have been increasing steadily due to the invigoration of tourist industry.

Table 8 : Annual status of connection, property and population

Year	2008	2009	2010	2011	2012	2013
Connections	5,315	5,376	5,454	5,778	6,089	6,107
Property	13,378	13,665	14,037	14,080	14,100	14,268
Population	20,017	20,331	21,269	22,210	22,241	22,433

4.2.2.2 Distribution network and pressure

The length of pipes obtained from GIS and statistical yearbooks is summarized in Table 9. There seems to be an error in water mains and communication pipe length in between 2010 and 2011. A large number of pipe information was corrected in 2011 through the total inspection while the local office was conducting a research about the WDSs maintenance plan. There was no average pressure data about the whole area but average pressure of each DMA has operated between 35metres to 45metres, hence, the average pressure was assumed to be 40 metres

Table 9 : Annual status of distribution network

Year	2008	2009	2010	2011	2012	2013
Total pipe length (km)	201	216	220	271	289	348
Water main (km)	93	103	107	200	216	255
Communication pipe (km)	108	113	113	71	73	93

4.2.2.3 Water loss performance indicators

Three types of performance indicators are calculated from Tables 8, 9, 11 and the results are presented in Table 10. One of performance indicators, ILI was estimated by dividing CARL into UARL. For example, CARL in 2008 was 2,259,146 m^3/year and UARL was 88,460 m^3/year. Both figures are shown in Table 11 and 12. Therefore, the estimated value is 25.54. As it can be seen from the latter table, this case study area has significantly reduced real losses due to intensive infrastructure investment in the time period shown.

Table 10 : Annual status of water loss performance indicators

Water loss PI Name / Year	2008	2009	2010	2011	2012	2013
m^3/km/year	24,292	11,504	8,271	3,886	3,461	2,502
m^3/km/day	66.6	31.5	22.7	10.6	9.5	6.9
m^3/km/hour	2.8	1.3	0.9	0.4	0.4	0.3
m^3/connection/year	425	220	162	134	123	104
m^3/connection/day	1.16	0.6	0.44	0.37	0.34	0.29
m^3/connection/hr	0.05	0.03	0.02	0.02	0.01	0.01
l/connection/hr	48.3	25	18.3	15.4	14.2	12.1
(ILI)	25.54	12.9	9.43	6.36	5.75	4.54

4.2.3 Current NRW level

The annual water balance of Danyang-gun between 2008 and 2013 is presented in Table 11. The table shows that the volume of NRW has fallen by more than a third from 2,823,933m^3/year in 2008 to 813,111m^3/year in 2013 due to the intensive operational and capital investments for NRW reduction. The CARL values were estimated by deducting apparent losses from water losses. Table 11 also shows that 109,713 m^3 has decreased between 2012 and 2013.

Table 11 : Annual water balance

Component	Total Volume (m^3/year)					
	2008*	2009*	2010	2011	2012	2013
System Input Volume	5,524,642	4,122,296	3,994,187	3,695,966	3,862,353	3,868,393
1. Revenue Water	2,700,709	2,641,109	2,850,823	2,733,323	2,937,848	3,055,282
- Build Authorized Consumption(a+b)	-	-	2,850,823	2,733,323	2,937,848	3,055,282
(a) Billed Metered Consumption	-	-	2,850,823	2,733,323	2,936,561	3,055,282
(b) Billed Unmetered Consumption	-	-	-	-	1,287	-
2. Non-Revenue Water(NRW)	2,823,933	1,481,187	1,143,364	962,643	924,505	813,111
- Unbilled Authorized Consumption(c+d)	-	-	78,637	19,186	3,022	1,071
(c) Unbilled Metered Consumption	-	-	-	-	-	49
(d) Unbilled Unmetered Consumption**	-	-	78,637	19,186	3,022	1,022
3. Water Losses	-	-	1,064,727	943,457	921,483	812,040
- Apparent Losses (e+f)	-	-	179,741	166,317	173,806	174,076
(e) Unauthorized Consumption	-	-		-	-	-
(f) Customer Metering Inaccuracies***	-	-	179,741	166,317	173,806	174,076
- Current Annual Real Losses	2,259,146	1,184,950	884,986	777,140	747,677	637,964

* Notes: there were no data about specific components in 2008 and 2009.

** Unbilled unmetered consumption is the sum of items such as fire fighting, flushing of mains and sewers, street cleaning, and frost protection.

*** Customer metering inaccuracies are estimated to be 4.5% of the System Input Volume according to the guidance of annual water balance analysis in South Korea.

4.2.4 Policy minimum

The policy minimum is the lowest achievable theoretical level of leakage through the active leakage control. It can be derived from minimum night flow analysis (Utilities, 2010). However, because of inaccuracy with the customer night use measurement, it is impossible to calculate policy minimum exactly. Alternatively, the UARL is used as a policy minimum and it was calculated by using equation (2-1). The results are shown in Table 12.

$$ILI = CARL / UARL \tag{2.1}$$

UARL (litres/day) = (18 x Lm + 0.8 x Nc + 25 x Lp) x P

- where Lm = mains length (km); Nc = number of service connections;
- Lp = total length of private pipe, property boundary to customer meter (km);
- P = average pressure (metres).

Table 12 : Unavoidable annual real losses (UARL)

Item	2008	2009	2010	2011	2012	2013
Water main(km)	93	103	107	200	216	255
Connections	5,315	5,376	5,454	5,778	6,089	6,107
length of private pipe(km)	5.32	5.38	5.45	5.78	6.09	6.11
Average pressure(metres)	40	40	40	40	40	40
UARL(m^3/year)	88,460	91,822	93,813	122,156	130,107	144,271
UARL(m^3/connection/year)	17	17	17	21	21	23

In Table 12, the UARL is increasing steadily year on year after the first three years where it was static. This is because the UARL is affected by the increase in various parameter values (i.e., water mains lengths, number of connections, private pipe lengths and average pressure). Especially, there was a rapid growth in the length of water mains and connections from 2011 to 2013. The other significant cause is that pipe properties were redefined in 2011 through total inspection. A large number of pipes that were classed as communication pipes were changed into water mains.

4.2.5 Economic level of NRW calculation

4.2.5.1 NRW cost curve

A cost curve is a key factor in the calculation of the economic level of NRW. This is because it enables water suppliers to predict future NRW control costs. A derived cost curve is subject to large uncertainty if there is not enough reliable data. In this section, through the comparison of each cost curve, the most suitable approach between the two will be selected and the most economically efficient level of NRW will be calculated using the chosen method.

1) Marginal cost of NRW control curve (Method 1)

The marginal costs of NRW control was calculated by dividing the annual costs of NRW control into the changes in NRW. The specific annual costs of NRW control are shown in Table 16 and the changes in NRW are explained in Appendix B. The marginal costs of NRW control curve can be drawn by using both the marginal costs of NRW control and the NRW per connections. Both the estimated values are presented in Table 13 and the marginal cost of NRW control curve is illustrated in Figure 14.

Table 13 : Marginal cost of NRW control

Year	End of year NRW	Changes in NRW(A)	Annual costs of NRW control (B)	Marginal costs of NRW control (B/A)	NRW/connections
	m^3/year	m^3	£	£ / m^3	m^3/connection/year
2008	2,823,933	-	125,500	-	531
2009	1,481,187	1,355,325	412000	0.3	276
2010	1,143,364	354,816	886,500	2.5	210
2011	962,643	234,522	314,000	1.3	167
2012	924,505	86,670	653,000	7.5	152
2013	813,111	152,225	1,142,500	7.5	127

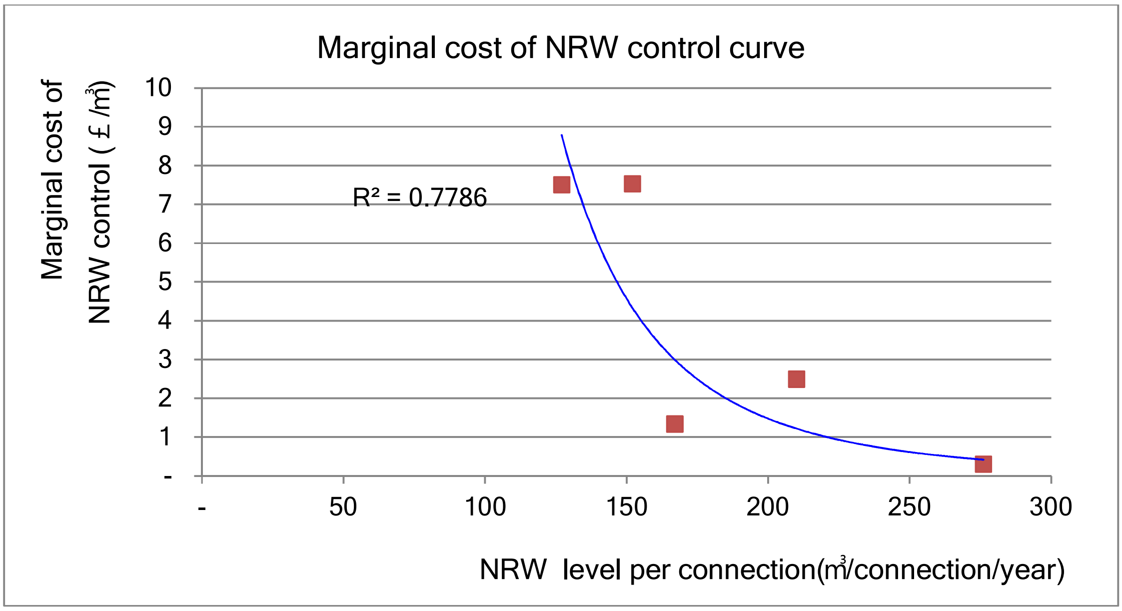


Figure 14 : Marginal cost of NRW control curve

2) Cumulative cost curve (Method 2)

The cumulative cost curve can be drawn into two ways according to the different X-axis values. X-axis of the first graph used the cumulative volume of the NRW reduction, and alternatively, the level of NRW per connection was employed. Commonly, cumulative cost of NRW reduction was used as a Y-axis. The components of cumulative cost curve are presented in Table 14. The Changes in NRW was estimated according to the Appendix B and the cumulative volume of NRW reduction was calculated by adding changes in NRW year by year. The NRW/connection was estimated by dividing annual NRW into number of connections. The cumulative costs of NRW control is shown in table 15. The cumulative cost curve A and B are illustrated in Figure 15 and 16.

Table 14 : Cumulative cost curve

Year	Changes in NRW	Cumulative Volume of NRW reduction	NRW/connection	Cumulative costs of NRW control
	m^3	m^3	m^3/connection/year	£ 1,000,000
2008	-	-	531	0.126
2009	1,355,325	1,355,325	276	0.538
2010	354,816	1,710,141	210	1.424
2011	234,522	1,944,663	167	1.738
2012	86,670	2,031,333	152	2.391
2013	152,225	2,183,558	127	3.534

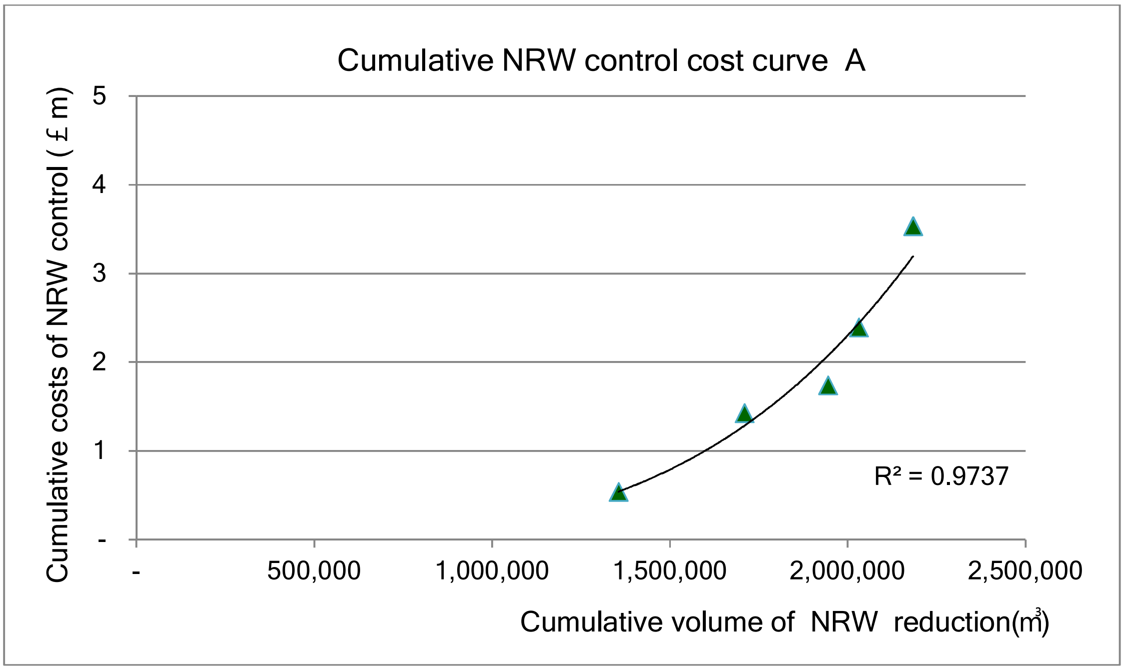


Figure 15 : Cumulative cost curve A

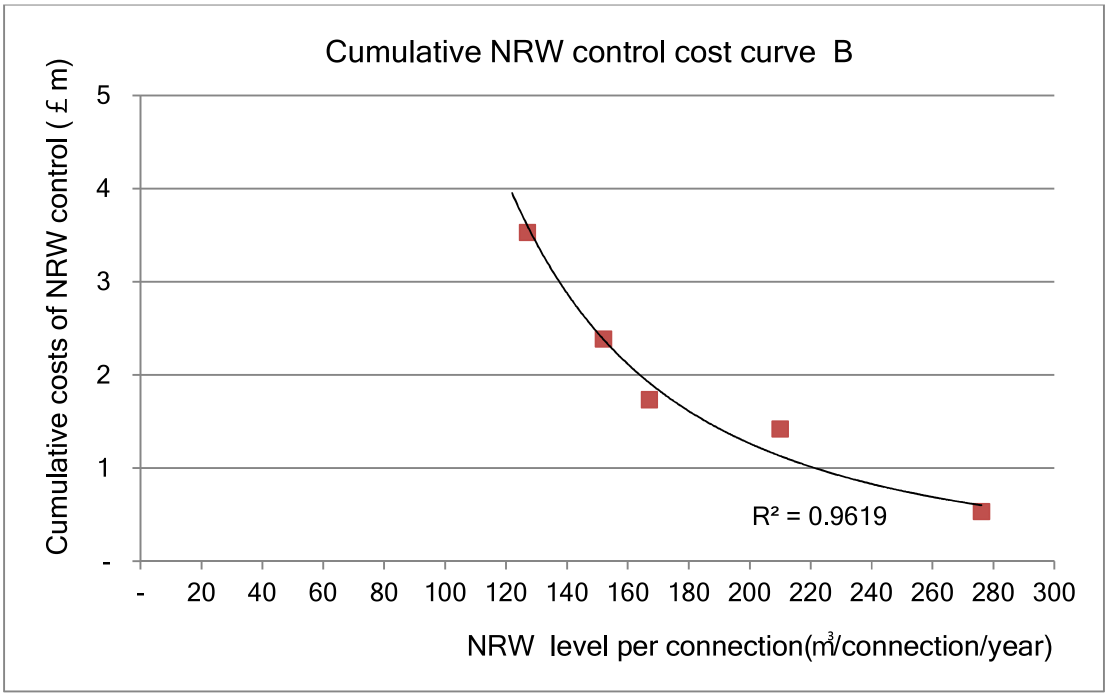


Figure 16 : Cumulative cost curve B

4.2.5.2 Reliability check

Among the two cost curves, the cumulative cost curve showed the best fit to data. Therefore, in this case study, the most economical level of NRW is estimated by the cumulative cost-benefit analysis (method 2).

4.2.5.3 Economic level of NRW calculation (Method 2)

1) Costs data

The NRW control costs in Danyang-gun between 2008 and 2013 are presented in Table 15. The Tabe 15 shows the annual costs for NRW reduction. Danyang-gun has tried to reduce NRW by using various methods which are shown in Table 15. Especially, Danyang-gun has focused on replacing water pipe and rehabilitation.

Table 15 : Cost data

Year		2008	2009	2010	2011	2012	2013
Cumulative Total costs (£)		125,500	537,500	1,424,000	1,738,000	2,391,000	3,533,500
Cost of NRW reduction (£)		125,500	412,000	886,500	314,000	653,000	1,142,500
	Pipe replacement and rehabilitation	1,000	152,500	400,500	77,500	460,000	939,500
	Old and faulty valve replacement	-	17,000	8,500	-	2,500	12,500
	Establishment of DMAs	-	-	228,500	30,000	2,000	-
	Water meter replacement	33,500	55,500	49,500	26,500	8,000	14,500
	Leakage Repair	30,500	100,000	106,500	90,500	88,000	79,000
	Leakage detection	60,500	87,000	93,000	89,500	92,500	97,000

2) Benefit data

The cumulative benefit of NRW reduction can be calculated from multiplying both the cumulative volume of NRW reduction and the marginal cost of water. The cumulative benefit of NRW reduction was expressed in Table 16. The marginal cost of water calculation is described successively.

Table 16 : Cumulative benefit of NRW reduction

Year	Cumulative Volume of NRW reduction (A)	Marginal cost of water (B)	Cumulative benefit of NRW reduction (A x B)
	m^3	(£)	(£ 1,000)
2008	-	-	-
2009	1,355,325	1.51	2,045
2010	1,710,141	1.51	2,581
2011	1,944,663	1.51	2,935
2012	2,031,333	1.51	3,066
2013	2,147,024	1.51	3,240

(1) Marginal cost of water

The marginal cost of water can be estimated as the sum of marginal operating costs plus marginal capital costs. It has been calculated using the 2013 data. The marginal cost of water was estimated to be £1.51/m^3 through the following calculation.

① Marginal operating costs

The components of marginal operating costs calculation is presented in Table 17. The marginal operating costs has been calculated through the Equation (3-1) described in section 3.3.5.2 and its costs were £0.08/ m^3.

Table 17 : Components of marginal operating costs in 2013

Components		Unit	Value
A	Annual volume of production	m^3/year	3,868,393
B	Annual volume of dam water	m^3/year	525,915
C	Annual volume of purchased bulk water	m^3/year	-
D	Pumping or Boosting costs	£	174,782
E	Water treatment costs	£	20,473
F	Sludge treatment costs	£	3,187
G	Usage charges of Dam water	£	13,227
H	Bulk water purchase costs	£	-

$$\text{Marginal operating costs} = \frac{D+E+F}{A} + \frac{G}{B} + \frac{H}{C} = £\ 0.08/\ m^3 \tag{4-1}$$

② **Marginal capital costs**

The marginal capital costs are calculated by dividing the sum of the present value of demand related investment into the present value of the growth in water demand over the time period. The discount rate for converting future investment into the present value of investment was assumed to be 5.2% according to the social discount rate (5.2~6.5%) of the Korea Development Institute report published in South Korea. The estimated value, (£9,782,499 and volume 6,827,836 m^3), through the following successive sections were used and its costs were estimated to be 1.43 £ / m^3 through Equation (3-2), as described in section 3.3.5.2.

$$\frac{\text{(a) Sum of present value of demand related investment}}{\text{(b) Present value of the growth in water demand}} =$$

$$\frac{9,782,499}{6,827,836} = £\ 1.43/\ m^3 \tag{4-2}$$

(a) Present value of demand related investment

Demand related to future investment and the present value of demand related future investment is given in Tables 18 and 19. The present value of investment, ￡9,782,499, in table 19 was used as a denominator in marginal capital costs calculation.

Table 18 : Demand related future investment

Items	Total	2015	2020	2025
Total(￡)	14,158,000	3,423,500	5,392,000	5,342,500
Reservoirs(￡)	94,500	-	-	94,500
Expansion of water main(￡)	12,797,000	3,181,000	4,953,000	4,663,000
Boosting station(￡)	369,000	20,500	100,000	248,500
Design costs(￡)	709,000	175,000	268,000	266,000
Supervision charge(￡)	188,500	47,000	71,000	70,500

Table 19 : Present value of demand related investment

-	Total	2015	2020	2025
Total investment(￡)	14,158,000	3,423,500	5,392,000	5,342,500
Present value of investment(￡)	**9,782,499**	3,093,420	3,781,288	2,907,741

(b) Present value of the growth in water demand

The present value of the growth in demand and the present value of no growth in demand are displayed in Table 20 and 21.

Table 20 : Present value of the growth in demand

Item	Total	2013	2014	2015	2016	2017	2018
Demand(m^3/d)	**284,023**	19,705	20,065	20,425	20,858	21,291	21,725
Demand(m^3/year)	**103,668,395**	7,192,325	7,323,725	7,455,125	7,613,243	7,771,361	7,929,479
Present value of Demand(m^3/year)	**77,054,542**	7,192,325	6,961,716	6,736,331	6,539,168	6,345,036	6,154,120
Item	2019	2020	2021	2022	2023	2024	2025
Demand(m^3/d)	22,158	22,591	22,741	22,891	23,041	23,191	23,341
Demand(m^3/year)	8,087,597	8,245,715	8,300,465	8,355,215	8,409,965	8,464,715	8,519,465
Present value of Demand(m^3/year)	5,966,574	5,782,533	5,533,202	5,294,391	5,065,669	4,846,623	4,636,854

Table 21 : Present value of no growth in demand

Item	Total	2013	2014	2015	2016	2017	2018
Demand(m^3/d)	**256,165**	19,705	19,705	19,705	19,705	19,705	19,705
Demand(m^3/year)	**93,500,225**	7,192,325	7,192,325	7,192,325	7,192,325	7,192,325	7,192,325
Present value of Demand(m^3/year)	**70,226,706**	7,192,325	6,836,811	6,498,870	6,177,633	5,872,274	5,582,010
Item	2019	2020	2021	2022	2023	2024	2025
Demand(m^3/d)	19,705	19,705	19,705	19,705	19,705	19,705	19,705
Demand(m^3/year)	7,192,325	7,192,325	7,192,325	7,192,325	7,192,325	7,192,325	7,192,325
Present value of Demand(m^3/year)	5,306,093	5,043,815	4,794,501	4,557,510	4,332,234	4,118,093	3,914,537

The present value of the growth in water demand over the time period can be calculated by deducting the present value of no growth in demand (70,226,706 m^3/year) from the present value of demand, (77,054,542 m^3/year). The difference between these two values, (6,827,836 m^3/year), was used as the numerator.

3) Cumulative cost-benefit curve

The economic level of NRW can be identified by adding cumulative benefit of NRW reduction curve which comes from table 15 and 16 into the cumulative cost curve. These data used in this analysis are real operational data collected and stored by K-Water. The two type of graph are illustrated in Figure 17 and 18.

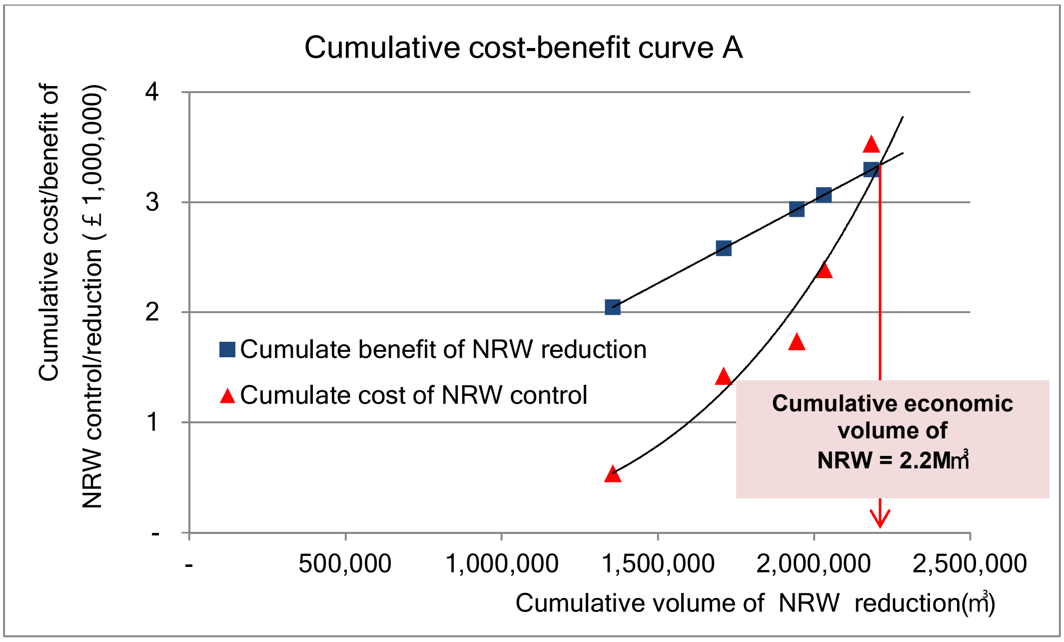


Figure 17 : Cumulative cost-benefit curve A

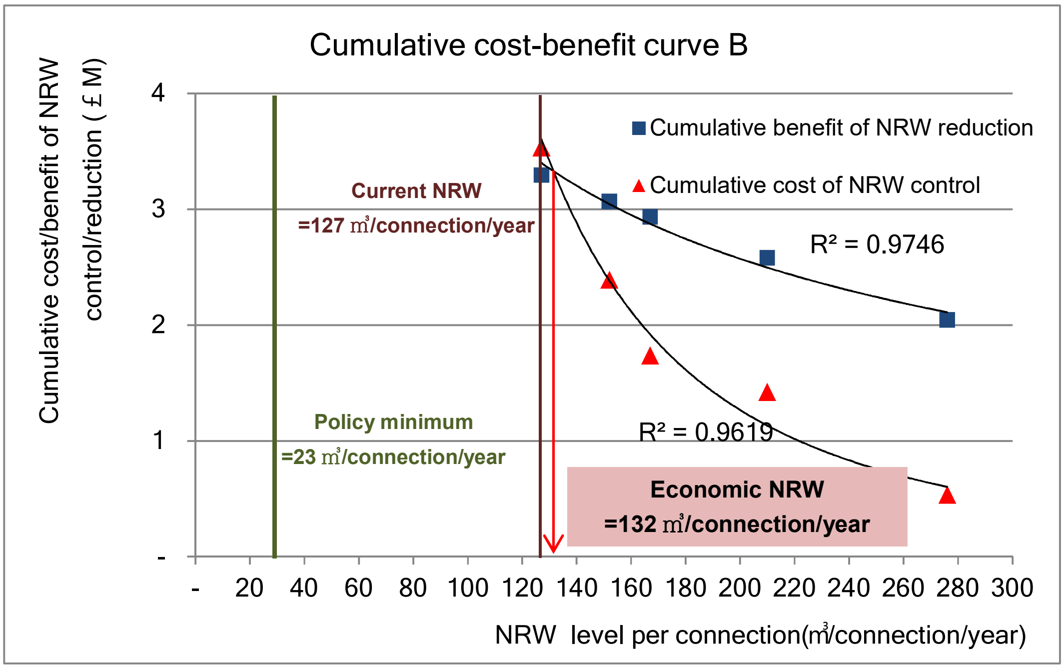


Figure 18 : Cumulative cost-benefit curve B

4) Optimal NRW level

The optimal NRW level can be identified by finding a point where the two curves meet. The calculated economic cumulative volume of NRW and the economic level of NRW are is 2.2 Mm^3/total and 132m^3/connection/year respectively. In this research, 132 m^3/connection/year was used for convenience.

4.3. Sensitivity analysis

Sensitivity analysis has been carried out to examine which factors would have the most impact on economic level of NRW level and how far the economic NRW level was changed. The results are summarized in Table 22 and shown in Figure 19.

Table 22 : Results of sensitivity test

Sensitivity Parameters	Economic level of NRW (m^3/connection/year)						
Value change	-15%	-10%	-5%	0%	5%	10%	15%
Volume of NRW(m^3/year)	145	140	136	132	128	125	121
Marginal cost of water(£ / m^3)	145	140	136	132	128	125	121
NRW control costs(£ M/year)	120	124	128	132	135	140	143
Connections	140	137	134	132	129	126	124

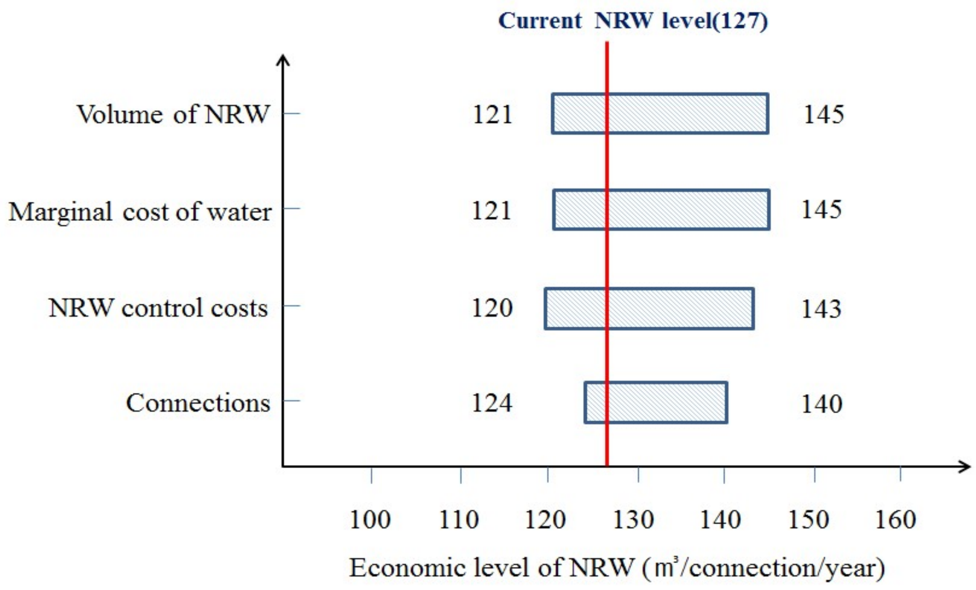


Figure 19 : Economic level of NRW sensitivity test

From the above results, both volume of NRW and the marginal cost of water were reduced by as much as 4m^3/connection/year at a steady rate when changes in parameters are applied. The NRW control costs, meanwhile, were increased at a similar rate to the volume of NRW and the marginal cost of water. The number of connections had a minimal impact on the level of NRW. Even though there is no significant governing factor affecting the economic level of NRW, this analysis demonstrates that economic NRW target can be set within the calculated limits actively or passively according to the financial conditions.

4.4 Setting NRW target

The optimal NRW levels were calculated by the cumulative cost-benefit analysis. The optimal level is 132m^3/connection/year. It should be noted the recent NRW level was recorded at 127m^3/connection/year by the end of 2013. It is illustrated with red line in Figure 17. This means the study area has already achieved the desirable NRW level. Therefore, it is recommended to maintain current NRW level and simultaneously to set this level as the optimal NRW level for this study area.

4.5. Summary

This chapter has presented the economic level of NRW calculation by applying the methodology developed in Chapter 3 to a case study. The cumulative cost-benefit analysis was selected as an evaluation method by cost curve reliability check. The estimated economic NRW level by cumulative cost-benefit analysis was 132 m^3/conn/year, which is beyond the current NRW level, 127m^3/connection/year. Thus, the NRW target of this case study can be set with maintaining current level but this needs to be reviewed when enough data is secured.

The sensitivity analysis attempted to identify the dominant factor and how far the economic NRW level changed. The results obtained by sensitivity analysis showed that all the parameters can affect to the economic NRW level to a similar extent, approximately ±4m^3/connection/year. Although it was impossible to identify the most influential factor, both lower and upper limits of the economic NRW level were determined

CHAPTER 5 SUMMARY AND CONCLUSION

5.1 Thesis Summary

What is the economically acceptable NRW level? Why do all the K-water projects have an identical NRW target in South Korea? This study has been conducted to address these questions. NRW reduction projects, which are being promoted by K-water, are to achieve 20% NRW within a short period (i.e. 5 or within 7 years). Over the last 11 years, there has been no discussion about whether 20% NRW is an economically reasonable and practical target, even though all the projects have shown different efficiency in NRW reduction.

Thus, this study was aimed at evaluating the current NRW level by developing a model for the calculation of the economic level of NRW and setting an economic NRW target. With this background, the literature review was conducted on both water loss management and Economic level of Leakage principles. Through the literature review, two methodologies were proposed; (1) Marginal cost analysis, and (2) Cumulative cost-benefit analysis. The first approach is commonly used method in the UK. The second method is newly developed allowing for the K-water business environment.

It should be noted that there was a difference in the way these methods have been applied. Methods 1 has basically been applied under steady state conditions (the state of maintaining NRW at a given level) using traditional active leakage control methods (i.e. monitoring, detecting, locating and pinpointing for repair). However, in this research, all the NRW control activities such as DMA installation, pipe replacement, and pressure management were considered at the same time. In that respect, a possibility of the application of those methods was examined through cost curve comparison in Chapter 4. Meanwhile, the method 2 was intended for integrating all the activities for NRW reduction. This is due to the fact that all the strategies for NRW reduction need to be adopted simultaneously to achieve 20% NRW within short period (i.e. 5years or 7years). This research was carried out based on this background.

Through the comparison of cost curve fitting in the Chapter 4, it was possible to determine the most suitable method. A case study area was determined to apply the chosen methodology from Chapter 3. The area, Danyang-gun, is a small city in South Korea with a population of approximately 30,000 and has managed its operation data by relating it to the NRW reduction systematically since 2008. In this research, the economic level of NRW was calculated through the cumulative cost-benefit analysis.

In the next stages, a sensitivity analysis was carried out to identify the most influential factor affecting the NRW level. This was followed by investigating, how changes in each component value from -15% to 15% can affect NRW level. Four main factors: volume of NRW, marginal cost of water, NRW control costs and number of connections were tested.

Finally, the estimated economic NRW level was compared with the current level to decide a reasonable target for the case study area. Since this study area has already achieved the desirable NRW level, it was recommended to maintain the current NRW level and simultaneously to set this level as the most optimal NRW level of this study area.

5.2 Summary of contributions

Economic leakage management is common in the UK but it has not been discussed nor investigated in South Korea until now. This study contributes to developing a change in attitude about economic NRW management in South Korea. The contributions of this study are described as follows:

- The newly developed methodology, cumulative cost-benefit analysis, enables water suppliers to evaluate economic NRW or leakage level with high reliability. Since this method uses cumulative values, it is less sensitive to data fluctuations. This leads to an acquisition of reliable results. Especially, it is useful to water systems that have a short data gathering period and rapidly growing systems where the number of connected customers changes substantially each year.

- This study suggests two types of calculation models for identifying economic NRW level. It is possible to apply them to various projects that could have a different business environment. Through the comparison with applied approaches, the most appropriate method can be selected and it can suggest the optimal NRW level. This allows water suppliers to select the most appropriate method and to estimate the most reliable NRW level for their system.

- Finally, this research contributes to managing water systems the most economically and efficiently by preventing overinvestment and focusing on optimal system operation. Ultimately, this would be beneficial to both water suppliers and customer in terms of budget savings, restraint of water rates and improvement of customer satisfaction.

5.3 Conclusions

The conclusions of this study are as follows:

Firstly, the Economic Level of NRW model developed and applied in this study shows the applicability to the South Korean water system as illustrated by the case study results. Because the new method uses cumulative data, data fluctuations due to the data records have less of an effect on the results. On the other hand, the UK model showed low reliability in cost prediction. The reason comes from the different investment methods for NRW control in the UK and South Korea. Water companies in the UK, because they have been managed economically and optimally, have maintained low costs to control NRW. In contrast, in the same 5-year period, South Korea has seen increased investment of about 40% of the overall project management costs resulting in systems that now have NRW level below the optimal one.

Secondly, the sensitivity analysis attempted to identify the dominant factor for NRW and how far the economic NRW level changed over time. The results obtained by sensitivity analysis showed that all the parameters can affect the economic NRW level to a similar extent, approximately ±4m^3/connection/year. Through the sensitivity analysis, both lower and upper limits of the economic NRW level were determined.

Thirdly, the comparison between the current project target and the calculated economic NRW level was made through this research. In many cases, optimal NRW level is lower than the current NRW level. However, the result of this study shows a similar level of the NRW target to the currently achieved. Hence, the relationship between the new model result and the current target needs to be confirmed by applying the methodology to other projects.

Lastly, another potential issue identified in this research is the difference between modelled economic NRW level and planned target of operation and management (O&M) contract. When the calculated economic level of NRW is much higher than the planned target or vice versa, a thoroughgoing review is needed whether current contract has to be changed or maintained in respect of cost-effective. This was not discussed in this study since this needs to be checked from an integrated point of view such as political, economic, social, technical, legislative and environmental factors.

5.4 Future work recommendations

The current study has attempted to apply a methodology commonly used in the UK and develop a new methodology for the South Korea water system. Since a large part of this study has been focused on evaluating the economic level of NRW, other related questions could not be dealt with fully due to the limitation of time. Specific recommendations for future research are described as follows:

1) It will be necessary to further test and validate the presented methods by applying it to various systems and operation conditions.

2) A method for systematic NRW related data collection and processing should be developed. This is because the calculation of economic level of NRW is data intensive and time consuming work.

3) The economic level of NRW can be an operational performance indicator. Although the economic NRW level was derived from the whole city level, without dividing into each DMA, if specific data for economic NRW calculation is available for small DMAs, it would be possible to use it as a performance indicator. This needs to be checked in the future.

4) Estimation standard for external social and environmental costs of NRW should be established. Recently, the averseness has increased that NRW has social and environmental dimensions. Although the externalities cannot greatly affect the economic level, this still needs to be considered.

5) In order to set up a long term NRW management plan, least cost planning method should be considered. The NRW management in the least cost planning is only a component for the supply/demand balance. This means the NRW management plan is treated more widely than the current marginal cost method. Furthermore, the least cost planning method contains a variety of factors influencing the supply/demand.

6) It is required to develop a NRW trend prediction method. Due to the short operation time, it was impossible to make a prediction of future trends in this study. The NRW reduction projects promoted by K-water are conducted under the fixed business time period. If a reasonable target or required time to meet the target become accurately estimated, it will be possible to allocate an exact budget and manage it to meet the target.

APPENDIX A

Data collection form

A.1 Components of economic level of NRW calculation

Table A- 1. Components of economic level of NRW calculation

	Basic data	NRW data
Data Collection	Number of DMAs Number of Connections Number of Properties Length of pipe Pressure Performance indicators	Annual Total Integrated Flow - System input volume - Billed authorized consumption - Unbilled authorized - Apparent losses
	Costs data	Benefits data
	Pipe rehabilitation, replacement Pressure management Valve install/replacement Water meter replacement Establishment of DMAs Own detection team operation Leakage repair costs All sorts of technical service	Bulk water purchase costs Pumping or Boosting costs Water and Sludge treatment Usage charges of Dam water Expansion of pipe diameter Construction of reservoir Construction of pumping station Construction of water treatment

A.2 Basic data

Table A- 2. Data form of Connection number, Property and Population

Year	2008	2009	2010	2011	2012	2013
Number of Connections						
Number of Property						
Population						

Table A- 3. Data form of distribution network information.

Year	2008	2009	2010	2011	2012	2013
Total pipe length (km)						
Water main (km)						
Communication pipe(km)						
Pressure(kgf/cm^2)						

Table A- 4. Performance indicators

Name	2008	2009	2010	2011	2012	2013
m^3/km/year						
m^3/km/day						
m^3/km/hour						
m^3/connection/year						
m^3/connection/day						
m^3/connection/hr						
l/connection/hr						
Current Annual Real Losses (m^3/year)						
Unavoidable Annual Real Losses (m^3/year)						
Infrastructure Leakage Index (ILI)						

A.3 NRW data

Table A- 5. Form of Total Integrated flow (Company or Water Resource Zone level)

Component	Volume(m^3/year)
System Input Volume	
1. Revenue Water	
(1) Build Authorized Consumption	
(a) Billed Metered Consumption(including water exported)	
(b) Billed Unmetered Consumption	
2. Non-Revenue Water(NRW)	
(2) Unbilled Authorized Consumption	
(c) Unbilled Metered Consumption	
(d) Unbilled Unmetered Consumption	
(3) Apparent Losses	
(e) Unauthorized Consumption	
(f) Customer Metering Inaccuracies*	
(4) Real Losses	

Table A- 6. Form of Total Integrated flow (Small DMA level)

Component	Volume(m^3/year)
System Input Volume	
Revenue Water	
Non-Revenue water	
Revenue water rate (%)	
Non-revenue water rate (%)	

A.4 Costs data

Table A- 7. Direct and Indirect costs for NRW reduction

Type	Activities	Contents
Direct costs	Pipe rehabilitation, Replacement	Old and deteriorated water pipe replacement Small-scale pipe replacement for leakage repair
	Pressure management	Pressure reducing valve instalment
	Water meter replacement	Water meter replacement
	Detection team operating cost (including detection service)	Salary, insurance, vehicle, fuels, Equipment costs Detection service costs
	Leakage repair costs	Leak repair costs
Indirect costs	Valve instalment /replacement	Old, non-working and leaking valve replacement
	Establishment of DMAs	DMAs establishment costs (including SCADA system costs)
	All sorts of technical service	Design and research service costs

A.4 Benefits data

Table A- 8. Benefit from NRW reduction

Type	Cost items	Contents
Operating Costs	Water purchase	Decrease in imported water from other water suppliers
	Pumping and boosting	Electric costs reduction for abstracting, producing and distributing water
	Water and sludge treatment	Chemical materials reduction for water treatment and sludge disposal
	Usage of dam water	Decrease in dam water abstraction charge
Capital Costs	New resources development	Deferment or cancellation of resource development
	Water pipe replacement	Deferment of pipe replacement or Quantity reduction
	Service reservoir	Deferment or cancellation of reservoir construction due to demand decrease
	Water pipe diameter enlargement	Deferment or cancellation of Water pipe enlargement

APPENDIX B

Changes in NRW

The "Changes in NRW" is a crucial factor not to be overlooked in the benefit calculation. Since cumulative benefit of NRW reduction is estimated by multiplying both the volume of NRW reduction over last year and the marginal cost of water. If the total volume of NRW is increased compared to the year before, due to the rise in connection numbers, the volume of NRW reduction, (compared to the previous year), would have minus value. This is the case even if NRW per connection has shrunk considerably because the rise in connections does not take this into account. Therefore, it is necessary to present a possible way to take into account increase in connection. Following Equation B-1 presents a possible way of factoring in this increase in connection:

Changes in NRW = (1) × (2)

(1) Connection number of last year

(2) NRW per connection of last year –this year (B-1)

ex) Changes in NRW in 2009 = (NRW/connection in 2008 – NRW/connection in 2009) × connection numbers in 2008

= (531-276) × 5,315 = 1,355,325

Table B- 1. Changes in NRW

Year	End of year NRW	Changes in NRW	Connection numbers	NRW/connection
	m^3/year	m^3	-	m^3/connection/year
2008	2,823,933		**5,315**	**531**
2009	1,481,187	**1,355,325**	5,376	**276**
2010	1,143,364	354,816	5,454	210
2011	962,643	234,522	5,778	167
2012	924,505	86,670	6,089	152
2013	813,111	152,225	6,414	127

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