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Procedia Engineering 119 (2015) 120 – 129

Procedia Engineering

www.elsevier.com/locate/procedia

13th Computer Control for Water Industry Conference, CCWI 2015

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

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Abstract

Leakage has become a crucial issue that needs to be addressed effectively by water suppliers in terms of economic management of water systems. A target setting method based on the ELL (Economic Level of Leakage) calculation is proposed in this paper. The methodology applied is developed specifically for the South Korean context to select a minimum achievable level of NRW (Non-Revenue Water) and verify 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 in this 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.

Peer-review under responsibility of the Scientific Committee of CCWI 2015

Keywords: Non-Revenue Water, Economic Level of Leakage, Leakage Target ;

1. Introduction

Industrialization, environment pollution, climate change, aging infrastructure and changes in level of customer expectations have made huge changes in water supply [1]. 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

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Peer-review under responsibility of the Scientific Committee of CCWI 2015
doi:10.1016/j.proeng.2015.08.862

on the water suppliers. According to the recent World Bank publication, the annual volume of NRW was estimated to be approximately 50 billion cubic meters globally and the losses were equivalent to at least US $15 billion per year [2]. Similarly, a large amount of water in South Korea is disappearing through leaks every year. The annual volume and lost revenue in 2013 were 656 million cubic meters and $753 million per year [3], 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 [4]. 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 ongoing 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 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 respective project including infrastructure installations and maintain this level until the end of project life cycle, typically 20 years [5]. 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. Moreover, it does not consider the operating environments such as finances, water use patterns and topographic conditions of the individual areas [4].

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 the economic principle for achieving and maintaining NRW target efficiently with the limited budget to the K-water projects. This introduction of economic framework will allow water suppliers to manage their water system economically and efficiently. The research carried out in this paper addressed the issues mentioned above. The verified two methods of the UK and newly developed calculation model, cumulative cost-benefit analysis, are proposed.

2. Methodology

In this paper, three types of methods are employed to estimate the optimal level of NRW by comparing costs and benefits; (1) Total cost analysis, (2) Marginal cost analysis and (3) Cumulative costs-benefits analysis. The first two methods are generally used in the UK[6]. The third method is the newly developed method specifically suited for South Korean situation. All three 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.

2.1. Total cost approach

This method is based on the UK's general ELL model[6]. The economic level of NRW will be represented by the level at which the sum of the both NRW control cost and the cost of lost water (the rising line) is minimum [7]. Once the total cost curve is developed it is easy to decide the economic level of NRW, which is the lowest point on that curve [6, 8]. This concept is illustrated in Figure 1.

2.2. 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. 2. In this graph, the intersection point of both curves is the most economic NRW level [6]. The marginal cost of water can be estimated by adding together both marginal operating costs and marginal capital costs [6]. 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 can be calculated by Equations (1) and (2).

$$\text{Marginal operating costs} = \frac{\text{Pumping and Boosting costs} + \text{Water treatment costs} + \text{Sludge treatment costs}}{\text{Annual volume of production}} + \frac{\text{Usage charges of Dam water}}{\text{Annual volume of dam water}} + \frac{\text{Bulk water purchase costs}}{\text{Annual volume of purchased bulk water}} \quad (1)$$

$$\text{Marginal capital costs} = \frac{\text{Sum of present value of demand related investment}}{\text{Present value of the growth in water demand}} \quad (2)$$

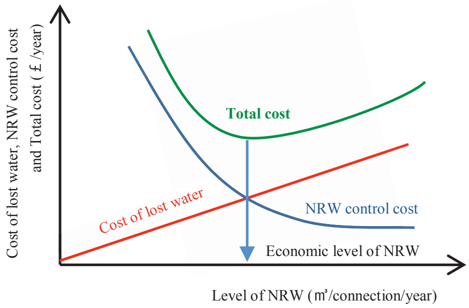

Fig. 1. Total cost curve

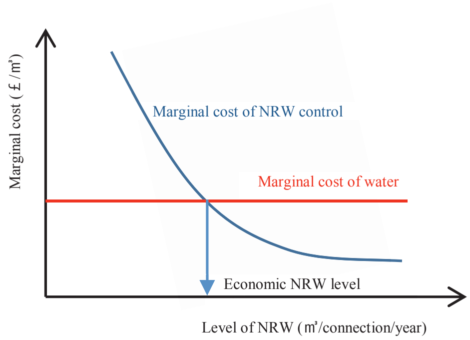

Fig. 2. Marginal cost curve

2.3. Cumulative cost-benefit analysis

Unlike the previous two methods, 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 analyzing 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 is calculated by multiplying both volume of NRW reduction over previous year 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 with two forms in Figures 3 and 4 against the cumulative volume of NRW reduction and the annual level of NRW per connection, respectively.

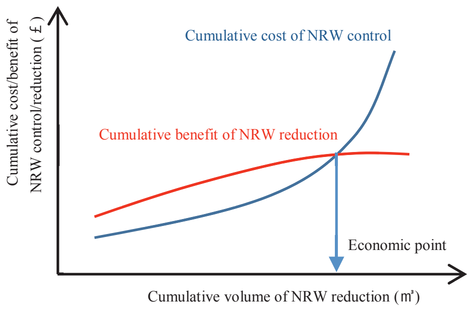

Fig. 3. Cumulative cost-benefit curve (A)

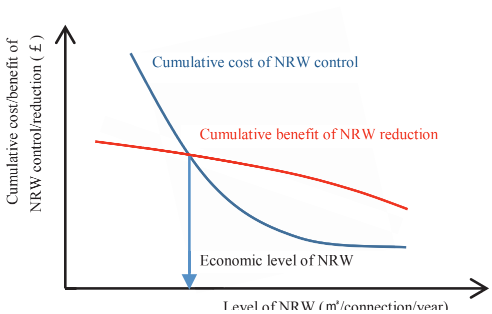

Fig. 4. Cumulative cost-benefit curve (B)

3. Case study

3.1. Description of study area

The study area is located in the north-east of South Korea. The water system of study area 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 21%. The study area is a small city covering a total area of 780.65 km². By the end of 2013, 22,433 people, out of a total population of 31,390 (71.5%), were supplied by K-water. The remainder of the population is using a small-scale water supply system based on ground water [3]. Three water treatment facilities have been providing water to this case study area. The average volume of supplied water is 8,370 ㎥/day. The study area is comprised of 3 large DMAs, 5 medium DMAs and 13 small DMAs since districts where established in March 2011.

3.2. Base data

Connections, property and population were obtained from the K-water billing system and statistical yearbooks of the area. The annual lengths of pipes in the system were obtained from GIS and statistical yearbooks. The NRW values were taken from the annual water balance.

3.3. NRW Cost Curves

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 among the three will be selected and the most economically efficient level of NRW will be calculated using the chosen method.

(1) NRW control cost curve (Total cost approach): The cost curve can be drawn by using both NRW per number of connections and the annual NRW control costs which consist of water pipe replacement and rehabilitation, aging or faulty valve replacement, pressure management, water meter replacement, and leakage detection /repair. The components of cost curve were presented in Table 4 and the derived costs curve can be seen in Figure 5.

Table 1. Components of NRW control cost curve.

Year	NRW (㎥/year)	Connections (nr)	NRW/connections (㎥/conn/year)	NRW control costs (￡k)
2008	2,823,933	5,315	531	126
2009	1,481,187	5,376	276	412
2010	1,143,364	5,454	210	887
2011	962,643	5,778	167	314
2012	924,505	6,089	152	653
2013	813,111	6,414	127	1,143

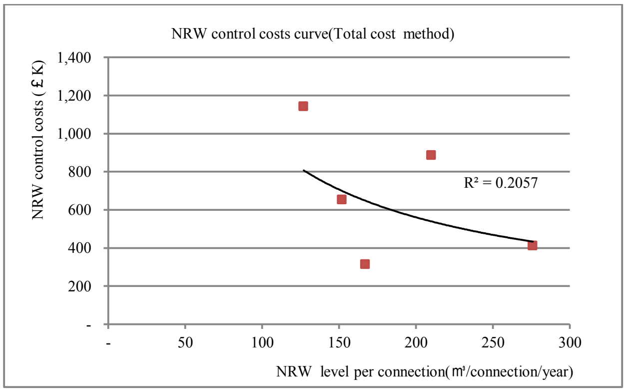

Fig. 5. NRW control cost curve

(2) Marginal cost of NRW control cost curve (Marginal cost approach): The marginal costs of NRW control was calculated by dividing the annual costs of NRW control by the volume of NRW reduction over previous year. 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 2 and the marginal cost of NRW control curve is illustrated in Figure 6.

Table 2. Components of marginal cost of NRW control cost curve.

Year	NRW	Volume of NRW reduction Over previous year	NRW control costs	Marginal cost of NRW reduction	NRW/connections
	㎥/year	㎥/year	£ /year	£ /㎥	㎥/conn/year
2008	2,823,933	-	125,500	-	531
2009	1,481,187	1,355,325	412,000	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	1,412,500	7.5	127

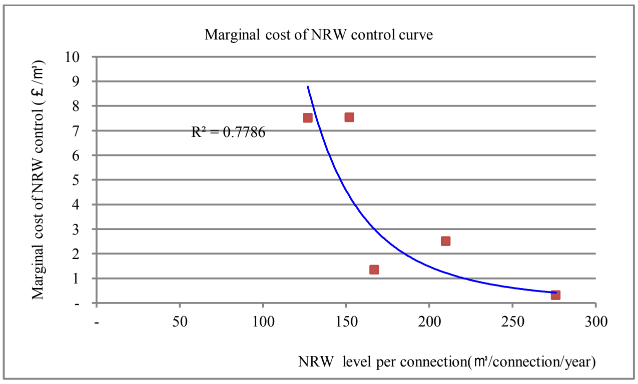

Fig. 6. Marginal cost of NRW control curve

(3) Cumulative costs curve (Cumulative cost-benefit approach): This curve can be developed in two ways according to what is plotted on the X-axis. The cumulative volume of the NRW reduction is used in the first graph, and alternatively, the level of NRW per connection was employed in the second. The cumulative cost of NRW reduction was used as a Y-axis for both. The components of cumulative cost curve are presented in Table 3 and the cumulative NRW control cost curve A and B are illustrated in Figures 7 and 8.

Table 3. Components of cumulative costs curve

Year	Volume of NRW reduction over previous year	Cumulative Volume of NRW reduction	NRW/connection	Cumulative costs of NRW control
	m^3	m^3	m^3/connection/year	£ M
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

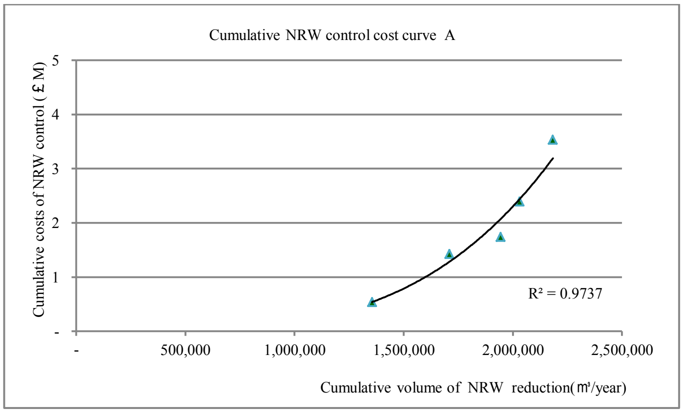

Fig. 7. Cumulative NRW control cost curve A

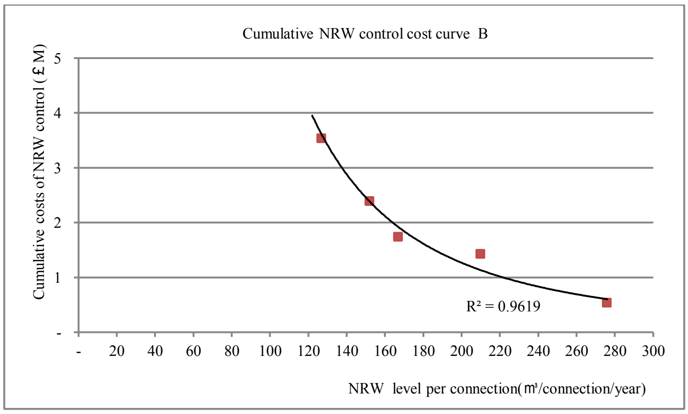

Fig. 8. Cumulative NRW control cost curve B

Among the three 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 3).

3.4. Economic level of NRW calculation

(1) Cost data: The NRW control costs for the case study area between 2008 and 2013 are presented in Table 4. The respective costs are brought to the present value by applying the price index

Table 4. Annual investment status for NRW control (£/year)

Year	2008	2009	2010	2011	2012	2013
Cumulative 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

(1) 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 5.

Table 5. 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) (£K)
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

(2) Cumulative cost-benefit curve: The economic level of NRW can be identified by adding cumulative benefit of NRW reduction curve into the cumulative NRW control cost curve. The two type of graph are shown in Figures 9. and 10.

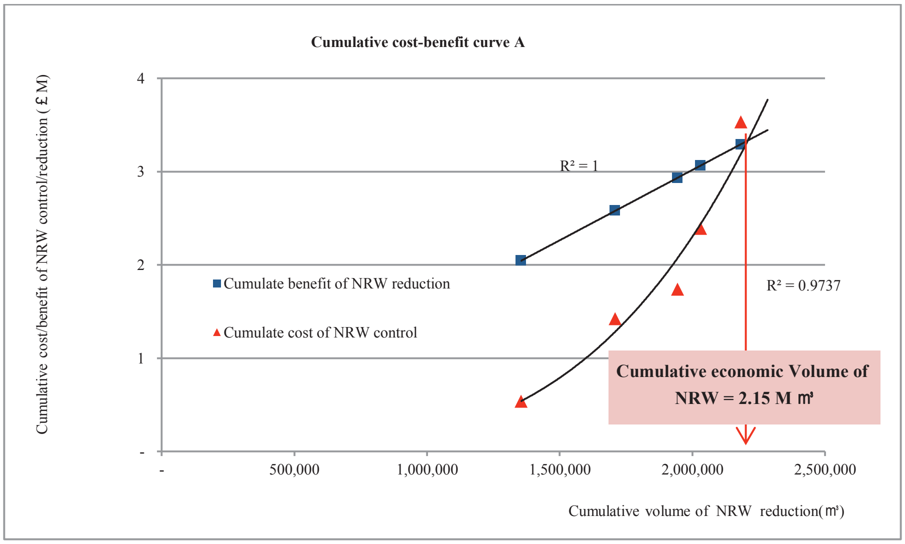

Fig. 9. Cumulative cost-benefit curve A

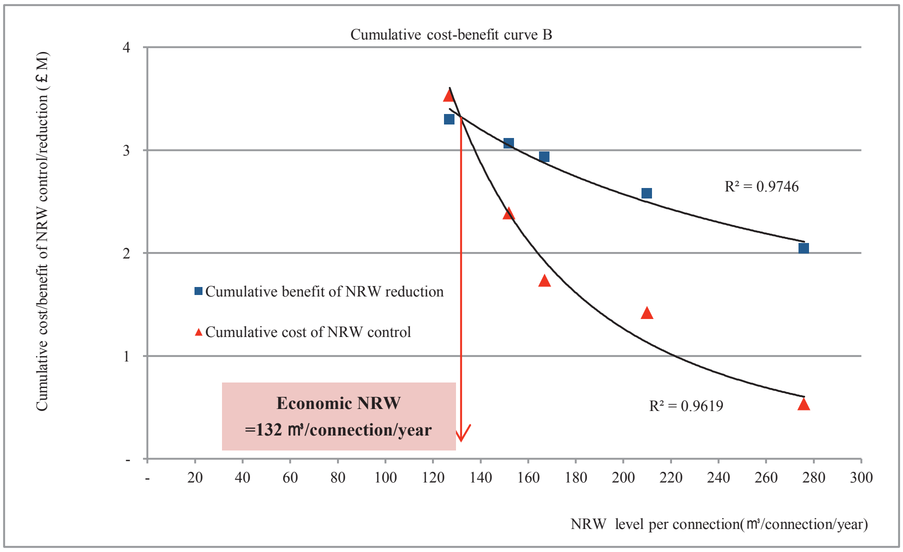

Fig. 10. Cumulative cost-benefit curve B

(4) The optimal NRW level: This 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 2.15M ㎥/total over multiple years and 132 ㎥/connection/year respectively. In this paper, 132 ㎥/connection/year value was used for convenience.

3.5. 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 would be changed. The results are summarized in Table 6 and shown in Figure 11.

Table 6. Results of sensitivity analysis

Sensitivity Parameters	Economic level of NRW (㎥/connection/year)						
Value change	-15%	-10%	-5%	0%	5%	10%	15%
Volume of NRW(㎥/year)	145	140	136	132	128	125	121
Marginal cost of water(£ /㎥)	145	140	136	132	128	125	121
NRW control costs(£ M/year)	120	124	128	132	135	140	143
Connections (nr)	140	137	134	132	129	126	124

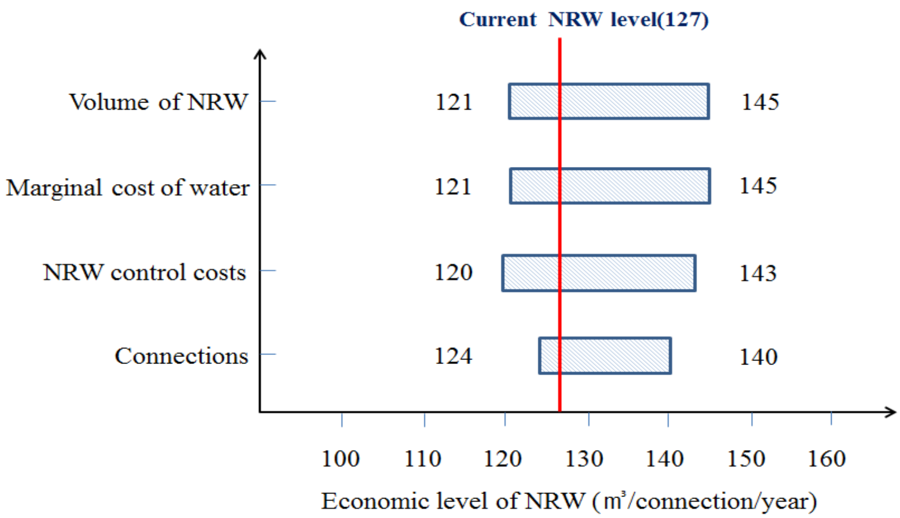

Fig. 11. Result of Sensitivity analysis

From the above results, both volume of NRW and the marginal cost of water were reduced by as much as 4 ㎥/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.

3.6. Setting a new target

The optimal NRW levels were calculated by the cumulative cost-benefit analysis. The optimal level is 132 ㎥/connection/year. It should be noted the recent NRW level was recorded at 127 ㎥/connection/year by the end of 2013. This 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 most optimal NRW level of this study area.

4. Conclusions

This research aimed at developing the economic NRW calculation model which can be applied to the South Korean water systems. In order to this, two existing methods used in the UK were analyzed. At the same time, the new methodology was developed for the South Korean business environment as the UK methods could not be applied without further modifications. As a result of applying this new approach, reliable results in NRW control cost prediction were achieved on the analyzed case study. Because the new method uses cumulative data it data fluctuations due to the small amount of data had less of an effect on the results. On the other hand, the two UK models showed low reliability in cost prediction. The reason comes from the different investment methods for NRW control. 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, about 40% of the overall project management costs.

Secondly, 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 ±4 ㎥/connection/year. Although it was impossible to identify the most influential factor, both lower and upper limits of the economic NRW level were determined.

Lastly, the economic NRW target was identified to achieve the earlier set company's target of 20% NRW based on the cumulate cost-benefit methodology. This research showed satisfactory results but further work is required to confirm this as a widely usable model by applying this to the other case studies.

Acknowledgements

This work has been funded and supported by K-water which is the public water company in South Korea.

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