A study on improving the approaches to set the economic level of water losses in water distribution system: A case study of South Korea

By

MOON, Hee-Keun

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Submitted to

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ABSTRACT

A study on improving the approaches to set the economic level of water losses in water distribution system: A case study of South Korea

By

Hee-keun Moon

The purpose of the research is to improve the methodologies for setting water losses targets applicable to local water supplies in South Korea. Recently, South Korea has been suffering serious water scarcity due to frequent droughts caused by climate change. Accordingly, Non-revenue water (NRW) reduction projects, given the uniform goals of NRW ratio either 15% or 20%, have been introduced as a countermeasure. The currently uniform water losses target does not take into account the different water supply conditions of local municipalities and should be revised with a proper rationale to determine the optimal water losses level.

Through the literature review, the standardized methodologies for economic leakage target widely used in international countries and new approaches of South Korea were reviewed. MCW method, which is regarded as an applicable approach considering domestic conditions and an alternative of cumulative method are considered for the application. While MCW method revealed limitations as a result of the case study, the alternative method was able to calculate the economic leakage standard. MCW method was especially sensitive to data quality, and it was found that a clear relationship between the leakage level and the cost is not feasible considering domestic data characteristics. In

addition, the effect of natural rate of rise of leakage and separation of effective NRW expenditure from total costs were identified as significant factors in calculating the leakage target. On the other hand, the cumulative method shows a more robust correlation than MCW, yielding the economic leakage target.

Through the case study, the cumulative method is demonstrated to be more suitable than the MCW method. And consideration of natural rate of rise of leakages and the social and environmental cost and benefits are proven to be significant elements of leakage calculations. In particular, it was confirmed that further research was required to estimate the natural rate of rise of leakage accurately, as the water losses target can be substantially lower. Besides, due to the effect of the previously established multi-area waterworks system in South Korea, it is likely to result in the less marginal cost of water. If the social and environmental aspects are taken into consideration, the high water losses level will lower and eventually contribute to efficient water management. Lastly, two cases of a short-term and long-term perspective have been considered, but further research is recommended to establish multiple water losses targets varying with time changes.

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I. Introduction

In 2015, the United Nations presented the Sustainable Development Goals (SDGs) for prosperity and peace of all humanity. SDG 6 is clean water and sanitation, which the UN reported that around half of the world's population is suffering from severe water scarcity due to excessive water use caused by rapid urbanization, socio-economic development, and increased water demand resulting from climate change (2019). In particular, the deterioration of water infrastructure will lead to a 30% loss of global water abstraction. Developing countries are likely to face a tremendous amount of leakage equivalent to water available for 200 million people per day and the United States, for example, will need 195 billion USD by 2040 to maintain the current status of water infrastructure (UNU-INWEH, 2017). Water should be managed in a sustainable manner, and leakage is a critical issue in terms of efficient water management because it can lead to water shortages and droughts (EU, 2015).

Tackling this water loss challenge, methodologies for assessing and establishing appropriate leakage levels in water distribution systems (WDSs) have been developed. For example, International Water Association (IWA) published the report in 1999 which provided a standardized approach to calculate water loss (LAMBERT et al., 2014). Water loss in WDSs can be expressed as Non-Revenue Water (NRW), which is the difference between the volume input to the water supply system and billed authorized consumption (Trow & Farley, 2004). In other words, NRW refers to the amount of water loss without collecting utility fees when supplied to customers. Besides, robust approach to estimate the optimal leakage level in terms of economic aspects, which is called Economic Level of Leakage (ELL), was developed in the United Kingdom. ELL is defined as "the point at which the cost of reducing leakage is equal to the benefit gained from further leakage reductions" (Tripartite Group, 2002) and now widely accepted as one of the key elements for leakage targets setting in EU and USA (US Environmental Protection Agency, 2016).

Leakage target based on ELL concepts should be determined first to reduce water loss. This is because the target affects the choice of leakage control strategies primarily (Trow & Farley, 2004) and enables shareholders to track the progress of leakage reduction. According to the EU Reference document (2015), the first recommendation for water loss management is leakage target setting and economic conditions with political, social, technological, legal and environmental aspects should be taken into consideration. In addition, the volumetric parameters based on NRW - "m^3/km mains/day" or "liters/service connection/day" - are useful for tracing leakage reduction. Currently in the UK, England water service regulation authority (Ofwat) requires water utilities to submit their leakage targets, which is grounded on ELL method in accordance with the environment.

In the case of South Korea, the water losses target has been set exclusively by the government without considering the economic, social, and environmental aspects. Recently, the Korean government launched NRW projects to modernize the aging local water supply system of 118 local municipalities by investing about 2.6 billion USD over 12 years (Korea Ministry of Environment, 2017). In this plan, the water losses target was determined as an identical 15% NRW ratio, which is NRW divided by the total water supply. Although both European countries and South Korea set the water losses target, the process of deriving targets shows the disparity.

Unified water losses goals and simple target process of South Korea, which do not take account of the different characteristics in water distribution networks like populations, water consumption, and service area, show limitations. In general, leakage control tends to be easily manageable, especially in a densely populated area with more consumers. Accordingly, different water losses targets should be set. A study by Kim and Choi (2018) also suggested that leakage targets for recent NRW projects should reflect the status of water infrastructure and the leakage level across regions.

In an effort to address the existing problem in measuring water losses target, several studies based on ELL have been conducted in Korea but with different approaches. The original report published by the UK proposed key principles and two formulas to elicit leakage-cost relationship curve, which is an essential element for ELL calculation. On the other hand, studies by K-water (2012) or Hwang, Choi, Lee, and KOO (2017) applied statistical techniques such as multivariate analysis to derive the leakage-cost relationship curve. In addition, Jang and Choi (2017) employed a new method based on an Artificial Neural Network (ANN) and enhanced the accuracy of output compared to multivariate analysis.

The preceding studies are meaningful in terms of improving inappropriate leakage target practice but varying methodologies depending on researchers failed to generate consistent and unified methodologies. Therefore, the purpose of this study is to explore how the ELL methodology can be applied to improve calculations of water losses target in Korea and to examine the appropriateness of the current water losses target.

This study consists of three main chapters. The first chapter, the literature review, will provide the theoretical background of ELL methodology and review recent research findings. In the second chapter, a case study will be implemented. ELL method will be applied to one of the cities managed by K-water to calculate and analyze its economic leakage target. The third chapter will include the implications derived through the case study. The results from the study will help K-water in establishing adequate strategic goals for future NRW projects and improving water supply efficiency. It will also provide useful information to water supply officials who need to set sustainable maintenance goals considering economic conditions, especially in the operational phase after the completion of the ongoing NRW projects.

II. Literature Review

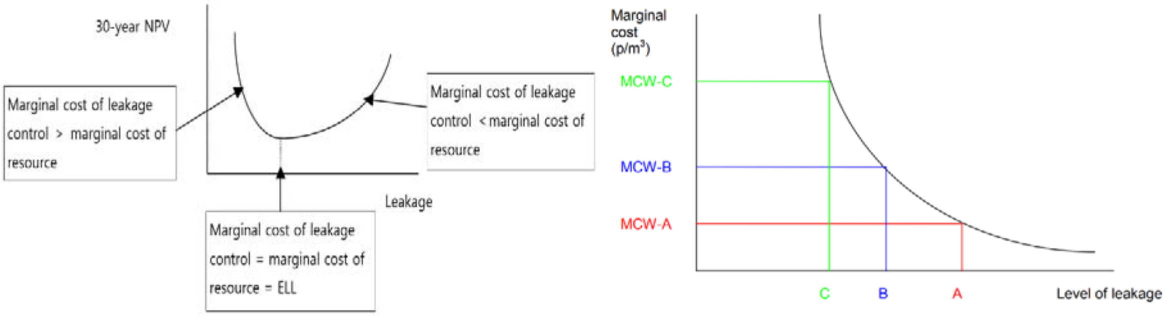
This chapter will review previous studies on methods for calculating ELL in the WDSs. The analysis is divided into three parts: the introduction of theoretical background regarding ELL methodology, recent achievements, and studies in South Korea.

2.1 ELL Methodology

Given that the level of leakage is considered as a key performance indicator for evaluating water utilities (Farley & Trow, 2003), Tripartite Group (2002) published a report to establish the key principles of ELL methods. The report presented two best practices for setting out the ELL target: Least Cost Plan (LCP) and Marginal Cost of Water (MCW). In addition, the report included the methods of deriving leakage-cost relationship, which is an essential part of ELL calculation.

LCP is defined as the approach to minimize net present value for managing water supply and demand balance over the long term of 25-30 years. When municipalities prepare a long-term water management plan, a development plan for new water source and leakage reduction programs should coincide with increasing water demand. Among diverse scenarios, the best option needs to be determined through a rigorous cost-benefit analysis. In the below graph, the lowest point represents ELL, which is the least cost option which can address water shortage problem in the future. If the city decides to lower the leakage than the ELL point, the total net present value cost will increase.

MCW can be used to find the optimal point of leakage level through comparing the marginal cost of obtaining additional water from leakage reduction and the marginal cost of obtaining water from the operating or developing new sources. In the below graph, MCW-A, which refers to the current operating cost for unit water production, resulted in a relatively high leakage level A. MCW-B and MCW-C could lower the leakage level because these costs reflect the additional cost for securing new water resources in order to address water shortage problems in the future. ELL could be determined at the interface between the leakage cost curve and MCW values in the MCW approach.



(a) Least Cost Plan (b) Marginal Cost of Water

Figure 2-1. Least Cost Planning – 30 year graph and Marginal cost of Water graph

Source: Tripartite Group report (2002)

For the above two approaches, calculating costs to reduce leakage is a fundamental component to deriving the leakage-cost relationship curve. To draw this curve, two methods are proposed by the report: Method A and Method B.

Method A can be achieved by adding the steady-state and transitional costs. Steady-state costs are the cost of maintaining leakage at a given level and transitional costs indicate the cost of moving from one level of leakage to another. To move the level of leakage, leakage reduction activities are necessary and transitional costs require investments. Steady-state equations consist of two key variables of policy minimum leakage and passive level of leakage, and the steady-state curve is asymptotic to policy minimum. Policy minimum is the lowest level of leakage achievable through reasonable leakage control efforts, while passive level means that the level of leakage with no active leakage controls only if water utilities responded to customer burst reports (Atkins, 2013).

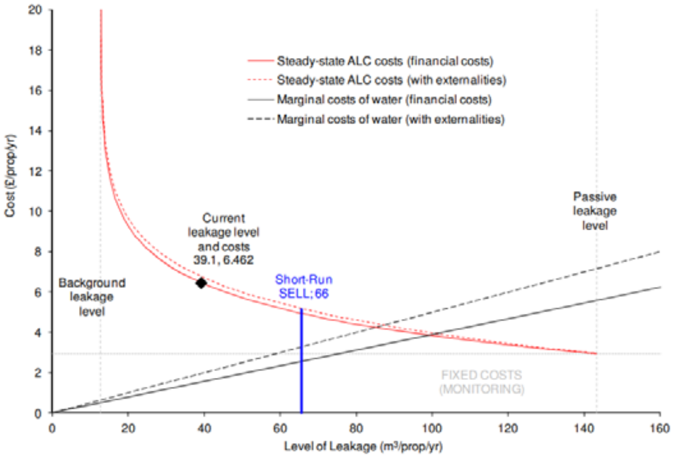


Figure 2-2: Leakage-cost relationship

Sources: Atkins (2013)

In the above graph, policy minimum, noted as background leakage level and passive level, are shown to be 12.67m^3/property/year and 143.27m^3/property/year, respectively. The transitional costs are based on real data from experiences and could be achieved from real leakage reductions activities of water utilities.

Method B uses the natural rate of rise (NRR) to estimate leakage-cost relationships. NRR is the rate that arises periodically when there is no active leakage detection. Common methodology to assess NRR is to compare the difference between pre- and post-leakage water flow. If this difference is large, it means that a leakage has occurred, which will increase the night flow that is usually low (United Utilities, 2018). However, leakage detection and repairs are unavoidable in operations due to customer complaints and it could complicate the calculations of NRR by changing the basic assumption that there are no leakage detection and repairs.

According to Environment Agency report (2012), water utilities in the UK preferred Method A but the report also stated that the selection between two methods should be made based on requirements of analysis. Sembcorp Bournemouth company followed Method A (ATKINS, 2013) but other water company with a considerable amount of operating data preferred Method B to improve the leakage-cost relationship (South East Water, 2017). The analytic continuum for evaluation with the same standards also seemed to affect the method determination. To sum, availability of data with high accuracy is a critical factor in selecting the models.

2.2 Applied Studies Regarding ELL Methodology

In this chapter, applied studies regarding ELL methodology will be reviewed to identify any significant improvements from the original concepts. As a result, the fundamental principles appear unchanged but additional considerations are recommended.

Pearson and Trow (2005) discussed the practical approach in determining ELL. Their research started with the underlying concept of ELL method that the increasing input in a leakage activity will lead to diminishing returns. The authors focused on the strategy to establish the economic balance between all activities, which requires an assessment of the benefit form proposed leakage reduction activities. The decision process with the priorities among the combination of leakage activities was suggested as a result.

The review report of ELL calculation by Environment Agency (2012) reported that reflecting social and environmental values in ELL is appropriate. ELL is a balance between the value of water and leakage reduction cost. An increase in the value of water should result in decreased leakage level but the correlation is inelastic. The reason is that the value of water mainly comes from operation cost, in which a large portion of cost is already fixed, regardless of water production change. Therefore, reflecting social and environmental externalities could contribute to solving the limitations and lowering the current leakage level. For instance, the leakage target for United Utilities lowered from roughly 100 m^3/prop/yr. to 85 m^3/prop/yr. by considering these externalities (2018).

The report also suggested that the method to assess these non-monetary values should be improved. Social and environment values comprise of ecological benefits by leakage reduction, carbon cost associated with electricity usage, and other related values. In terms of environmental benefits, water utilities showed the tendency to calculate benefits higher when the service area suffers from water deficit. The absence of systematic and detailed guidelines account for the differences.

The rationale for externalities looks valid but the practical methods should be developed fully in prior to taking into consideration. Regarding estimation constraints in social and environmental values, this study did not fully cover.

2.3 ELL Studies in South Korea

A number of studies have been conducted in an effort to seek the optimum leakage level of Korea in WDSs based on ELL methods. Among the two approaches described above, MCW approach was commonly found in papers, whereas LCP was not preferred in Korea. The reason is that LCP, as a long-term plan over 25 to 30 years, is likely to face challenges like estimation uncertainties for future water demand and data collection. Concerning leakage-cost relationship, various statistical techniques, such as regression, multi-regression, and artificial neural network, are employed in Korea's research as well as modified marginal cost curve equation instead of Method A and B due to differences in data availability. Statistical techniques look more suitable for Korea's cases to derive the regression curve when conditions contain multiple variables. Detailed findings of studies are summarized as follows.

K-water (2012) attempted to derive leakage-cost relationships by using accumulated operating data of 17 cities from 2006 to 2011 through regression analysis. The Pearson correlation coefficient of the curve between leakage level and required costs was 0.3839 because 17 cities had different characteristics in terms of population, water consumption, pipe lengths, among others. The results illustrated that data classification is crucial to reach a high level of accuracy.

The study by Hwang, Choi, Lee, and Koo (2017) identified the leakage-cost relationship by adapting multi-regression analysis. In particular, the comprehensive leakage strategy using multiple measures, such as old pipe replacement, leakage detection, and water pressure management, was applied simultaneously to the study site. Therefore, a multi-regression method was chosen as the best option to deduce the relations curve of each method. After statistical analysis, three resulting cost equations were combined and utilized by the sequence of cost-effectiveness. The most beneficial measure with a comparably small cost was used as a priority. The study's limitations included the lack of accurate data.

Similarly, Jang and Choi (2018) performed a study using Artificial Neural Network (ANN). As a result, 21% higher reliability was observed compared to the previous two studies in terms of R^2. Through the review of three studies, one can observe that the three cases have inherent limitations, which are insufficient data and the resulting low reliability. Although the statistical approach proceeded to address existing restraints, the statistical significance of the leakage cost equation remains problematic.

A study by Lim (2015) can be distinguished from the previous studies in this regards. His research focused on the derivation of ELL method by using the newly developed method of cumulative curve. An alternative approach defined as a cumulative method was designed to minimize data fluctuation and increase the reliability of curve estimation. However, it also left a room for further tests on the validity owing to deficient six years' data. Furthermore, the newly attempted method needed to be proved in District Metered Area (DMA), with the execution of LCP.

Several studies in Korea applied different methods to induce the leakage-cost relationship. This disparity could be interpreted as the different business structures between Korea and UK in WDSs. Privatized water utilities in the UK take long-term and stepwise strategies for leakage reduction in the pursuit of minimizing total expenditure, whereas Korea is guided by the government's short-term mandates. Consequently, the cost curve tends to increase in proportion to the decrease in the leakage level. On the contrary, mixtures of various strategies in Korea blur the causality between investments and its effect. This difference seems to be attributed to the increase in segregated methods of calculating ELL in Korea.

III. Case study

In this chapter, conventional MCW method and an alternative cumulative method reviewed in literature review were applied to Jeongeup city, which is managed by K-water to eventually find water leak target. Jeongeup is chosen given that it is second oldest NRW reduction project site for K-water, which enables the research to collect data over 14 years.

The target areas consist of Jeongeup and Jangmyeong area. Jangmyeong is the downtown of Jeongeup city and the process of calculating the water losses target is shown in Figure 3-1 below.

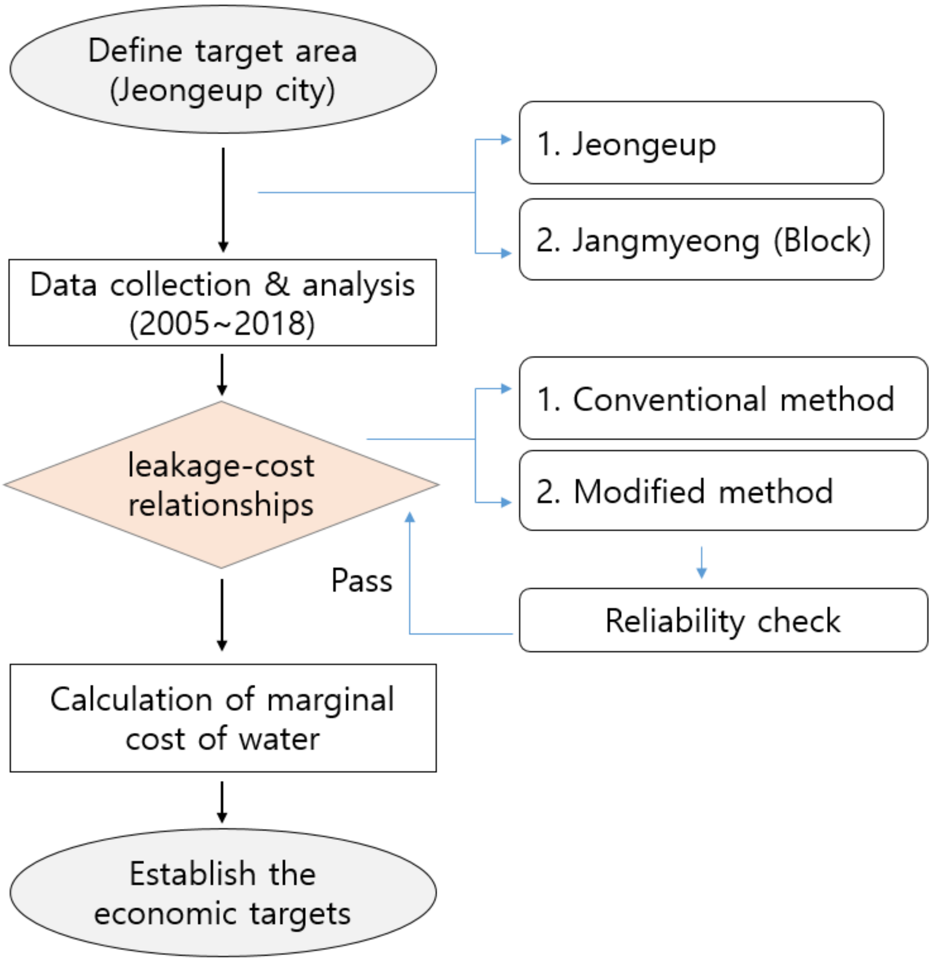


Figure 3-1: ELL Calculation Process

3.1 Status of Target Areas

Jeongeup is a city located in the southwestern part of Jeongbuk Province, with a population of approximately 116,000 and an area of 692.91m^2 as of 2017 (Statistical year book of Jongeup, 2018). The water supply system in Jeongeup was commissioned by K-water in 2005 to reduce production costs and improve operation efficiency by increasing the Revenue Water Ratio (RWR), and total project cost was roughly 109.9 billion won. The project's objective was to improve the initial RWR of 52.1% in 2005 to 80% by 2009, and maintain this by 2024. The RWR as of 2018 is 81.3%.

The purified water from Seomjingang multi-regional waterworks distributed to service area of Jeongeup through 11 distribution tanks and pipelines are shown in Table 3-1 and Figure 3-2 below. In addition, the water service areas are divided into 33 small blocks for water leakage management.

Table 3-1

Water Facilities Status of Jeongeup City

Year	Average water supply (㎥/day)	Distribution reservoirs	Pumping Stations	Pipe lengths (km)	Service connections
2017	39,107	11	22	1,448	43,363

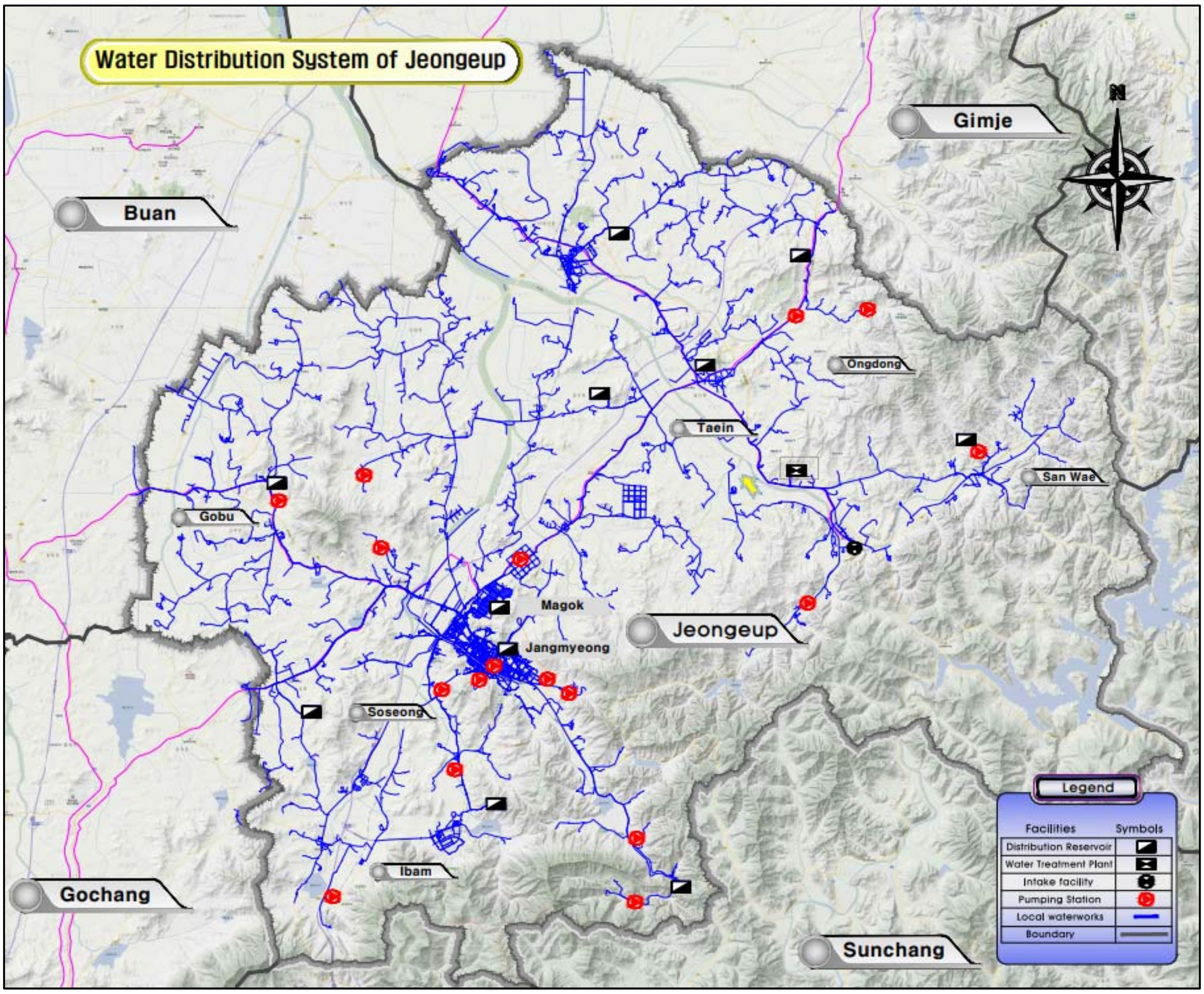


Figure 3-2: Water Distribution System of Jeongeup City

3.2 Data collection and Analysis

Operational data was collected for a total of 14 years from 2005 to 2018 in order to calculate the optimal leakage target. The collected data includes water balance and number of service connections, pipe lengths, NRW quantity, rehabilitation and operational costs (K-Water).

The current status of the RWR ratio and NRW for each year is shown in Table 3-2 below.

Table 3-2

Annual Water Balance

Component	Total Volume (thousand ㎥/year)						
	2005	2006	2007	2008	2009	2010	2011
Revenue Water Ratio (b/a, %)	51.2	63.2	69.9	79.4	81.5	80.4	80.9
- System Input (a)	16,094	13,413	12,327	10,815	10,779	11,560	11,943
- Revenue Water (b)	8,234	8,475	8,622	8,589	8,780	9,295	9,664
- Non-Revenue Water (NRW, a-b)	7,860	4,938	3,705	2,226	1,999	2,265	2,280

Component	Total Volume (thousand ㎥/year)						
	2012	2013	2014	2015	2016	2017	2018
Revenue water ratio (b/a, %)	80.6	80.7	81.0	80.7	80.9	81.1	80.7
- System Input (a)	12,584	13,507	13,374	13,805	14,223	14,274	14,963
- Revenue Water (b)	10,138	10,903	10,830	11,143	11,513	11,580	12,080
- Non-Revenue Water (NRW, a-b)	2,446	2,603	2,544	2,662	2,710	2,694	2,884

Note. From K-water

A volumetric indicator such as m^3/connections/year is required to assess the leakage status every year. Service connections and pipe lengths by year were collected for the calculation of the indicators, and the data were organized as shown in Table 3-3 below.

Table 3-3

Annual Status of Service Connections and Pipe Lengths

Component	2005	2006	2007	2008	2009	2010	2011
Service connections	29,765	30,801	31,734	32,540	33,839	35,702	36,836
Total pipe lengths(km)	962	1,042	1,110	1,191	1,422	1,463	1,531
- main pipe(km)	562	616	666	717	829	883	914
- service pipe(km)	400	426	444	474	593	580	617
Component	2012	2013	2014	2015	2016	2017	2018
Service connections	38,073	39,620	41,308	42,776	43,659	43,799	43,876
Total pipe lengths(km)	1,600	1,657	1,731	1,784	1,820	1,851	1,873
- main pipe(km)	944	960	1,002	1,028	1,044	1,053	1,058
- service pipe(km)	656	697	729	756	776	798	815

Note. From K-water

Two types of leakage indicators were calculated from Table 3-2 and Table 3-3. According to Lambert (2014), IWA recommends ‘per connection’ is more appropriate when connections/km is larger than 20, which means most of leakage occurs in the service connection. On the contrary, ‘per km’ is suitable if connections/km are less than 20. The target areas of the research were a mixture of urban and rural areas, and because of that, two types of leakage indicators were assessed. As the result shows at least 40 per connection/km, m^3/connection/year is applied. Although the leakage level shows gradual decrease over the operating period, as shown in Table 3-4 below, leakage increase compared to the previous years was identified in the year 2010, 2012, 2013 and 2018.

Table 3-4

Annual Leakage Indicator

Leakage Indicator	2005	2006	2007	2008	2009	2010	2011
Revenue water ratio(%)	51.2	63.2	69.9	79.4	81.5	80.4	80.9

㎥/km/day	22.4	13.0	9.1	5.1	3.9	4.2	4.1
㎥/connection/year	264.1	160.3	116.7	68.4	59.1	63.4	61.9
connection/km	53	50	48	45	41	40	40
Leakage Indicator	2012	2013	2014	2015	2016	2017	2018
Revenue water ratio(%)	80.6	80.7	81.0	80.7	80.9	81.1	80.7
㎥/km/day	4.2	4.3	4.0	4.1	4.1	4.0	4.2
㎥/connection/year	64.3	65.7	61.6	62.2	62.1	61.5	65.7
connection/km	40	41	41	42	42	42	41

Note. From K-water

The total expenses of the rehabilitation and operation for each year are summarized in Table 3-5 below. Investing costs are categorized according to project stage as two phrase: increasing RWR to 80% (from 2005 to 2009) and maintaining 80% of RWR (2010-2018). While average 8.1 billion won was executed annually by introducing a block system, replacing old pipes and modernizing old facilities, 1.2 billion was invested on average by replacing small parts of old pipes and repairing leakages. In the table, old system and facility modernization costs mean the establishment of a block system, the improvement of aging old facilities and devices like flow meters in distribution tanks and others. Others refer to expenses that do not occur regularly, such as vehicle purchase cost, replacement cost of old valves, and other service cost.

Table 3-5

NRW Reduction and Maintenance Cost of Jeongeup (2005~2018)

Component	2005	2006	2007	2008	2009	2010	2011
Total cost(Million won)	7,077	5,071	10,481	11,520	6,028	1,204	845
- Pipe replacement/ rehabilitation	3,753	2,877	7,752	9,218	5,207	735	417

- Old System/facilities modernization	1,757	1,012	1,929	1,158	278	149	71
- Water meter replacement	569	169	147	543	248	212	225
- Leakage detection/repair	6	-	180	273	139	55	128
- Others	992	1,012	473	328	156	52	3

Component	2012	2013	2014	2015	2016	2017	2018
Total cost(Million won)	631	734	795	1,783	1,416	1,638	1,310
- Pipe replacement/ rehabilitation	250	-	432	812	587	755	625
- Old System/facilities modernization	-	97	136	529	500	183	85
- Water meter replacement	227	507	98	275	120	393	320
- Leakage detection/repair	155	130	129	131	191	285	248
- Others	-	-	-	36	18	22	32

Note. From K-water

3.3 Leakage-cost Curve

3.3.1. Jeongeup leakage-cost curve

The NRW reduction marginal costs were calculated based on the previous data collection and analysis, and the results are shown in Table 3-6. For 2010, 2012, 2013 and 2018, amount of leakage had increased compared to previous years and it led to negative NRW change, Marginal cost of NRW control.

In addition, two different indicators like RWA as percentage parameter and NRW as volumetric parameter show similar treads but some differences were discovered as well. For example, from 2012 to 2013, RWR of % indicator increased 0.1%, indicating leakage reduction. But the volumetric unit of m^3/connection increased by 1.4 m^3/connection, revealing the opposite result that can be interpreted as 2.2% leakage increase.

Table 3-6

Annual Marginal Cost of NRW Control (Jeongeup)

Year	Service Connections (a)	NRW (㎥/year) (b)	Leakage Indicator		NRW change (10^3 ㎥/year) (d, $(c_n-c_{n+1})xa_n$)	NRW control cost (10^6 won) (e)	Marginal costs of NRW control (f, e/d)
			NRW / Connections (c, b/a)	Revenue Water Ratio(%)			
2005	29,765	7,859,579	264.1	51.2	-	7,077	-
2006	30,801	4,937,687	160.3	63.2	3,088	5,071	1.6
2007	31,734	3,704,815	116.7	69.9	1,342	10,481	7.8
2008	32,540	2,225,911	68.4	79.4	1,534	11,520	7.5
2009	33,839	1,999,360	59.1	81.5	303	6,028	19.9
2010	35,702	2,264,871	63.4	80.4	-147	1,204	-8.2
2011	36,836	2,279,597	61.9	80.9	55	845	15.2
2012	38,073	2,446,390	64.3	80.6	-87	631	-7.2
2013	39,620	2,603,283	65.7	80.7	-55	734	-13.3
2014	41,308	2,544,235	61.6	81.0	163	795	4.9
2015	42,776	2,661,794	62.2	80.7	-26	1,783	-68.0
2016	43,659	2,709,629	62.1	80.9	7	1,416	203.2
2017	43,799	2,694,330	61.5	81.1	24	1,638	68.5
2018	43,876	2,883,504	65.7	80.7	-184	1,310	-7.1

The leakage-cost relation curve graph was prepared using leakage indicator as x-axis and the marginal cost of NRW control as y-axis in Table 3-6, and the results are shown in Figure 3-3. In general, the lower leakage level tends to result in higher marginal cost of NRW control. Similarly, the leakage level around 60m^3/connection/year shows a higher cost than 160m^3/connection/year in the below graph.

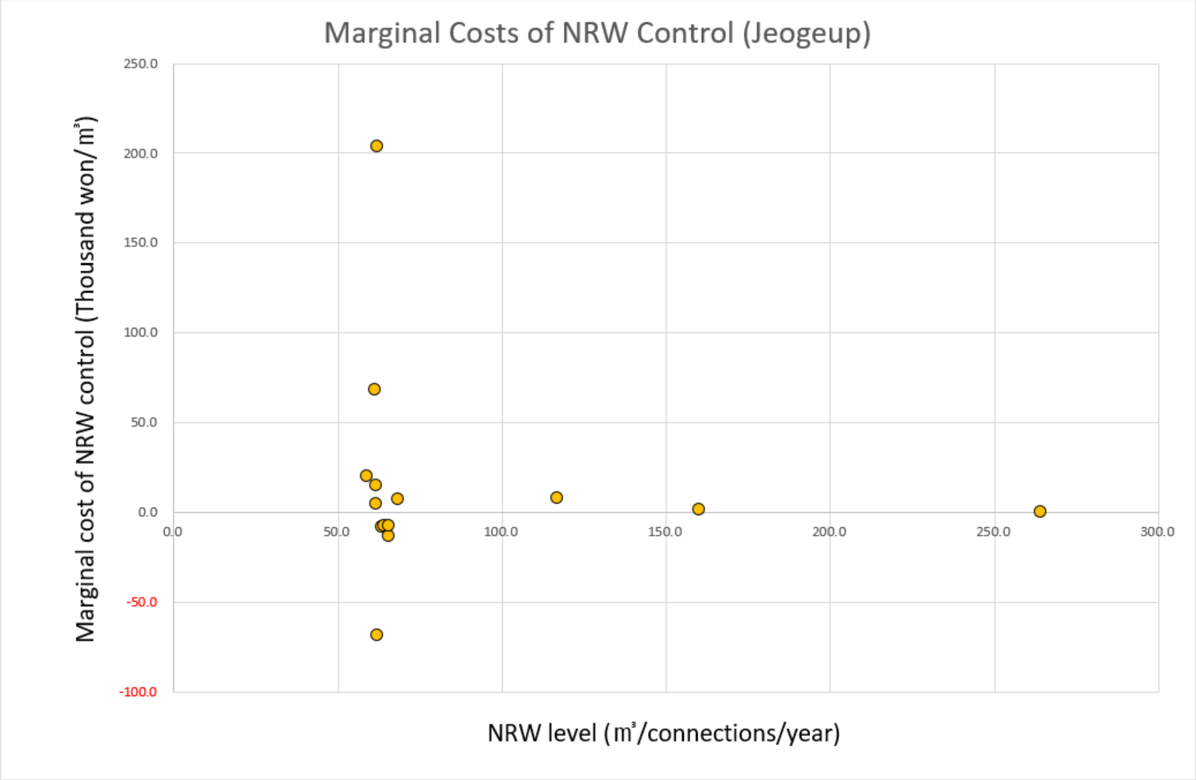


Figure 3-3. Marginal Cost of NRW Control Curve (Jeongeup)

The graph shows some limitations like negative observations and data fluctuation even on similar leakage level. First, regarding deviations of marginal costs of NRW control, it varies greatly from - 68,000 won/m^3 to 203,000 won/m^3 even though leakage level is similar around 62 m^3/connection/year. The increased NRW control cost since 2015 accounted for these deviations. As it can be seen in Table 3-5, after the consequential water quality accident occurred in Jeongeup in 2014, the cost of replacing old pipes roughly doubled compared to the previous year. However, the leakage decrease was not proportional to cost growth, resulting in an increase of marginal cost of NRW control. Secondly, in 2010, 2012-2013, 2015 and 2018, despite leakage reduction activities, leakage quantity exceeded the previous leakage volume, resulting in negative leakage changes. It is assumed that the reason for the leakage increase is due to the natural rate of rise of leakage.

To address the problems, in maintenance phase (2010-2018) only leakage detection and repair cost was reflected, excluding replacement cost of deteriorated pipes, which is deemed to have little impact on increasing RWR. In addition, the negative values are removed and the final graph is shown in Figure 3-4. In consequence, the determination coefficient (R^2) of the regression equation is calculated as 0.79. For generalization, it is believed that this approach leaves room for improvement, including sufficient data collection and additional verification of methods.

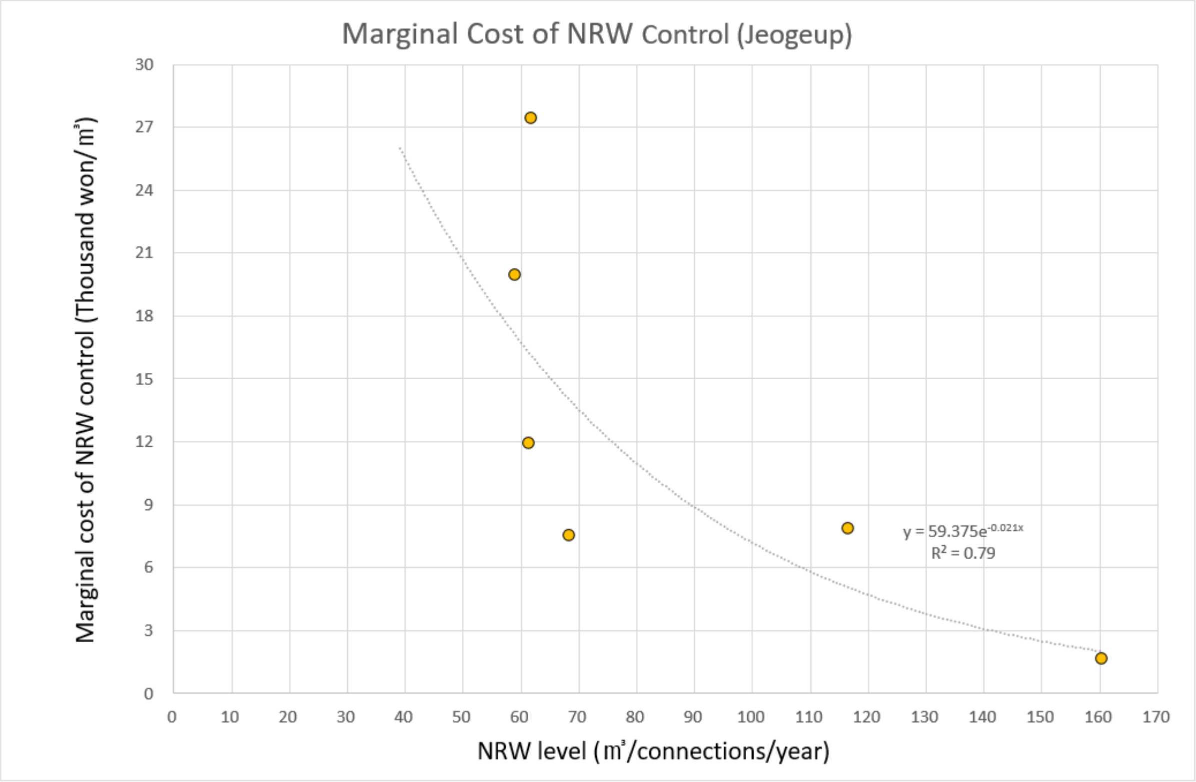


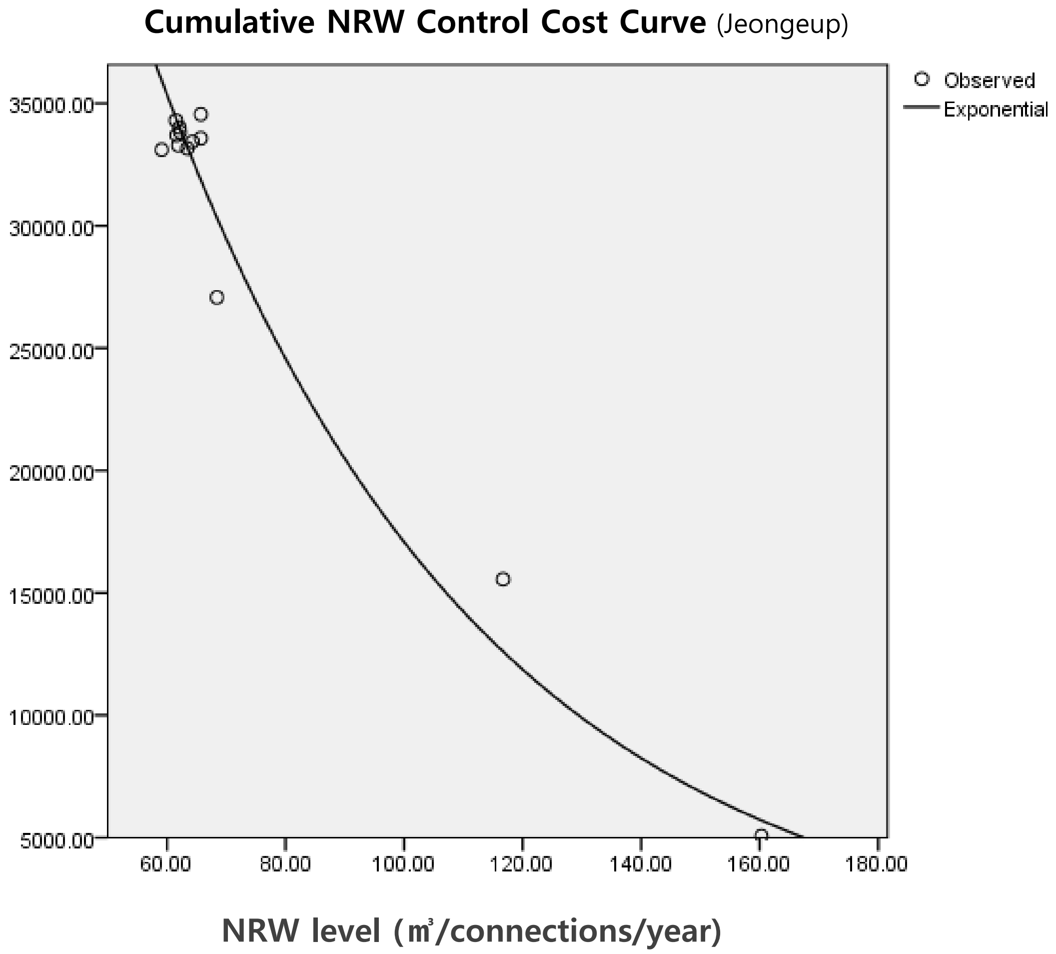
Figure 3-4. Modified Marginal Cost of NRW Control Curve (Jeongeup)

Besides, alternative method defined as cumulative method proposed by Lim (2015) is also tested. The calculation of cumulative NRW control cost, which is the value of the y-axis, are shown in Table 3-7. A regression analysis based on Table 3-7 is shown in Figure 3-5. The coefficient of determination (R^2) for the calculated regression equation was 0.975, which means that the NRW level are able to explain the change of cumulative cost approximately 97%. And this regression formula was found to be statistically significant because a significant level is below 0.05.

Table 3-7

Cumulative NRW Control Cost(Jeongeup)

Year	Service Connections (a)	NRW (㎥/year) (b)	Leakage Indicator		NRW control cost (10^6 won) (e)	Cumulative NRW control cost (10^6 won) (f)	Remark
			NRW / Connections (c, b/a)	Revenue Water Ratio(%)			
2005	29,765	7,859,579	264.1	51.2	-	-	NRW reduction stage
2006	30,801	4,937,687	160.3	63.2	5,071	5,071	
2007	31,734	3,704,815	116.7	69.9	10,481	15,551	
2008	32,540	2,225,911	68.4	79.4	11,520	27,071	
2009	33,839	1,999,360	59.1	81.5	6,028	33,100	
2010	35,702	2,264,871	63.4	80.4	55	33,155	NRW maintenance stage
2011	36,836	2,279,597	61.9	80.9	128	33,283	
2012	38,073	2,446,390	64.3	80.6	155	33,437	
2013	39,620	2,603,283	65.7	80.7	130	33,567	
2014	41,308	2,544,235	61.6	81.0	129	33,696	
2015	42,776	2,661,794	62.2	80.7	131	33,828	
2016	43,659	2,709,629	62.1	80.9	191	34,018	
2017	43,799	2,694,330	61.5	81.1	285	34,303	
2018	43,876	2,883,504	65.7	80.7	248	34,552	



Model Summary and Parameter Estimates

Dependent Variable: Cumulative NRW Control Cost

Equation	Model Summary					Parameter Estimates	
	R Square	F	df1	df2	Sig.	Constant	b1
Exponential	.975	435.678	1	11	.000	105239.126	-.018

The independent variable is NRW level

Figure 3-5. Regression Analysis of Cumulative NRW Control Cost Curve (Jeongeup)

3.3.2. Jangmyeong leakage-cost curve

The leakage-cost curve for Jangmyeong was drawn in the same way as before. The analysis period was determined from 2010 to 2017, considering securing stable data collection after the installation of the block system in 2007. The cost was estimated by reflecting a number of leakage detection and repair for each year in Jangmyeong. The calculated marginal cost of NRW control and graphs are shown in Table 3-8 and Figure 3-6 below.

Table 3-8

Annual Marginal Cost of NRW Control (Jangmyeong)

Year	Service Connections (a)	NRW (㎥/year) (b)	Leakage Indicator		NRW change (10^3 ㎥/year) (d, $(c_n-c_{n+1})xa_n$)	NRW control cost (10^6 won) (e)	Marginal costs of NRW control (f, e/d)
			NRW Connections (c, b/a)	Revenue Water Ratio(%)			
2010	8,748	569,046	65.0	81.9	-43	68	-1.6
2011	8,991	572,595	63.7	82.3	12	90	7.6
2012	9,196	540,688	58.8	83.0	44	98	2.2
2013	9,357	503,953	53.9	84.3	45	107	2.3
2014	9,552	465,272	48.7	85.5	48	108	2.2
2015	9,789	461,193	47.1	86.0	15	122	7.9
2016	9,941	425,839	42.8	87.3	42	116	2.8
2017	10,054	382,709	38.1	88.3	47	71	1.5

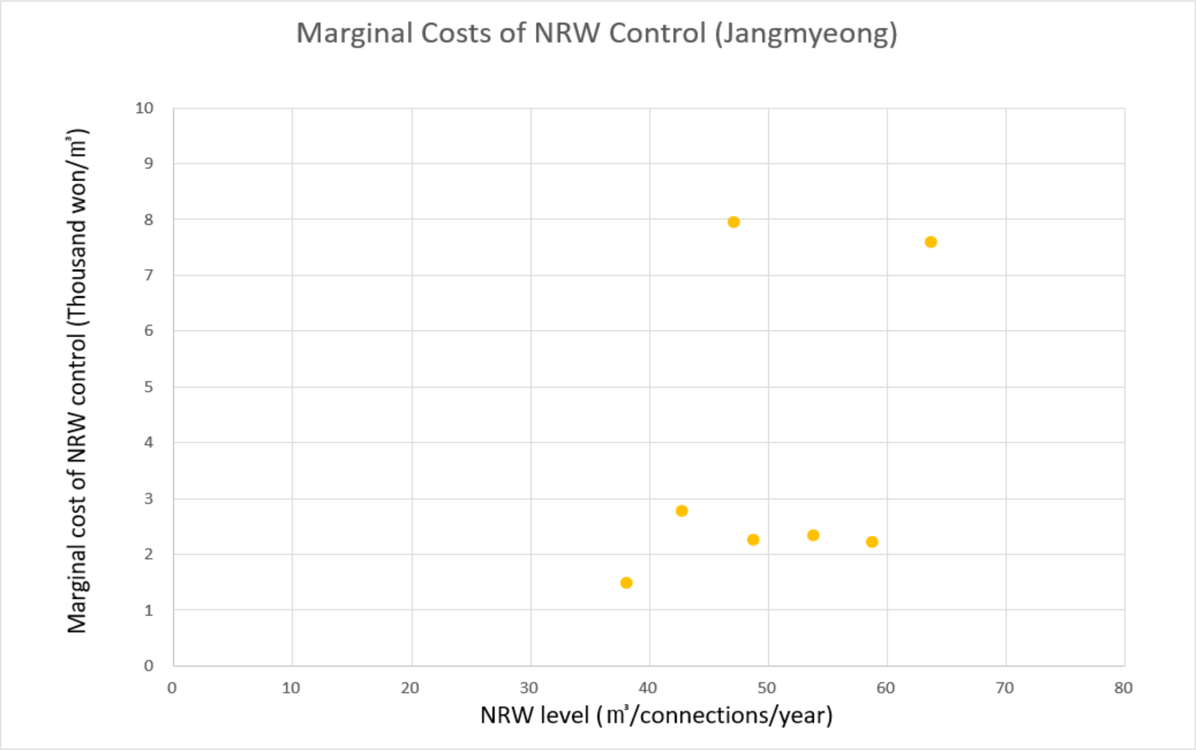


Figure 3-6 Marginal cost of NRW control curve (Jangmyeong)

As seen in the graph, it was not clear to verify the explicit relationship between two variables such as NRW level and marginal cost. Generally, the cost tends to grow with the decrease of NRW level but the result did not show this expected pattern. The reason seemed that the NRW level changes from 38 m^3/connection/year to 64 m^3/connection/year, are not significant, unlike Jeongeup. Additionally, the reason for the large variation of data is the volume of leakage repairs. In other words, if the number of leakage is high and the repaired leakage quantity is relatively low, it will result in the high marginal cost. This limitation is able to be overcome with data analysis over a long period of time.

Table 3-9 shows the variables for applying a cumulative method. The results of regression analysis based on the Table 3-9 data are shown in Figure 3-7. R^2 was high as 0.944 and a significant level is below 0.05, indicating the regression equation is statistically significant.

Table 3-9

Cumulative NRW Control Cost (Jangmyeong)

Year	Service Connections (a)	NRW (㎥/year) (b)	Leakage Indicator		NRW change (10^3 ㎥/year) (d, $(c_n-c_{n+1})xa_n$)	NRW control cost (10^6 won) (e)	Cumulative NRW control cost (10^6 won) (f)
			$\frac{\text{NRW}}{\text{Connections}}$ (c, b/a)	Revenue Water Ratio(%)			
2011	8,991	572,595	63.7	82.3	12	90	90
2012	9,196	540,688	58.8	83.0	44	98	188
2013	9,357	503,953	53.9	84.3	45	107	294
2014	9,552	465,272	48.7	85.5	48	108	402
2015	9,789	461,193	47.1	86.0	15	122	524
2016	9,941	425,839	42.8	87.3	42	116	639
2017	10,054	382,709	38.1	88.3	47	71	710

Model Summary and Parameter Estimates

Dependent Variable: Cumulative NRW Control Cost

Equation	Model Summary					Parameter Estimates	
	R Square	F	df1	df2	Sig.	Constant	b1
Exponential	.944	83.914	1	5	.000	19203.997	-.080

The independent variable is NRW level

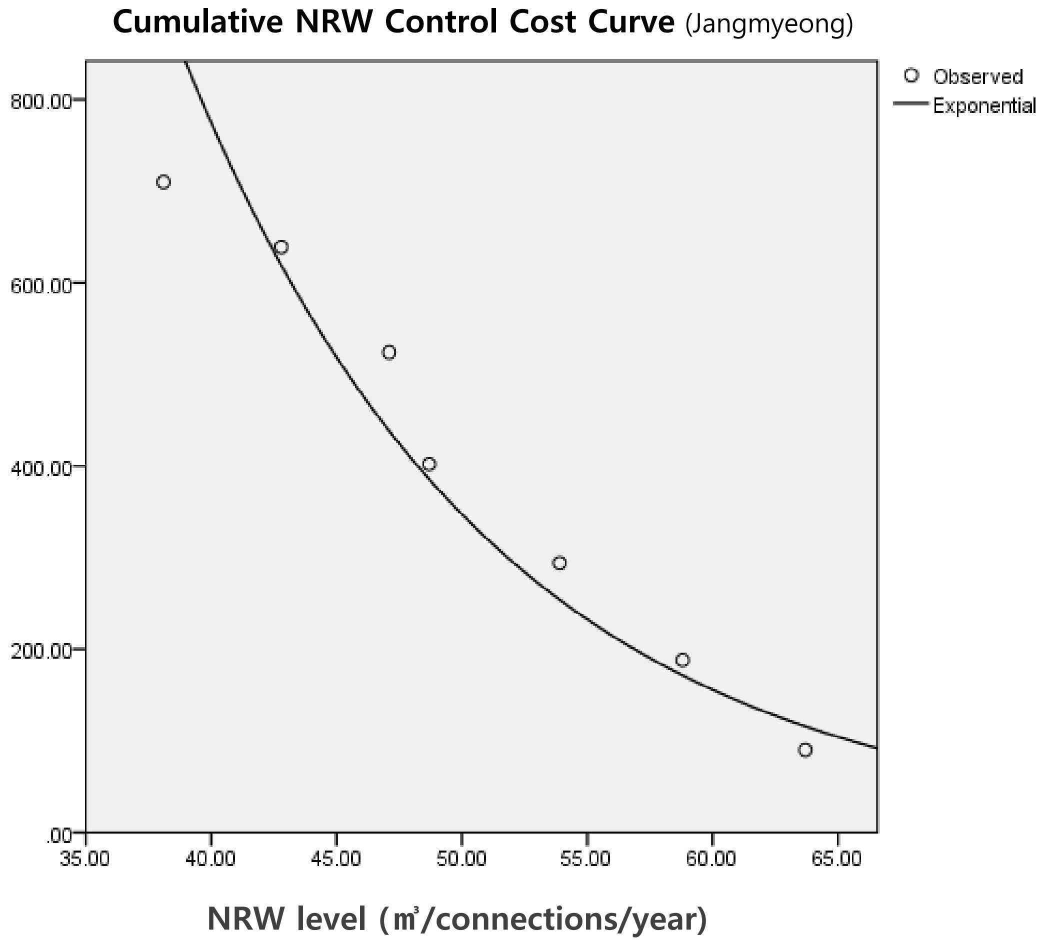


Figure 3-7. Regression Analysis of Cumulative NRW Control Cost Curve (Jangmyeong)

3.4 Marginal Cost of Water(MCoW)

The Marginal Cost of Water(MCoW) can be estimated from a short-term perspective by considering variable operating costs for electricity and chemical costs or from a long-term perspective by reflecting capital costs to balance water demand and supply.

The short-run MCoW for Jeongeup consists largely of tap water and electricity fees. Purchased tap water fee is the cost of obtaining purified water from K-water, and the electricity fee is the cost of distributing water to service areas by operating pumping stations. The tap water fee is taken into consideration as the constant price per m^3, and the electricity fee was calculated through dividing the water supply by the whole electricity cost over the past three years, and the calculated cost was 438.8 won/m^3, as shown in Table 3-10 below.

Table 3-10

Variable Operating Cost of Jeongeup

Component		Unit	Value	Remark
Sum			438.8	
A.	Treated Water Costs	Won/㎥	432.8	
B.	Pumping(Electricity) Costs	Won/㎥	6	2016~2018

The long-run marginal cost of water is regarded as unnecessary because the capacity of water treatment plant, which is the water source of Jeongeup city, is sufficient as 90,000m^3/day. This plenty capacity is enough to cover not only the average water supply of 41,000m^3/day in 2018 but also the future demand in Jeongeup city. However, this is a special case as the plant have almost double capacity of current supply. When the normal plant, which is built to supply a certain amount of water by target year, reached to the target year, the facility needs the extension to meet future demand. If it taken into consideration, the long-term marginal cost of water will rise sharply.

Accordingly, the current capacity needs to be modified for practical simulation. In this regard, capacity of the facility is assumed to be smaller than the existing facility and a long-term marginal cost for preparing future demand are estimated. Assuming conditions are that the capacity of Seomjingang multi-local waterworks facility scale down to 45,000 m^3/day, and that the daily peak demand of 2028 is predicted 50,000 m^3/day from 45,000 m^3/day in 2019. This increase in demand estimate is presumed to be conservative, taking into account the 3.5% increase from about 44,000 m^3/day in 2005 to 65,000 m^3/day in 2018 without no NRW reduction activities. New water resource development (capacity: 10000 m^3/day) should be prepared to cope with future demand, and the expected construction cost is about 34.4 billion won according to the guideline, as shown in Table 3-11 below.

Table 3-11

Cost Estimation of WTP Expansion Construction

Design Capacity(㎥/day)	Sum	Estimated Construction Cost (million won)				Remark
		Intake Facility	Treatment Process	Distribution Tank	Transmission Pipelines	
10,000	34,409	3,983	24,320	4,250	1,856	Discount Rate 4.5%

Note. From Cost Estimation Guidelines for Waterworks Facility (Ministry of Environment, 2016)

To convert the cost of construction into unit cost per cubic meters, the difference between present and future demand is calculated as roughly 9 million cubic meters, which is shown by Table 3-12 below, and the capital cost per cubic meters is determined roughly as 3,771 won/ m^3.

Table 3-12

Forecast of Future Water Demand (unit: ㎥/day)

Component	Sum	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
Future Demand (a)	475,000	45,000	45,556	46,111	46,667	47,222	47,778	48,333	48,889	49,444	50,000
Present Demand (b)	450,000	45,000	45,000	45,000	45,000	45,000	45,000	45,000	45,000	45,000	45,000
Difference (㎥/day)	25,000	-	556	1,111	1,667	2,222	2,778	3,333	3,889	4,444	5,000
	*Difference (㎥/year) = 25,000㎥/day x 365day = 9,125,000㎥										

From the long-term perspective, MCoW is calculated as the final 4,210 won/ m^3 by summing the variable operating cost of 438.8/ m^3 and the capital costs of 3,771 won/ m^3.

3.5 ELL estimations

The economic leakage target was analyzed by applying the MCW method for Jeongeup and Jangmyeong. The benefits are derived from multiplying two different MCoW by the leakage reductions in Table 3-6. In addition, a cumulative method with high statistical significance was used to calculate the economic leakage target.

First, the result of applying two different MCoW to Jeongeup area is shown in Figure 3-8 below. When variable operating cost are taken into consideration, the benefits from leakage reduction were low, implying that water loss control are unnecessary. However, long-run marginal cost of water was found to have an appropriate leakage target of 85m^3/connection/year or equivalent to RWR of 76.4%.

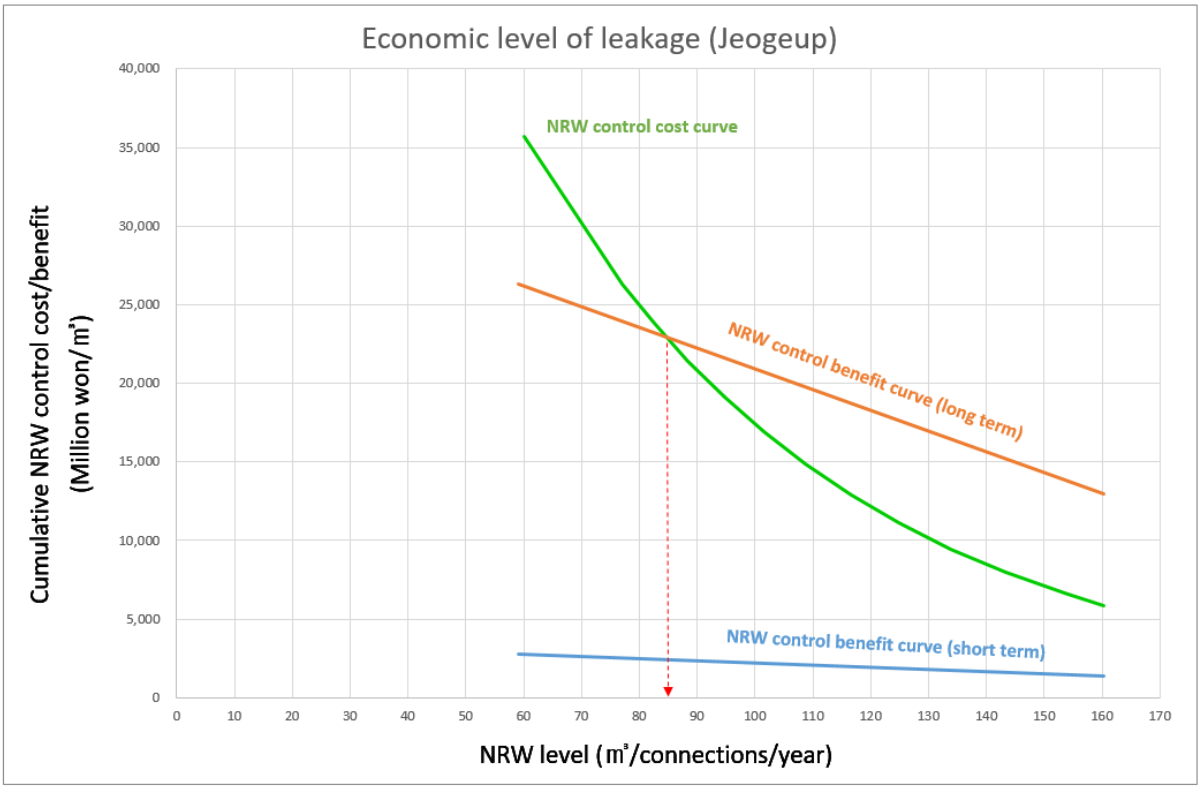


Figure 3-8. ELL Curve (Jeongeup)

Second, the result of Jangmyeong area is shown in Figure 3-9 below. In the case of variable operating cost, water loss control activities are not necessary, same as Jeongeup, and the appropriate leakage target for long-run marginal cost is around 35 m^3/connection/year or equivalent to RWR of 89.2%.

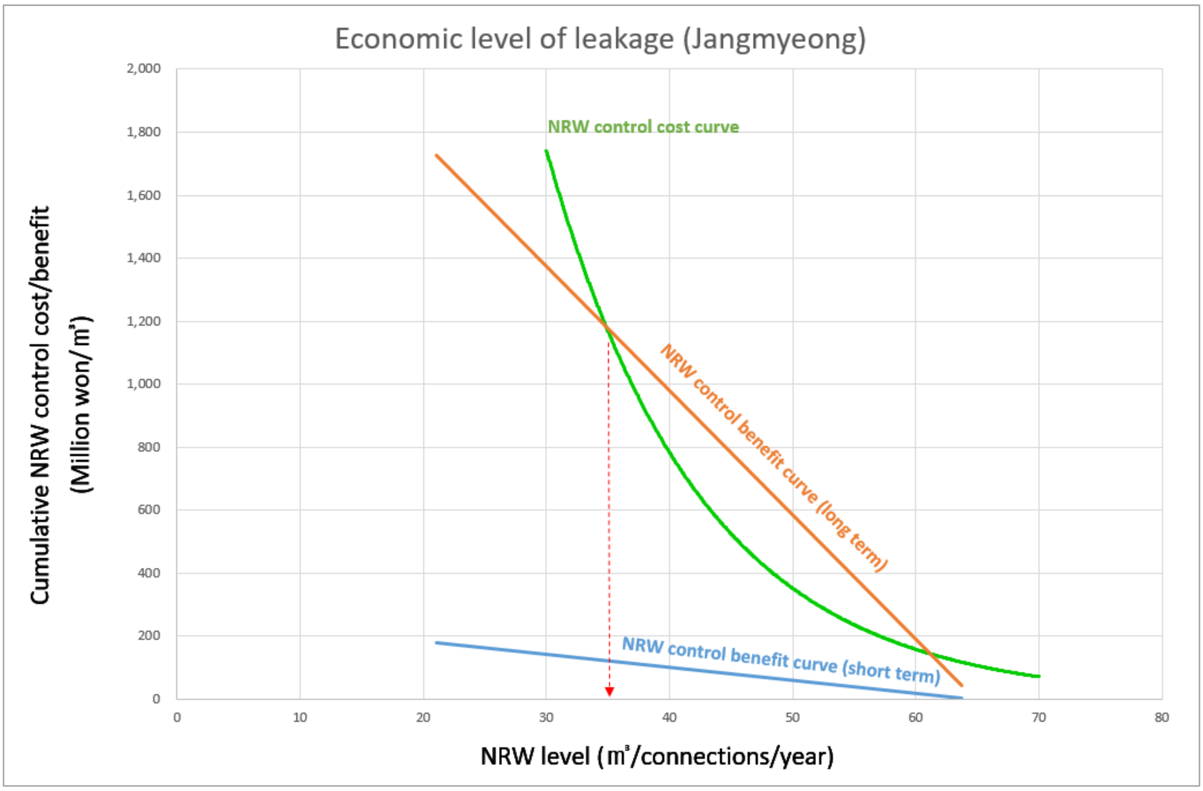


Figure 3-9. ELL Curve (Jangmyeong)

IV. Implications

The research featured a case study to assess the adaptability of MCW method in South Korea. Several significant factors that affect the water losses target and the proper methodology for Korea are derived from the case study, and the major findings are as follows.

4.1 Limits for Applying MCW Method

MCW method presented by Tripartite Report reveals some limitations after the case study. First, when the non-revenue water surpasses the volume of previous year due to natural rate of rise of leakage, marginal cost is determined as a negative value. This negative value impedes the utilizations of MCW method. Second, the deviation of the marginal cost ranged broadly in the operation phase, where there is no substantial change in the leakage level. Particularly, as shown in graph 3-6, the deviation of marginal cost varied from 2.2 to 7.9 even though their leakage level is similar to 47 to 48 m^3/connections/year. The efficiency of leakage repairs seems to affect the deviation and impedes leakage target determination through MCW method. Third, due to the characteristics of domestic NRW reduction projects, there was a lack of data available for each leakage level compared to the U.K., and the accuracy of the regression analysis seems insufficient. In detail, most available data was converged on the specific leakage level as around 80% and led to difficulties for MCW method application.

4.2 The Effect of Natural Rate of Rise of Leakage

The leakage increase compared to the previous year had been identified occasionally due to natural rate of rise of leakage in the process of analyzing the collected date. Also, the leakage target could vary greatly depending on the assumed quantity of natural rate of rise of leakage. As shown in Figure 3-9, when a long-run MCoW was 4,210 won/ m^3, the economic leakage level was analyzed as 35 m^3/connection/year. However, when the natural rate of rise of leakage is assumed as 40,000 m^3/year based on the data from 2009 to 2010, the prediction of the appropriate leakage level showed 21 m^3/connection/year as shown in Figure 3-10 below. As shown above, the appropriate leakage level was reduced by around 40%, and accurate prediction of the natural rate of rise of leakage was proven to be an important factor in determining the leakage target.

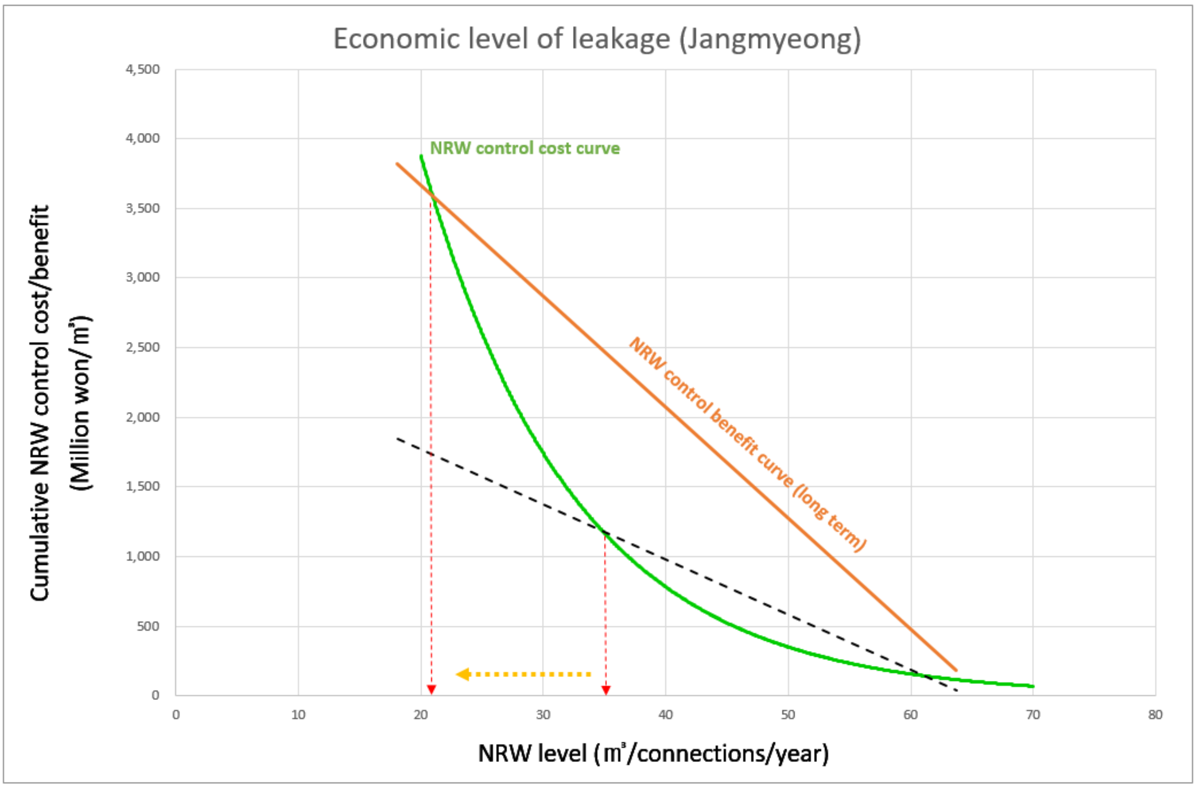


Figure 3-10. ELL Curve with Natural Rate of Rise of Leakage (Jangmyeong)

4.3 Accurate Separation of Leakage Reduction Costs

It was confirmed that extracting the effective expenditure that contributed to the decrease of leakage is imperative to determine the accurate leakage target. Generally, rehabilitation projects have mixed purposes such as reducing leakage, resolving water quality, and low-pressure complaints. As shown in Figure 3-3, the problem may arise if the NRW cost is not clearly separated from total construction costs without consideration. As a result, the inclusion of ineffective costs which does not account for the leakage reduction will deteriorate the correlation and obstruct the elicitation of statistically significant regression.

4.4 Low Marginal Cost of Water

Marginal cost of water is an important determinant, as well as the leakage cost relationship curve when estimating the proper water losses target. For domestic water distribution system, the marginal cost of water is calculated relatively small as the multi-regional waterworks system have sufficient capacity to cover future water demand to some extent. Particularly, for Jeongeup water distribution system, additional expansion of waterworks seems to be unnecessary because the multi-regional waterworks system, the water source of Jeongeup, can afford to meet both the present and the future water demand after a decade. Therefore, when only variable operating cost, 438.8 won/ m^3 is taken into consideration, the leakage level proved to be very low. However, this approach does not reflect the environmental and social value of water and leaves a room for improvement in future.

V. Conclusion

5.1 Summary of Study

This study aimed to improve the present water losses target methodology of South Korea. While the EU countries have developed a systematic methodology to estimate leakage targets, South Korea are pursuing the equal goal like Revenue Water Ratio of 85%. However, this study claims that individual water losses target should be delivered to each water utility because the characteristics of water distribution system vary from local municipalities. Besides, an excessive goal can lead to problems in terms of sustainability. Therefore, the purpose of this research is to derive improvements from present methodology in calculating water losses target through a case study.

To implement the case study, the MCW method presented in the Tripartite Report ('02), and the cumulative method suggested by Lim (2015) were applied. The case study targets were two areas of Jeongeup and Jangmyeong in Jeongeup City, and the analysis period is from 2005 to 2018.

According to the results of the case study, the MCW method, which is widely used in the U.K., shows limitations in application such as negative values and data deviation. In general, as the leakage level decreases, the NRW cost is increasing rapidly. But the MCW method shows difficulties to identify a clear relationship due to negative value and data deviations. The reason for the deviation accounts for the incomplete separation of effective expenditure from total costs which contribute to NRW reduction. Considering the features of domestic NRW projects, which are limited to five years of project period, acquiring wide range of data for different water losses level may not be possible. Most of data converge on the 80% of Revenue Water Ratio. However, the revised cumulative method was found to be less vulnerable by these facts than MCW method.

Two different marginal costs of water have assessed the economic level of leakages in study areas. Short-run MCoW derived from the variable operating cost and long-run MCoW is estimated by summing up capital costs and the variable operating cost. The purpose of capital costs is to prepare future water demand. The short-run marginal cost of water was computed as 438.8won/m^3 by the sum of the tap water fees and the electricity fees for operating pumping stations. The long-run MCoW is identified to be unnecessary as the previously established multi-regional waterworks has sufficient capacity. Besides, the present water demand had decreased when compared with initial demand as a result of leakage reduction activities, indicating the secure of the more extra capacity. However, as this is not a general case, the hypothetical conditions assumed like reduced waterworks' capacity and speculation of future demand were put into account in order for an enhanced methodology. As a result, the long-run MCoW was calculated at 4,210 won/m^3.

The economic level of leakage for the two study areas was assessed by considering short-run and long-run marginal cost of water. For short-run MCoW, leakage control activities were found to be unnecessary for both cities because accumulated benefits did not outweigh the required costs. For long-run MCoW, the economic level of leakage in Jeongeup is estimated 85 m^3/connection/year, or equivalent to Revenue Water Ratio of 76.4%, which is lower than current leakage level. The economic level of leakage in Jangmyeong is calculated 35 m^3/connection/year, or equivalent to Revenue Water Ratio of 89.2%, which is higher than the present leakage level.

5.2 Policy Recommendations

Several important policy implications were identified through the application of the ELL methodology and four policy recommendations have been proposed.

First, it has been proven that a cumulative method is more appropriate than MCW method for the leakage target determination in South Korea when considering the currently available data. Because, MCW method which is considered more sensitive to data quality than the cumulative method, shows limitations in application. In particular, sufficient operational data over the years and clear separation of effective NRW cost through the breakdown of total input expenses, including the evaluation method of natural rate of rise of leakage are a prerequisite for the applicability of MCW. Thus, it is advised to deploy the cumulative method to estimate the optimal water losses level in South Korea.

Second, further research and guidelines to assess natural rate of rise of leakage should be implemented because it significantly impacts the water losses target. As natural rate of rise of leakage is influenced by various factors such as pipe deterioration, pipe material, pressure and temperature, it can be complex to establish the standard guideline for the estimation. Nevertheless, the development of the quantitative assessment methods could enable the present water losses level to be lower and ultimately this effort will contribute to efficient water management.

Third, it is recommended to reflect social and environmental costs and benefits in calculating marginal cost of water in order to increase the efficiency of water resources. In Korea, due to the sufficient capacity of the previously established multi-regional water supply system, demand for new water supply development is relatively low. Besides, marginal cost of water could be resulted in the underestimated price by considering only variable operating cost. Underestimated marginal cost of water is likely to lead to the conclusion that the present leakage level is excessive and cause the abuse of water resources. There are concerns associated with lower water losses level that it will not effectively respond to natural disasters such as droughts caused by climate change. In this regard, EU already prepared the guideline to reflect social and environmental cost and benefits when leakage target is considered. Therefore, it is highly required to establish the systematic standards of analyzing social and environmental cost and benefits after a comprehensive research.

Lastly, In the case study, the water losses target was calculated based on two cases from a short-term or long-term perspective. However, a more detailed approach like annual targets is more appropriate to facilitate effective water supply operations. Therefore, water losses target profile varying with time changes is highly required. Besides, an adequate methodology for the temporal approach should be developed when the water losses target is prepared.

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