Efficient Drinking Water Supply System: Revenue Water Ratio(RWR) Improvement Project

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1. Time of Policy Implementation

The Revenue Water Ratio (RWR) Improvement Project has begun with the start of the special organization focused on drinking water, i.e., Seoul Water Authority, in 1998. Although there were projects to increase the system efficiency before, it can be said that the real plans and projects to improve RWR have been carried out by Seoul Water Authority since 1998.

In 1990's, the first priority of drinking water policy was still on qualitative issues. As the drinking water quality of Seoul was improved to the world-best level, the city of Seoul made plans to increase the efficiency of water system, i.e., RWR improvement, and started new projects.

Improvement of RWR can be directly related with streamlining the management in water business.

2. Situational Background for Policy Implementation

The beginning of water system can go back to the earliest history of human being as we need water to live. The archeological evidence told us that the history of water system in Korea goes back to the 7th century[2]. The system was very fundamental one to supply the citizens with

[1] Translation by ESL®

[2] "It was known that drinking water was supplied through clay pipes in the period of the United Shilla Dynasty in the 7^{th} – 10^{th} century after aqueduct and water ways with clay pipes were found in the An Ap fond in Ku Hwang Dong, Kyung Ju city, Kyung Sang Book Do in 1974" – A Centennial History of Seoul Waterworks System, 2008

groundwater and clean surface water through pipe system made of wood and/or clay.

Modern Waterworks System

The modern waterworks system of Seoul started to be operated in 1908 with construction of Tukdo WTP and supply the citizens with the treated water from the Tukdo WTP[3]. During the Japanese occupation starting in 1910, the capacity of drinking water production and supply system was not increased with population growth during the period as the treated water was supplied to only few restricted citizens. Although Korea won its independence in 1945 with the end of the 2nd World War, political turmoil and social instability continued. Due to the chaotic conditions, few people concerned about urban development and operation/maintenance of social infrastructures.

The Korean War

The political turmoil grew to the tragedy of the Korean War in 1950. During the war, the total number of the dead, missing, and wounded soldiers was 973,000 while that of civilians was 2.1 million, i.e., One of five-membered family was dead, missing or wounded. This was not only enormous damage for individual and for society but also national tragedy. The damage on industrial facilities was so huge that about 35~90% of urban infrastructure was destroyed by the war[4]. It took years for Korea to recover the damage by the war.

Economic Growth

Water demand grew rapidly with expansion of urban area and explosive increase of population by economic development in 1960's. The population of Seoul increased by about 3.3 times from 2.5 million in 1960 to 8.1 million in 1979. The population growth rate was same as the rate to build a city with population of 300,000 every year [□]. The city of Seoul spurred urban development to accommodate the rapidly increasing population. The 25% of the current urban area of Seoul was developed in 1960's and 1970's [□].

Expansion of Tap Water Production and Supply

Seoul made every effort to correspond to the changes in 1960's and 1970's by increasing drinking water production capacity and expanding the network system for treated water supply. It could not be enough to cope with the explosively increasing water demand with rapid

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[3] September 1, 1908 is known to be the beginning of drinking water supplied in Seoul from the modern style water treatment plant, the Tukdo WTP.

[4] "In terms of the infrastructure for waterworks system, 30~90% of water treatment plants, 5~10% of pipe network system, 60~80% of booster stations, and 90% of communication systems were destroyed by the war." [□]

population growth.

310,000 m3 of drinking water was produced every day but about 57% of the treated water was lost due to the dilapidated waterworks facilities (i.e., RWR of 43%) [☐].

Seoul had extended the waterworks system with the 3-year plan since 1965 even with the difficulties mentioned above. The goal of the plan was old pipe replacement and scientific leak management. The financial problems could be solved by the international funds and issuing national bonds.

Although some of the plan had problems in coping with the population increase, the water supply condition of Seoul had been improved gradually (Figure 1).

Figure 1. Time line of population and drinking water production capacity of Seoul

Over 90% of the citizens could get water service in 1980's from 60% in 1960's5. As the water demand could be met by increasing the production capacity, the city increased the storage capacity of water reservoirs, built booster stations, and decreased leakage by replacing old pipes.

As discussed above, there were rapid industrialization and urbanization with the implementation of the national economic development plans, and rapid increase in water demand with population growth, in Seoul in 1960's. The city focused on increasing drinking water production capacity and improving supply systems in 1970's and 1980's. As the results, the waterworks system of Seoul could provide the citizens with sufficient drinking water, in terms of quantity.

Quality Improvement of the Tap Water

The source water, i.e., the Han river, was polluted with incomplete treatment of waste water in the early 1980's. The city had difficulties to treat the dirty source water such as using too much

[5] The percentage of population connected to drinking water service was increased from 92.7% in 1980 to 99.9% in 1992 by expansion of drinking water production capacity from 3.1 to 6.2 million m³/day [☐]

chemicals.

With the Asian Games in 1986 and the Olympic Games in 1988, the city made many efforts to set the Han river in good condition including building and expanding the waste water treatment plants.

There were many accidents of water pollution including increase of ammonia nitrogen concentration in local waterworks system and phenol flowing in to the Nakdong river located in south-eastern part of Korean peninsula. The tap water quality became a national issue as more of the citizens did not trust the quality of tap water [☐]. The central government of Korea made the 'Comprehensive Plan for Clean Water Supply' and launched innovation projects including aggressive protection of water sources, prevention of water pollution, and improvement of drinking water treatment system.

The city of Seoul made the waterworks service highly specialized6; 1) Launching a research institute for research and development on water treatment technologies, scientific water quality management, and increase in system efficiency, 2) streamlining monitoring and management of source water protection areas and active correspondence, 3) improvement and replacement of the old facilities in the water treatment plants, and 4) massive replacement, cleaning, and rehabilitation of old pipes in the supply network [☐].

The drinking water quality as well as the source water quality could be maintained in world-class level with the launch of Seoul Water Authority and the efforts made by the city (Figure 2).

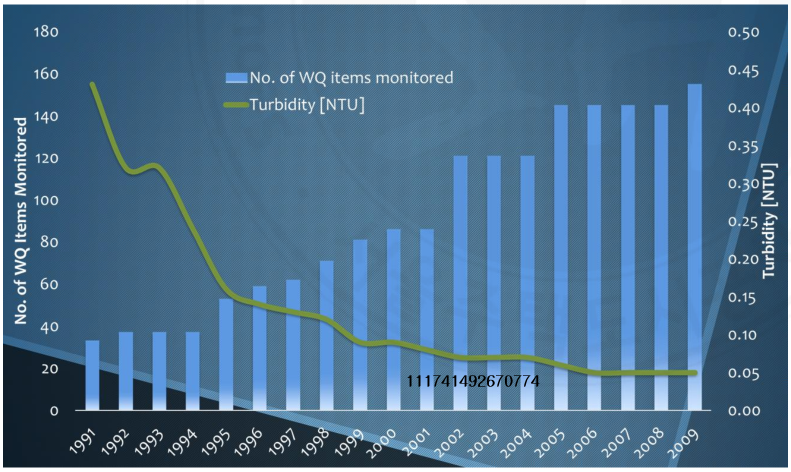

Figure 2. The number of water quality monitoring items and the turbidity of the treated water [☐]

Improving Efficiency of the Water Business

The goal of drinking water policy changed from quality and quantity to efficiency of the system

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[6] The Seoul Water Authority only for drinking water production and supply for Seoul was launched in November 1989

as the city secured enough capacity of the waterworks system for qualitative and quantitative goals. The city could produce enough drinking water by increasing the capacity of water treatment plants and supply the citizens consistently with enough of high quality drinking water.

Water reservoir is a water storage facility in the middle of water supply system and can secure consistent supply of the drinking water to the citizens by controlling the amount of water supplied directly to the citizens. The capacity of water reservoir is critical for consistent supply of drinking water to the citizens, as well as the capacity of water treatment.

Expansion and improvement of water reservoirs were not in the main project list as the priority of the policy was on capacity building for drinking water production.

More resources could be invested in the early 1990's after the city had enough production capacity. The total capacity of the water reservoirs reached to 1.3 million m3 in 1999, which could guarantee continuous supply of drinking water of 6.4 hours in any case.

As discussed above, the city could increase the RWR dramatically through installation of indirect water supply system using water reservoirs, and detailed leakage management by block system7.

The 'Revenue Water Ratio (RWR)' is defined as the ratio of the volume of water paid by the customers to that supplied (Figure 3). The higher RWR means water loss in supply system is minimized. The water system with higher RWR can increase the managerial efficiency as the water demand and supply can be controlled precisely.

System Input Volume (corrected for known errors)	Authorized consumption	Billed authorized consumption	Billed metered consumption (including water exported)	Revenue water
			Billed unmetered consumption	
		Unbilled authorized consumption	Unbilled metered consumption	Non-Revenue Water (NRW)
			Unbilled unmetered consumption	
	Water Losses	Commercial (apparent) Losses 111741492670774	Unauthorized consumption	
			Customer Metering Inaccuracies and Data Handling Errors	
		Physical (real) Losses	Leakage on transmission and/or distribution Mains	
			Leakage and overflows at utility's storage tanks	
			Leakage on service connections up to point of customer metering	

[7] A block system can be defined as a pipe network system composed of "blocks" considering the characteristics of the area (i.e., elevation, road, streams, and rail ways) in order for efficient network management and easiness of water demand control [□]. It is also called as District Metered Area (DMA).

Figure 3. International standard terms on water balance by IWA [☐]

3. Importance of the Policy

The water business of Seoul is quite different from other public organizations in its organizational, managerial, and financial characteristics. The water business of Seoul is one of the public services provided by the local government of Seoul. At the same time, it is operated as a local public company, i.e., the finance of the Seoul Water Authority is controlled as a special budget system depending only on the water tariff from the customers based on a self-supporting accounting system.

The Seoul Water Authority has the mission to provide the citizens with clean and safe drinking water as one of the public services. At the same time, the Authority has to achieve the goal of rationalization of administration and management as a company.

It is very important to reduce the prime cost and the operational cost through increasing the RWR and to collect the water tariff correctly for rationalization of water business management. It is critical to maintain the finance sound by increasing the RWR which is the ratio of the volume of water secured as tariff income to that of total produced and supplied [☐].

Although it's not easy to increase the RWR, the goal can be achieved through long-term plan for reducing non-revenue water by cause and consistent implementation of the plan. The main goal of water business is, generally, improvement of the system in terms of quantity and quality. Cost reduction and improvement of the lives of the citizens by increasing the system efficiency, can be the goal for the next step project. The city of Seoul could build an efficient water system through RWR increasing project.

As the results of the efforts, the Seoul Water Authority could increase the financial self-sufficiency and achieve rationalization of administration including replacement of old pipes, renovation of water treatment plants, outsourcing of a part of operation to private sector, and advanced redemption of debt with higher interest rate

The financial self-sufficiency of the Seoul Water Authority increased from 95.4% in 2002 to 100% in2004. The debt decreased by 75% between 2002 and 2007, i.e., 600 billion KW in 2002, 540 billion KW in 2003, 396 billion KW in 2004, 325 billion KW in 2005, 203 billion KW in 2006, and 150 billion KW in 2007. The city of Seoul could have frozen the water tariff for 12 years8 since 2001 and return the benefits to the customers [☐].

High RWR is a base for safe and sustainable water system as it can rationalize management of water business and make the finance sound. RWR is one of the most important factors to continue the virtuous cycle of water business [☐]. A system, financially and technically stable, can achieve the essential goal of water business, i.e., to maintain water safe in quality and secure

[8] 서울시 The water tariff of Seoul was raised by 9.6% only once in 2012 since 2001. The increased production cost could be covered by rationalization of management.

water enough to supply, and also have direct advantages in water tariff. The real meaning of the policy related with higher RWR is to provide the citizens with happy lives by supplying clean and safe drinking water.

The RWR of Seoul was 55.2% in 1989 when the Seoul Water Authority started its business. It reached to 95.2% in 2015 after continuous efforts to increase the RWR. The results of the project between 1990 and 2013 can be summarized as reduction of drinking water of 7.5 billion m3 (which can be used by 10 million citizens of Seoul for 6 – 7 years) and calculated as 4.2 trillion KW of financial benefit. The number of leak cases was reduced by 82.5%, by which the city could save about 1.8 trillion KW of budget. As the production could be reduced by the increased RWR, the 4 of the 10 WTP's (total capacity of 7.3 million m3/day) could be closed, i.e., 6 WTP's with the capacity of 4.4 million m3/day was enough to meet the water demand.

The WTP's closed were renovated to parks and recreational spaces for the citizens to increase the standard of life [☐].

4. Relationship with Other Policies

Although the policies for water demand and supply is related with other policies of the city, it is not affected much by other policies as the impact by changes of other policies is not that large to the water policies. Therefore, the policies related with the RWR may not directly relate with other policies than water.

<u>Regeneration and Rehabilitation of Urban Areas</u>

Regeneration and rehabilitation project for old residential areas are closely related with the RWR project. As the projects for urban rehabilitation may take more than 10 years from plan to completion, it may be hard to replace old pipes and manage pipe network efficiently. The project for higher RWR can be hindered by inadequate maintenance and remaining old pipes

and abandoned pipes. Inadequate post-project measurement after demolition of buildings and treatment of abandoned pipes, can increase the possibility of leakage. It can also increase the amount of water leaked as it takes long to repair the supply system when it has a leak.

It is necessary to have measurement for facilities management including preventing leak, and closing abandoned and forked water posts, at the early stage of the urban rehabilitation project. A systematic management using O/M card can be a good example. Detailed water demand management by installing water meters on the main pipes in the area where the rehabilitation project is carried on. Control on water supply and pressure is also required to meet the decreased water demand by closed water posts and household move.

Upgrading GIS

It is necessary to update the GIS for systematic management of the facilities as well as for urban rehabilitation project. Although the projects related with upgrading GIS can be performed separately from the project to increase RWR, it is recommended to design the two projects together as GIS is a very useful tool to increase RWR. The project to increase RWR can be managed efficiently by registering and managing the information related with urban regeneration project and data related with pipe network.

Facilities to Control Electrolytic Corrosion

The most important technical target for the project to increasing RWR is the pipe network and corrosion is related with leakage in the pipe network. Installation of the facilities to control electrolytic corrosion can affect the RWR directly in the conditions with lots of underground facilities. As the corrosion control facilities installed on the water pipes can promote corrosion on other facilities, the corrosion control facilities need to be installed and operated considering the effect on other facilities in underground.

Urban Safety

Leak from water main can cause safety problems such as road sink. The RWR project has to be designed to help other projects for the safety of the citizens.

Other Water Policies

Other water policies related with the RWR improvement project are, water demand and supply management [9], pipe network improvement projects (replacement, rehabilitation, and management of old pipes), and investment and budget operation strategies.

5. Target of the Policy

The RWR of Seoul is world-top-level of 95.7% as of August 2016. After thorough evaluation on

[9] Water Demand Management (WDM) is a managerial approach of developing and implementing strategies to affect water demand to consume the restricted water resources fairly, efficiently, and sustainably [□ , □]

capacity of each local service office including conditions of mid-size block management, field conditions such as regeneration/rehabilitation, and water supply management by flow monitoring systems, the city decided that 0.2 – 0.3% of increase every year could be achieved and set the goal of 97% in 2022. This level of RWR may be the maximum level that a waterworks system can achieve. As investment may be more than profit by increasing RWR above this level of RWR, the goal of a RWR project needs to be set systematically and scientifically.

The ultimate goals of RWR project are, 1) improvement of efficiency of water system by management of RWR at higher but appropriate level, 2) steady supply of drinking water with higher quality, and 3) improvement in productivity of water system through balanced demand/supply management.

6. Main Contents of the Policy

The main contents of the policy include;

- Launching and operating a dedicated organization for drinking water
- Projects to reduce leakage using scientific and systematic leak detection based on ICT
- Projects to measure night minimum flow
- Projects to replace and rehabilitate old pipes
- Installation of water reservoir system using gravity
- Scientific water management based on water flow monitoring system
- Knowledge sharing programs to improve RWR

The project to improve RWR was carried out by phase as follows.

[1st Phase] was the initial stage of RWR increase project. It started from 1989 when the Seoul Water Authority was launched and until 1995. One of the largest advancements at that time was launching of the drinking water dedicated organization. It is necessary to have a dedicated organization to carry out projects related with increasing RWR through the strategy of ‘selection and concentration’.

Another goal in this time of period was to construct fundamental basis to increase RWR, i.e., installation of monitoring systems. Zonal flow meters were installed to monitor water flow by unit area. Each local service office could complete the monitoring system to estimate precise water flow in and out of the system. The projects carried out between 1991 and 1993 for replacement and rehabilitation of old pipes could be another basis for the RWR improvement project.

[2nd Phase] was the stage of full-scale project promotion between 1996 and 1999.

The Seoul Water Authority made a task-force-team for RWR improvement on October 12, 1998. The TFT was one of actions for the strategies for field operation of the project based on 'selection and concentration' concept. More detailed data and information were collected from the monitoring systems installed in the 1st phase. The project to manage RWR started with analyses on the accumulated data and information.

Precise amount of water supplied was measured and the RWR was estimated and managed. Inadequate water meter was replaced for more systematic and scientific flow monitoring. The whole distribution area in Seoul was re-organized into 2,037 small blocks and minimum night flow was measured. The RWR could be increased based on the strategy of 'divide and conquer'.

Another important policy related with the improvement of RWR was one about urban regeneration. As discussed above, urban regeneration projects takes long time from plan to completion and the waterworks systems within the project area might be managed poorly. It is required more concentrated and detailed management on the waterworks system. As the city had more of urban regeneration projects, the management on the waterworks system within the project area was managed systematically and intensively since 1999.

[3rd Phase] was focused on making the results of the previous projects sustainable. In other word, the project of RWR increase was settled in this phase starting in 2000 until now.

The main goal of the policy in this phase was to maintain the high RWR consistently by constructing production and supply system for RWR increase.

The TFT for RWR increase was reformed into a permanent organization, the department of RWR, and the department became an organizational base to increase the RWR continuously and systematically.

The city had changed the water supply system into the 'indirect water supply' system by expanding water reservoirs between 2000 and 2003. With the 'indirect water supply' system with operation of booster stations, the authority could manage water pressure within appropriate level. Water meter reading was outsourced to private sector in 2001 as it had little to do with RWR increase although meter reading was very important business of the authority.

The management of pipe network was carried out in two approaches; the abandoned pipes were managed systematically and the RWR was managed by mid-size block unit.

In the water supply management, the city started supply analysis and flow control based on the information from the flow monitoring system.

The city could detect leaks in the pipe network successfully by introducing technology called 'multipoint leak noise correlator'.

As the results of the project, the RWR of Seoul has reached to world-class of 95.2% in 2015 (Figure 4).

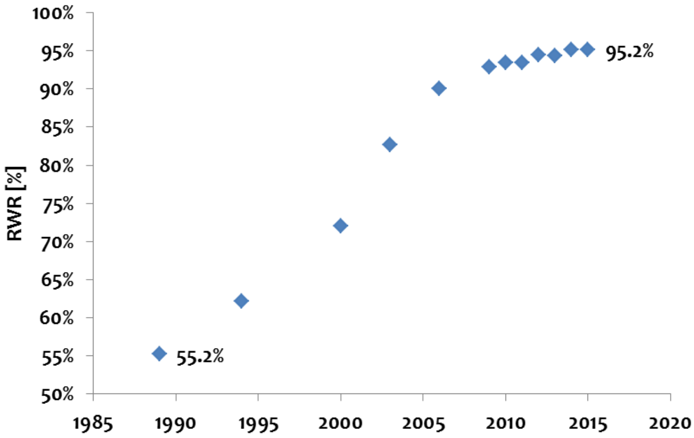

Figure 4. The RWR of Seoul

Economic feasibility is one of the most important factors to be considered to design an RWR improvement project. Economic loss by leaked water must be compared with the project cost to increase RWR (Figure 5). The cost by water loss is originated from physical loss and commercial loss. Physical loss is calculated with operational costs such as labor cost, chemical cost, energy cost. Commercial loss is estimated from water tariff. The cost for RWR management is defined as the costs used for RWR improvement including costs for labor, equipment, and transportation. The cost for RWR management definitely increases with RWR increased [☐]. Although it depends on the financial and technical conditions of the water business in the area, the RWR over 95% is close to the break-even point of investment and revenue. The focus of policy for future RWR needs to be more on managing and maintaining the RWR efficiently while increasing RWR is still important.

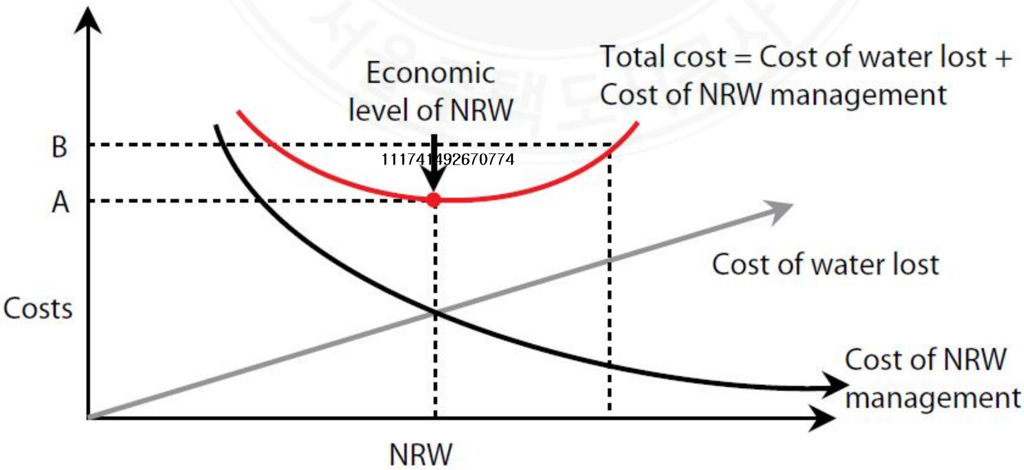

Figure 5. Determination of NRW considering economic feasibility [☐] (As RWR is the opposite concept of NRW, the graph can be understood as upside down relationship of RWR and economic feasibility)

7. Technical Contents

Replacement of Old Pipes

As of 2015, the total length of the pipe network of Seoul is 13,697 km, i.e., about 1.1 times longer than the diameter of the earth (12,756 km). The most effective way to increase the RWR is to replace the old pipes in the supply network system. The Seoul Water Authority invested budget of 1.7 trillion KW between 1984 and 2013 to replace the 87% (11,221 km) of the old pipes. The authority has replaced 97% (13,292 km) of the old pipes in 2016 with total budget of 3.3 trillion KW. Remaining 405 km of the old pipes will be replaced until 2018.

Although it differs by pipe material and diameter, the life of the pipe asset is generally 30 years10. The replacement of the old pipes has to be a continuous project based on technical and financial consideration. Criteria to determine the old pipe has to be established for the project to be effective. Studies on asset management are required to secure the efficiency of financial investment for RWR increase.

Measuring Minimum Night Flow (MNF)

Minimum Night Flow is defined as the measured rate of flow into any distribution network or district meter area during the minimum demand period on a given night. Usually it is between midnight and 4 AM. Although the conclusion of measurement depends on type of water supply, when the result of the flow measurement is between the minimum allowable leak of 0.5 m3/hr-km and 1.0 m3/hr-km, leak detection is carried out intensively and measurements to manage leakage is taken. The city of Seoul had measured the MNF at the 2,037 small-size blocks between 1998 and 2005. Currently, the MNF is measure for selected blocks. It takes overnight for 5 staffs to measure MNF of a block. After the valve installed at the boundary of blocks is fully closed to separate the block, the water flow and the water pressure into the block are measured (Figure 6). The remaining staffs check water meter with noise detecting poles. The water flows in all of the manholes in the block are also checked by naked eyes. If the staffs find any suspicious observation, they get into the manhole by themselves to check any leakage.

[10] Life time: Literally, it means time to use a device or a facility with original condition. In waterworks system, it means time to maintain the facility in conditions acceptable by the city or the national standards even after contamination and physical deformation and changes in water supply. Life time of a pipe is hard to be specified as it can be affected by various factors including pipe material, age of pipe, underground condition where the pipe is buried, soil corrosiveness, traffic condition, population served, population density, water pressure, and water flow. Currently, the life time of pipe system is decided considering financial depreciation.

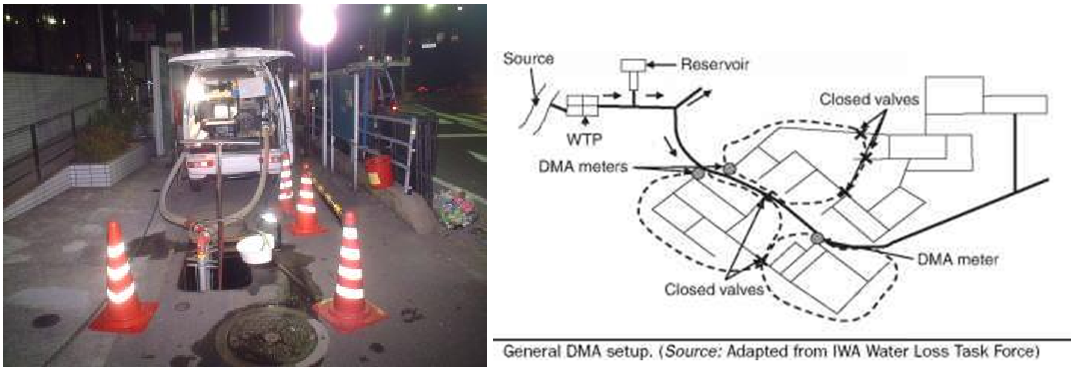

Figure 6. Minimum Night Flow and District Metered Area [http://goo.gl/gjnMI1(Left), http://goo.gl/Ju0azi(Right)]

<u>Systematic Leakage Management based on the Block System</u>

A ‘block system’ is defined as a system of water supply network consisted of separated areas considering the characteristics of the area (altitude, roads, streams, railroads etc.) for efficient management of the water supply network and control on water demand and supply [☐]. Similar concept of District Metered Area (DMA) is also used internationally. It is very effective to analyze the changes in water demand and supply and leakage when the area for water supply is divided into small unit areas based on the hydraulic conditions. The water supply (flow, pressure, and quality of water supplied) in a block can be managed efficiently based on the more detailed data and information, and it helps increase the RWR.

As of the end of 2014, there are 2,037 small-size blocks, 100 mid-size blocks, and 29 large-size blocks in Seoul. The water supply network of blocks was constructed based on the unit block, the small-size block. Old pipes replacement, leak detection, and facilities check are carried out by the small-size block. The MNF measurement for all the 2,037 small-size blocks had been completed between 1999 and 2005. The RWR management by the small-size block is very efficient but requires too much of time, cost, and labor (

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Table 1). Currently, the city of Seoul manages the RWR by the mid-size block. If the RWR of the mid-size block is low, the RWR is managed by the small-size block.

Table 1. Process of RWR management by the small-size block [☐]

Step	Goal	Contents
1st step	Fundamental investigation of the block	To make list of current condition of the block including separation of the block, characteristics of the block, and current conditions of facilities for water supply
2nd step	Selection of block	To select relatively weak block with many leak cases among the blocks separable
3rd step	Measuring water supply and consumption	To measure water supply and consumption in the small-size block three times
4th step	Estimation of the RWR; Plans and strategies for the RWR goal	To make strategies and plans to increase the RWR considering changes in water supply and consumption

<u>Geographic Information System (GIS)</u>

The essential point in the RWR improvement project is to reduce water loss in the water supply system. The most fundamental and effective approach is 'leak detection' and 'replacement of the old pipes'. For the RWR improvement project, it is essential procedure to diagnose the conditions of pipes buried underground, prevent leaks, and reduce loss by aged pipes.

Precise information of location and attributes of water pipes are quintessential to increase the RWR. GIS is a database and computerized management system to accumulate and manage graphic and attribute data for common facilities, water pipes and attached facilities. A user can search for spatial information using waterworks GIS, manage construction, analyze and predict leakage. This can be a preemptive management method for the RWR improvement.

The city of Seoul built waterworks GIS between 1998 and 2001 for efficient management of the pipe network for water supply (Table 2).

Table 2. History of GIS building in Seoul [☐]

Goal	Contents
Building the waterworks GIS	1998: Plan for the waterworks GIS of Seoul 1999: Launching the project to build the GIS 2001: Completion of the GIS
Stabilization of the GIS	2002~2004: Maintenance of the GIS
Advancement of the GIS	2005: Improvement of the GIS 2007~present: Improving the accuracy of the GIS DB

The number of leak cases has been decreased continuously by the precise spatial information after the waterworks GIS was installed in the Seoul Water Authority. The cost for repairing leaked pipes could be saved big as precise drilling on the leaking point was possible. The quick and precise repair could reduce time to cut off water supply and increase the citizens' satisfaction on water service of Seoul. The waterworks GIS will evolved into a decision making support system with scientific analysis and prediction as well as support field work efficiently.

Water Pressure Control using Water Reservoir System

A water reservoir is water storing facility to supply the citizens in the area with water supplied from water treatment plant. The drinking water supply system in a city has to maintain consistent water flow and pressure even in the case of black out or leakage. Without water reservoirs, the function of continuous water supply cannot be secured. As the city of Seoul has many hills and mountains, the city makes use of the water reservoir system based on elevation difference for effective water pressure management as well as effective water quality and energy management.

The city of Seoul had constructed the local, the 1st and the 2nd water reservoirs since 2000. As of 2015, there are total 120 water reservoirs in Seoul with the total capacity of 2.4 million m3. The elevation difference between the reservoirs is about 30 m. A community is supplied with the drinking water from the upper water reservoir (Figure 7). With this system, any excessive water pressure can be controlled at appropriate level. It is very effective system for reducing leakage. In addition, as the water from WTP can be pumped to water reservoirs using relatively cheap power at night time and supplied to the citizens by gravity at day time, the cost for energy to pump can be saved a lot.

The total retention time in the water reservoirs is about 17 hours, which is much longer than 12 hours required by the waterworks system standards of the Ministry of Environment.

5% of all the water reservoirs in Seoul have shorter retention time than 12 hours. The authority has plans to increase the capacity of water reservoirs and build new reservoirs.

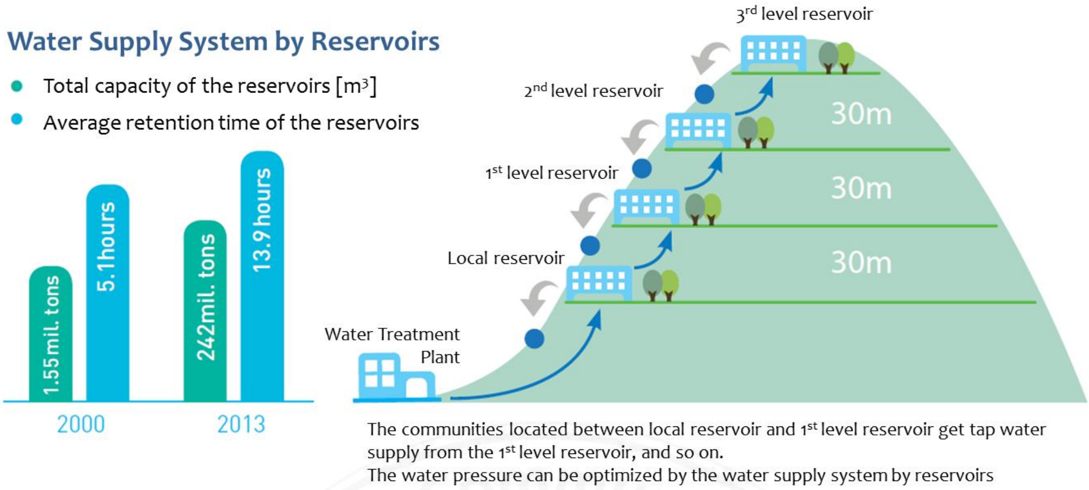

Figure 7. Water supply system of Seoul based on water reservoirs [☐]

[Multipoint Leak Noise Correlator] is a device or a system fining leaking point by detecting, collecting and analyzing acoustic data by leakage from water pipe. The device is very effective to determine leakage by the accuracy of 80%. When there are many pipes buried in relatively narrow space or the water supply and consumption is fluctuated much in the area, or there is big noise by structural characteristics, it may be very hard to analyze the data as the ratio of signal to noise (S/N) is too small. Therefore, it is recommended to collect data at night time when the water consumption and noise from surroundings is smallest, and increase the number of data collection.

Figure 8. Leak detection using multipoint leak noise correlator [☐] (Upper left: leak detection device, upper middle: installing data logger in the valve room, upper right: data collection from the logger, lower left: data analysis, lower middle: symptom of leak (red dots), lower right: leak confirmation through data analysis)

8. Effect of the Policy

As mentioned above, the effects of the project to improve the RWR is evident and direct for water policy. Higher RWR means that water loss in drinking water production and supply is less. It could reduce drinking water production, cost for water source, and costs for materials and energy for treatment and supply processes.

As the result, the managerial efficiency of the waterworks business becomes higher and the citizens can have financial benefits and trust the public service of Seoul including the drinking water service. The social benefit from the citizens' satisfaction is priceless.

As the RWR of Seoul was over 80% in 2000, the city could supply the citizens with enough drinking water from the WTP's with the total production capacity of 3.4 million m3/day. The rate of the WTP operation was about 60% lower than the recommended 75%. As the results, the part of Gui WTP in 2002, the part of Tukdo WTP in 2003, and the Shin Wall WTP in 2003, and Bo Kwang WTP in 2004 were closed. Extra water due to increased RWR could be supplied to the nearby cities with rapid population growth and increased water demand and the city of Seoul could make additional profits11.

Increased benefit of the citizens due to the improved RWR resulted in frozen water tariff. The city of Seoul could freeze the water tariff for 10 years between 2001 and 2011 with increased financial capacity through the RWR improvement project.

The increased production costs could be compensated by the RWR increase and organizational reform, and the city could reduce financial burden of the citizens. In 2012, the water tariff of Seoul was raised by 9.6% to make budget for financial investment on the advanced water treatment process. The water tariff has been frozen again since 2013 through continuous RWR improvement and efficient management.

The closed WTP's were transformed into parks and recreational facilities for the citizens and contributed to increasing the quality of public service for the citizens.

The successful project of RWR increase improved the citizens' satisfaction on various public services of Seoul including drinking water service by the Seoul Water Authority.

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[11] After investigation of water supply conditions in nearby cities within water supply area of Seoul in 2001, the city decided to supply the cities of Kwang Myung, Han Nam, Ku Ri, Nam Yang Joo, Kwa Chun, and Sung Nam with drinking water of 75,000 m^3 every day. The Seoul Water Authority has a plan to supply other cities of Eui Jung Boo and Dong Doo Chun as a long-term project and makes every effort for 'tap water sales' [□].

9. Difficulties and Overcome

One of the largest difficulties for the project to improve the RWR was the underground facilities buried with the urbanization of Seoul, as the complicated conditions did not allow effective replacement or rehabilitation of old pipes. Through the project to improve the precision of the waterworks GIS, the city could understand accurate location and structure of underground waterworks facilities including pipe network. The GIS has improved continuously.

More systematic and scientific separation and management on block unit has been carried out for more detailed management on leakage.

The urban infrastructure for waterworks system in Seoul has been stabilized decades ago. Another aspect of stabilization of system is that the system gets old. Although 97% of old and corrosive pipes were replaced and all of them will be replaced with new pipes by 2018, the pipe replaced in 1984 when the replacement project started became old pipe to be replaced. That is to say, consistent financial investment and preemptive old pipe replacement are required to maintain the performance of the waterworks system in outstanding level. The problems can be solved with long-term financial investment plan and asset management system.

Although the water reservoir system is also stabilized, support from the citizens in the area and the borough office is inevitable for increasing the capacity of water reservoirs and building new reservoirs. To make parks and recreational facilities on top of the water reservoirs can be a good approach to solve civil complaints related with water reservoir construction. The city needs to communicate with the stakeholders at the beginning of the project to build water reservoirs.

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