# Efficient Drinking Water Supply System

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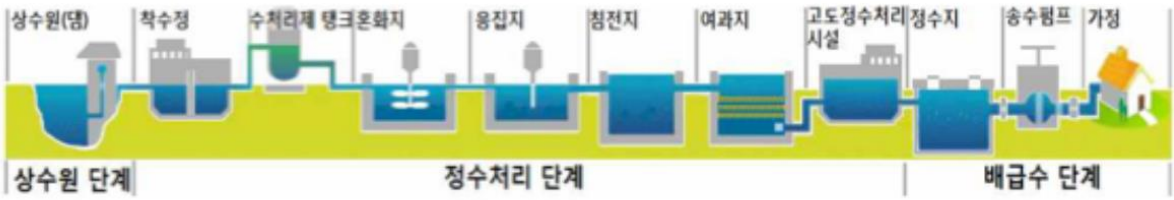
## SUMMARY

The challenges faced over the course of establishing a waterworks system for Seoul can be broken down into three sectors: 1) aggressive expansion of the water network to serve a growing population; 2) addressing demands for quality improvement; 3) efficient management and operation of the waterworks. Once a satisfactory level of continuity and efficiency in the water supply was achieved, the next policy agenda for the water utility became the achievement of a higher quality of service and management efficiency. There are two main stages in water supply. The most important and basic stage involves the obtaining of fresh water sources and preparing an adequate quantity of purified water. The second stage is ensuring a stable distribution of the water to the end users. When it comes to delivery, pressure boosting is one option for facilitating the process to highland areas. As water is essential for human life, securing a stable water supply in anticipation of emergencies or disasters also needs to be considered.


[Figure 1. Water Production Process]

<Figure 1> Water Production Process

# Early Seoul Water Supply

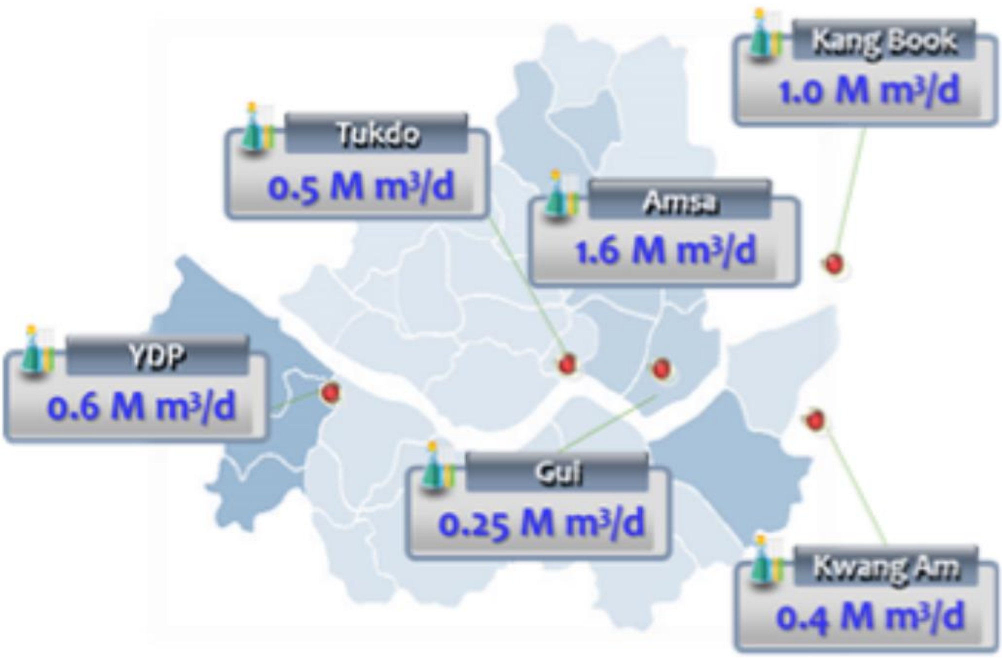
The first modern water supply system was introduced on December 9, 1903 when C.H. Collbran and H.R. Bostwick were granted a license to construct and operate a water supply system by Gojong of the Korean Empire. In August 1905, the license was transferred to Korean Water Works Co., which initiated the construction of a slow filtration basin at the Tukdo Water Treatment Plant in August 1906. This first official water supply system in Korea was completed two years later in 1908 and went into operation in September of that year, delivering 12,500$m^3$ of water to 125,000 people daily. As for organizational support, in order to address water issues in Seoul and boost the efficiency of its tap water management, Public Services Bureau was established to undertake water supply management. Eight local operations offices were installed for the management of water affairs in various administrative districts in Seoul. Notwithstanding all this hard work, most of Seoul's waterworks were severely damaged by the Korean War, which broke out in 1950. By the end of the war, which lasted just over three years, 30~90% of the treatment facilities were ruined, along with an estimated 90% of the communications system. While facing such critical losses, the authorities and other people in the water industry managed to tend to urgent needs. In 1954, a year after the ceasefire agreement, and for the next five years, major rehabilitation and expansion projects began with the help of UN aid and state funds. Due to financial difficulties, the government had to resort to foreign aid and state loans to restore the devastated water system. Korea received aid from the Foreign Operations Administration (FOA) in 1954 and the retitled International Cooperation Administration (ICA) in 1956 for the restoration and expansion of waterworks. By 1961, a total of $1.742 billion in foreign credit was brought in from the ICA, DLF (Development Loan Fund) and their consolidated body, the AID/DG (Agency for International Development/Development Grant). This series of post-war recovery projects was completed in 1955. With the completion of the No. 2 facility at the Gueui Purification Plant in 1956 by an all-Korean team, a series of ambitious expansion and improvement projects began. Continuous investment resulted in tripling the capacity, which increased from 59ℓ/person in 1945 to 163ℓ/person in 1960.

# Expansion of the Treatment Facilities for Greater Capacity

Demand for water increased exponentially with drivers such as fast urbanization and industrialization, making the necessity of expanding the water facilities obvious. In particular, additional administrative support was needed in vulnerable regions with lower water pressure, such as the highlands and the extremities of the water supply lines. Seoul Metropolitan Government mobilized financial resources through foreign aid and state subsidies, which enabled a full commitment to investment in water production facilities, water supply facilities, and auxiliary water treatment plants. During the postwar restoration stage from 1945 to 1960, Seoul sought to establish the foundation for a self-sufficient waterworks technology with technical and financial assistance from foreign countries. Along with the Water Act, which was established in 1961, facility investment in the water sector was promoted under the Five-year Economic Development Plan in 1962. The funding sources at this time began to diversify from what had predominantly been just the United States, to include Japan and Germany, among other countries. The IBRD (International Bank for Reconstruction and Development), the IDA (International Development Association) and the ADB (Asian Development Bank) also supported the development of Seoul's waterworks system through loans and free technical assistance.

Since 1952, overseas training programs for Korean tap water technicians have helped to advance domestic tap water-related technology to the next level. Introduction of tap water project centers, coupled with education programs, contributed to the training of working-level professionals. Under the first facility expansion plan (1960-1963), supplementary reservoirs in Sinchon, Miari, and Bulgwang-dong were built to serve the fringe areas, while expansion and repair works were done on the Gueui, Ttukdo and Noryangjin Purification Plants. With the completion of these projects, the city's water production capacity went from 277,600㎥/day to 348,600㎥/day by 1963. The second expansion project was conducted between 1964 and 1969. It included the construction of two purification plants (Bogwang and Siheung-dong), along with improvement and expansion of the existing treatment facilities. As a result of the second expansion project, capacity was increased by 430,800㎥/day, making the daily production of the Seoul waterworks system 826,600㎥/day by late 1969. Another ambitious project which would double the capacity of Seoul's waterworks system was slated for a short period in 1970-1971, but full execution of the project was not possible due to the delay in introducing foreign funds, so the project ended up with some expansion works done on Tukdo, which added 453,400㎥/day in water production. In 1972, a 10-year plan for waterworks expansion was begun to address the exploding demand for water as part of the Comprehensive Municipal Administration Plan. This plan involved construction of large-scale purification plants (Yeongdeungpo, Bogwang and Seonyu) and improvement and expansion works at several existing facilities. By the 1980s, as the result of such endeavors, Seoul's waterworks system improved significantly, with a total capacity of 3,070,000㎥/day. During this period, the waterworks project was self-supporting. Seven major Korean cities (Seoul, Busan, Incheon, Daegu, Daejeon, Gwangju and Cheongju) embarked on waterworks facility improvement projects with state funds, which also financed waterworks projects by local municipalities. In the late 1970s, the Multi-regional Water Supply Project was launched, consisting of six stages. This was the country's largest project to develop a reliable water supply system for residential and industrial use, and once completed, would deliver water to 24 local communities in the metropolitan area, including Seoul, using raw water from the Paldang Dam. Due to a lack of local funds, the project was transferred to the Ministry of Construction. By the 1980s, owing to the steady expansion of production facilities and the slowing of population growth, the water supply began to stabilize. The service rate went beyond 90%, and the daily water supply per person reached 400ℓ, a level comparable with advanced countries. However, this did not stop Seoul from pursuing further expansion in its endeavor to keep up with its citizens' rising demands for wider accessibility, and so improvement in the reliability of the waterworks system continued. To finance further modernization projects for water supply facilities in the 1980s, the city acquired loans from the [Overseas Economic Cooperation Fund (OECF)] (KO-22) in 1983 and the OECF (KO-30) in 1984. These loans provided funding for the basic plan and the designs for the project, as well as the acquisition of leakage restoration equipment. Local bonds, together with foreign loans, were critical in financing the water supply.

Introducing foreign funds and local bonds for the construction of water supply facilities not only mitigated the financial strain, but also promoted technology transfer from foreign countries. This enabled Korean engineers to accumulate experience and expertise while working with international experts.




[Figure 2. Capacities of Purification Plants]

■ Tackling Quality Issues of Raw Water

Since the City was able to secure sufficient production capacity by the 1980s, increasing production was no longer a priority. However, when water pollution became a serious issue worldwide, concerns for the quality of source water began to rise. As the quality of the Han River deteriorated (from industrialization and urbanization), the management and protection of water sources became a priority. At the same time, headlines concerning frequent water quality problems led to public distrust in the quality of the tap water, rendering the protection of water quality a national concern.

As the public's interest in safe drinking water grew, Seoul Metropolitan Government (SMG) came up with the Water Facility Modernization Plan in 1985, coupled with a comprehensive plan to raise national water quality standards. Included in the plan was the provision for a computerized system which would provide optimal management for tap water quality through more effective pollution control.

■ Supplementation of Pressure Booster Stations and Distribution Reservoirs

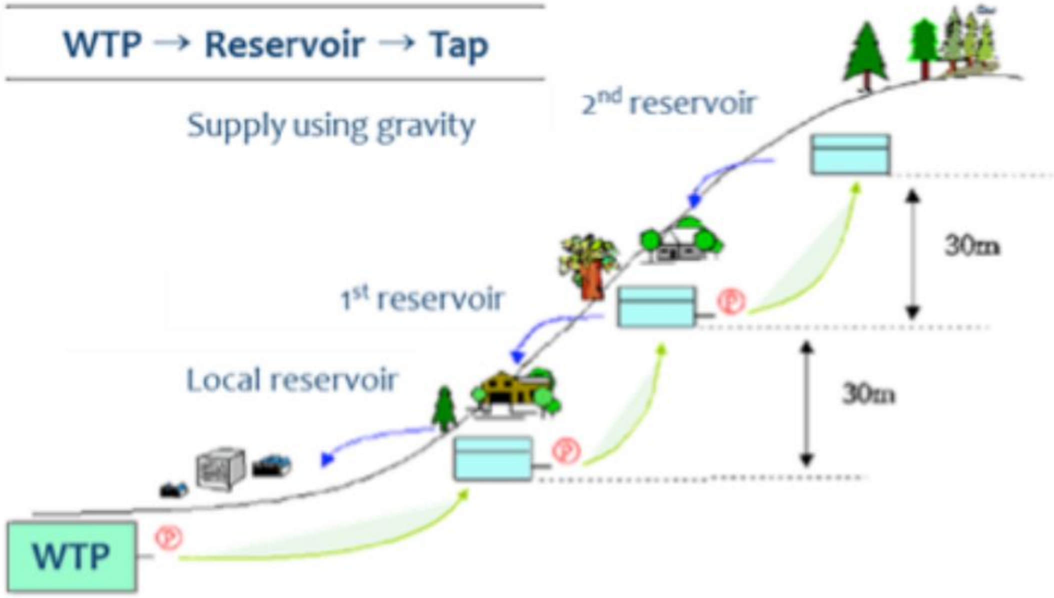
To address the sustained water shortage in the underserviced areas, 122 pressurizing stations in total were secured by 1989 and privately-held stations were nationalized. From 1985 to 1987, a total of 11 large distribution reservoirs were constructed, adding 648,000㎥ in capacity. With the acquisition of these new facilities, the capacity of Seoul's water supply system more than doubled.

■ Improving the Delivery System

Although the implementation of continuous expansion projects throughout the 1980s brought a substantial improvement in the capacity of Seoul's water supply system, further investment in waterworks was carried out to satisfy the higher standards demanded by citizens. Moreover, city authorities wanted to ensure a reliable supply without outage against all eventualities, so it was necessary to secure a spare production capacity.

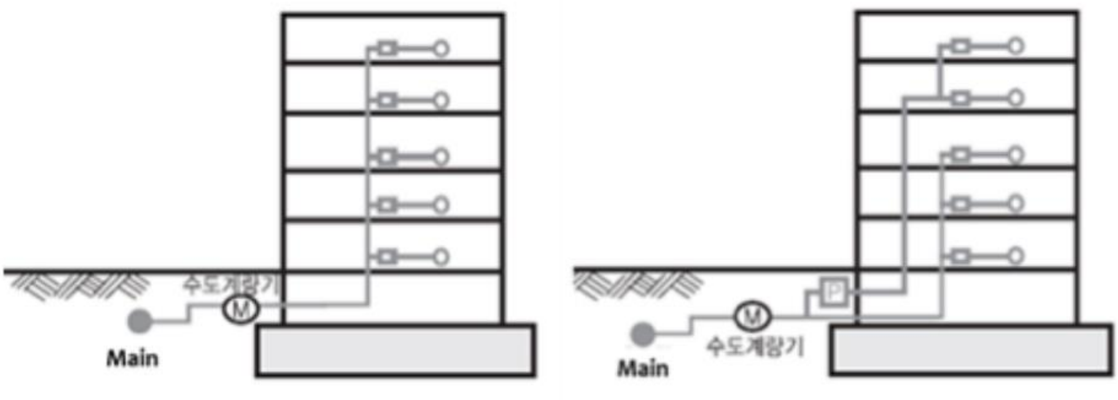
Along with investments on new purification facilities, existing facilities underwent renovation as well. One example is a three-stage expansion project for Amsa in 1989, 1991 and 1998, with a capacity increase target of 250,000㎥/day, 320,000㎥/day and 300,000㎥/day respectively. Construction of Gangbuk Water Purification was also performed around this time in two phases: phase 1 was completed with a capacity of 500,000㎥/day in 1998 and phase 2, with an additional 500,000㎥/day in 1999. After completing facility expansion works on the Tukdo, Bogwang and Yeongdeungpo plants, a total production capacity of 7,300,000㎥/day was attained as of 1999, sufficient to guarantee a reliable supply.

In keeping with the newly-added capacity in production facilities, investment was made in the construction of a series of large-scale reservoirs. This indicated a shift in the mode of tap water supply from a direct distribution system to an indirect system, which would ensure higher operational availability and reliability. These investments resulted in the opening of 22 new distribution reservoirs, achieving a total storage capacity of 1,260,000㎥ and drainage dwelling of 4.4 hours.




[Figure 3. Indirect Water Distribution System Using Reservoirs]

To improve the quality and reliability of tap water, a direct-coupled water supply system which delivers water directly to each floor using the pressure of pipes, bypassing indoor water storage, was promoted. This new system utilized the pressure created by the different reservoir heights, saving the cost of pressure boosting and also improved water quality, eliminating dead storage problems.




[Figure 4. Direct and Boostered Direct Water Supply System]

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| ` <Figure 4> Direct and Boosted Direct Water Supply Systems |

# Improvement of Revenue Water Ratio

While supervising massive-scale facility investments, the authorities in Seoul's waterworks faced a series of management challenges in the 1990s that threatened the quality of tap water and water services; challenges such as waterworks pipe deterioration, billing and tariff collection difficulties and rising operation costs. Such problems demonstrated the necessity of an independent agency in charge of coordinating water-related affairs among different regional bodies, resulting in the launch of the Seoul Waterworks Authority in 1989. The water supply in Seoul was significantly improved during the 1980s~90s, with the acquisition of new major treatment plants and improvements made to existing plants. By 1999, the city had achieved sufficient production capacity of 7,300,000㎥/day. In the 2000s, with continued facility expansion and investments to increase geographical coverage in challenging areas such as hillsides and extremities of the supply lines, the service rate in Seoul reached 99%. Following the establishment of a reliable supply system, the policy agenda for waterworks went from supply-oriented schemes to improvement of waterworks management via control of water quality and increase of revenue water ratio (RWR). RWR is an indicator for measuring the percentage of billed water as a share of net water produced in filtration plants. Higher RWR means reduced tap water loss from leaks and metering failures, positively affecting the financial viability of water utilities by increasing water profits and reducing unnecessary operating costs. Unaccounted-for-water (UFW), a term widely used by international organizations and scholars, means the difference between the quantity of water supplied via a city's network and the metered amount of water actually used by customers. UFW consists of two components: (a) physical loss due to leakage from pipes, and (b) operational losses owing to illegal connections and under-registration of water meters. Lowering the UFW is crucial to improving the financial health of water utilities and protecting scarce water resources. Although slightly different, both UFW and RWR are indicators of how well water utilities are managed.

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|---|---|
| Groundwork for RWR Improvement (1989 - 1995) | Installation of flow meters by district offices (1990) |
| | Replacement of old pipes (4,200 km) (1991 - 1995) |
| | Establishment of metering system based on district flow meters (1990 - 1995) |
| Administrative Support For RWR Improvement (1996 - 1999) | District level measurement of water production and RWR (1995 - 1997) |
| | Introduction of small block system (2,037 blocks) for Minimum Night Flow (MNF) analysis (1998) |
| | Inauguration of a Water Assessment Team (1998) |

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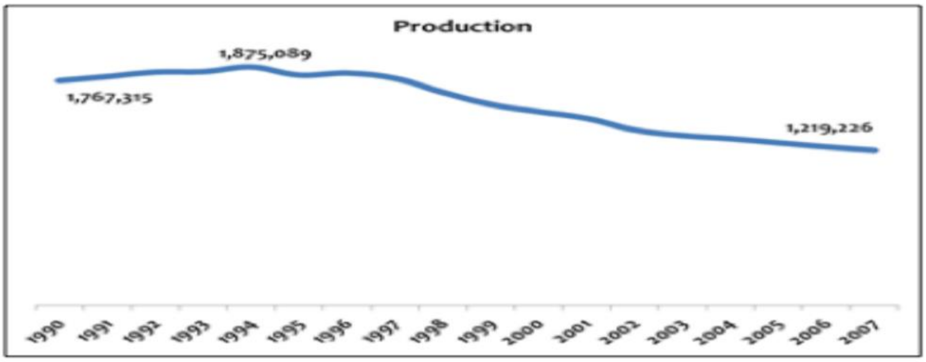
|---|---|
| | Inauguration of an organization in charge of the RWR improvement project (1999) |
| | Installation of smaller diameter pipes and standard flow meters (1996 – 2000) |
| | Establishment of a district-level database on RWR (1998) |
| | Intensive facility management of redevelopment sites (1999) |
| Attaining International Competitiveness (2000 – ) | Shift to indirect water distribution system (2000 – 2003) |
| | Systemic management of unused pipes (359 km) (2003) |
| | Launch of medium block system (2004) |
| | Introduction of multipoint interaction leak detectors (2004) |
| | Introduction of a flow detection system for production quantity analysis and flow control (2005) |

While investing in capacity expansion programs in the 1980s~90s, constant efforts were made to reduce physical loss from the deterioration of the piped network. The programs introduced to increase RWR by the authorities in Seoul waterworks are summarized in Table 1.



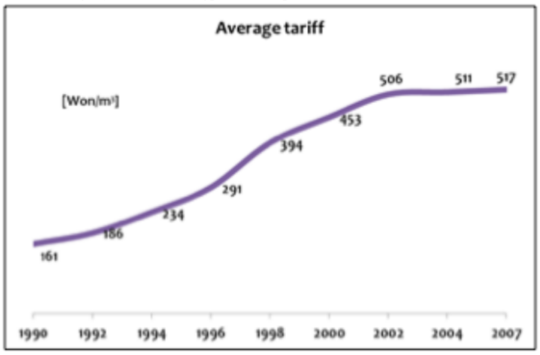

[Figure 5. Trends in Tap Water Production]

Such dedication to improve water losses brought about a significant improvement in RWR for Seoul, and this was followed by closure of aging treatment plants. After modifications, Seoul's waterworks was able to maintain a capacity of 5,400,000㎥/day as of 2004. Following the downsizing of production since 2000, SMG transformed closed water treatment plants into public recreational space (i.e. Seonyudo Park).

[Figure 6. Sunyudo Park (Former Water Treatment Plant)]

<Figure 6. Seonyudo Park (Former Water Treatment Plant)>

Increased RWR and reduced production demands facilitated the rationalization of management, which enabled the downsizing of staff and a reduction in operating costs. As a result, water tariffs remained the same between 2001 and 2009. The reduction of water losses ultimately led to an improvement in water quality, as it involved facility upgrades and management rationalization.




[Figure 7. Average Water Tariff]

# Efforts to Improve RWR

Controlling RWR and repairing pipelines had been the two foremost policies at the Office of Waterworks since the institution's foundation in 1989. To prevent deterioration and maintain the pipe networks, it was necessary to replace or repair aged pipelines that could rust and cause leaks. For the maintenance process, the existing pipelines were arranged into blocks, based on which replacement and repair work was carried out. This new arrangement allowed for systemic management of water flow rates and meticulous quality control.

Water loss is the amount of tap water lost before it reaches the end user. Water leakage can cause water quality deterioration and physical damage to the environment, which in turn leads to financial loss.

Causes of leakage can be as diverse as deterioration of pipes, malfunctioning of valves, poor construction, overpressure, rupture, and numerous kinds of physical damage to the pipes. As for leaking pipes, the surrounding physical environment may be responsible, but this can also occur when unused pipes are not removed or just left open.

■ Leakage Detection: Minimum Flow Analysis

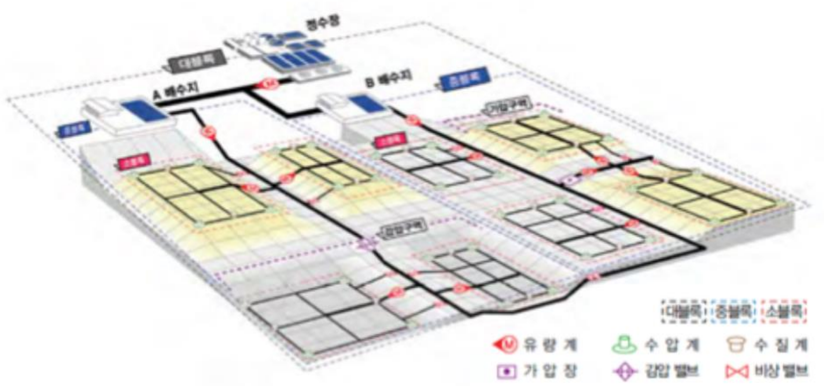
As an effective measure for evaluating water loss Seoul's water network adopts Minimum Night Flow (MNF) analysis, which is based on the average flow measured in a block within a time band (12:00 am to 4:00 am) when water consumption is at a minimum. When any observation over the minimum flow level is identified, the block is examined to make sure there are no leaks. This system conducts real-time assessment as well as delivering information to assist in the timely detection of irregularities. Each of Seoul's tap water networks is divided into blocks to facilitate minimum flow analysis. In 1998, the minimum flow was defined at 1 $m^3$/hr·km, then during the 2003 to 2005 period, it was set even lower, varying from 0.5 $m^3$/hr·km to 1 $m^3$/hr·km depending on the situation for each block. From 2006 onwards, only blocks with an estimated flow beyond the allowable amount (2.0 $m^3$/hr·km) are tested.

## ■ Rehabilitation of Old and Unused Pipes

Deterioration of pipes can create a critical water loss and public distrust in the water service. An important factor to consider when planning water main renewal therefore, is pipe material. Pipes made of material such as grey cast iron, zinc, steel, and PVC installed before 1984 were prone to corrosion that causes frequent leakages and discoloration of tap water. Pipes made of non-corrosive material which are more than 40 years old need be replaced due to the expiry of their lifespan. The city's replacement programs were promoted based on the priorities outlined in the Guideline for Water Distribution Pipe Repair Work. Retrofitting water mains with a frequent leak history was a priority, as were pipes misaligned with the grid system and blocks with a concentration of older pipes. Repairs on areas with a history of red water or overpressure were integrated with scheduled maintenance on nearby blocks, or a separate repair program was conducted which focused on areas with numerous complaints of red water and low pressure. Among the old leak-prone pipes buried near streets, those near main roads would be eligible for replacement first. Some of the unused pipes which were still connected to others which were in use were also subject to the pipe replacement program. Some pipes become abandoned when their connection to the mains is not disconnected after replacement or repair work, causing severe water deterioration and leakage. Removal of these abandoned pipes resulted in a significant improvement of RWR.

## ■ Block-level Water Distribution System

To facilitate management of the water supply, Seoul's entire water supply network was divided into 2,037 small blocks. Based on this block system, the pipe network was rearranged so that tasks such as facility repairs and leakage detection could be managed more efficiently.




[Figure 8. Block System]

MNF analysis was first introduced in 1999 to select blocks. Using flow meters installed at strategic points in these blocks, assessment of supply and usage is conducted at the block level. This methodology provides a useful set of data for identification of irregularities, helping to increase RWR. Conducting flow analysis can be more accurate and enables timely intervention if the water network is divided into smaller blocks, but this can also be costly. For this reason, most blocks are of medium size, with the exception of low RWR regions or frequent trouble-areas, as Seoul's water utilities has an RWR of 99%. In addition to employing the small block design, which reduces water loss in the target areas with lower RWR, this has also involved relentless monitoring and leakage repairs as well as intensive repairs to deteriorating pipes and maintenance of unused pipes. In the past, a pressurized irrigation method was used to supply tap water to the highlands, and this often caused surges and leakage, as the rate of water loss through leakage can increase with excess pressure. Block-level management has proven to be successful in reducing and controlling overpressure problems.

■ Managing Risks in Redevelopment Sites

Redevelopment projects often involve demolition and infrastructure modification and take an average of 10 years from appointment to completion; no investments in water facilities are allowed during this period, causing deterioration of the water pipes in the area. Existing water facilities which are buried underground are also very susceptible to damage from construction work. Such disruption of water supply facilities violate city ordinances and cause water loss, therefore the condition of this valuable asset needs to be continuously monitored. Good management practices can reduce water loss resulting from deterioration of facilities buried in a redevelopment site. This means monitoring the following: 1) fraudulent activities such as unauthorized use of water, 2) leakage, 3) disclosure of distribution mains and joints, 4) open pipe ends, 5) redundant flow meters or power connections, and 6) ruptures or freezing of water meters. Seoul's experience in preventing water loss at redevelopment sites has demonstrated that most water damage can be prevented with mitigation efforts and diligent management.

# Improving Water Quality

**Management of Water Sources**

A key to the production of clean, safe water is securing a good water source. Since Seoul's tap water is reliant on the Han River, it (the river) is subject to numerous sources of pollution from Seoul and the surrounding region. The main drivers of pollution are industrialization and population growth, and this raises the necessity for adequate countermeasures to protect the river from contaminants and pollution.

Aware of the Han River's degradation, Seoul Metropolitan Government came up with a system to monitor the quality of the Han's upper reaches, including a 24-hour automated measuring system at intake stations to detect the presence of microorganisms or phenolic compounds. In addition, to protect the source water from any accidental inflows, physical barriers such as fences and silt protectors are installed around intake stations. To promote the support of the citizenry and encourage their engagement in protecting source water, corresponding policy support accompanies these actions. This includes the designation of special conservation areas near the upper reaches of the Han River. A case in point would be the Paldang Watersource Conservation Zone, so designated in 1975 in the area of the 4 municipalities near the Paldang Dam. There are also special riverside zones in areas adjacent to dams and streams with regulations on discharging pollutants as well as other types of water source exploitation. To protect Jamsil's water supply source, which provides a substantial portion of Seoul's water supply, in 1995 the city banned pollution-inducing activities in the area. By July 1998, some of the aquatic facilities which affected water quality were relocated to the lower reach. There can be no doubt about the importance of governance in implementing such measures. The management of water quality of the Han River is a complex task as it involves a number of different municipal bodies and agencies. To integrate the efforts of different entities and stakeholders, the Jamsil Water System Management Council was inaugurated on September 27, 1999, following the enactment of the 'Act on the Improvement of Water Quality and Support for Residents of the Riverhead of the Han River System' on February 8, 1999. Chaired by The Minister of Environment, members of the council has included the Mayor of the Seoul Metropolitan Government, the governor of Gyeonggi-do, and the presidents of Korea Water Sources Corp. and Korea Electric Power Corporation. This council decides on issues pertaining to the Jamsil region of the Han River, such as collection and management of water fees, allocation of funds, regulations on pollutants, and preparing pollution reduction programs. To raise funding to compensate for the inconvenience to residents in the water conservation zones, a tariff of KRW 80/㎥was introduced in 1999. As of 2009, Seoul Metropolitan Government charges KRW 160/㎥of tap water; the collected fees go to the Han River Water System Management Fund. By 2008, a total of KRW 2,665.2 billion had been raised, including the total water rate collection of KRW 1,222.8 billion. KRW 640.1 billion had been spent on community support projects, KRW 513.6 billion on the acquisition of lands in the basin area, KRW 705.9 billion on the installation of environmental facilities, KRW 640.1 billion on operation and maintenance of environmental facilities and KRW 357.6 billion on other water quality improvement projects.

**Monitoring Water Quality and Securing Supplementary Water Resources**

When the quality of the Han River became a serious issue in the 1980s, one of the first countermeasures was to take water from the upper reaches of the river. KRW 48.3 billion was invested to construct a new intake facility of 700,000㎥/day in Pungnap-dong, construction for which began in August 1990 and was completed in April 1992. The installation of a new intake facility resulted in a substantial improvement in the quality of Seoul's water system. The quality of source water is a determinant factor of the purification process. Regular and integrated monitoring of source water can not only help to ensure the quality of the water, but is also the most essential step in producing reliable tap water. Pursuant to the Framework Act on Environmental Policy, Seoul Metropolitan Government has conducted regular monthly tests on 5 items at 20 water points of the North Han River since July 1990. Currently, Seoul's automated monitoring system performs regular tests on 42 items at 33 water source points and 135 items at 6 intake points. The new pollution monitoring system was devised after the widely-reported phenol spill incident at the Gumi Industrial Complex in 1991 which led to the release of volatile pollutants into the area drinking water. Following this incident, water quality assessment and pollution management were identified as a major focus of Seoul's water policies. A network of water quality monitoring stations was established throughout the city to detect pollutants and provide alerts when accidents arise. In 1992, an investment of KRW 580 million was made to activate a new system network that could constantly monitor water quality, and six automated monitoring stations were installed in the Amsa, Gwangam, and Gueui plants. Two similar stations were installed in the Jayang and Pungnap intake stations in 1993, allowing 24-hour automated water quality monitoring for all source waters that flow into Seoul. The data collected from the six stations are sent to the central system, which was integrated into the Seoul Water Now System in 2005.

### Managing Drinking Water Quality

Managing the quality of drinking water is an essential issue as it affects citizens' health. Seoul's waterworks system uses a risk assessment process to determine drinking water quality standards. This process assumes that the average adult drinks 2 liters of water per day throughout a 70-year lifespan. Risks are estimated separately for cancerous and non-cancerous effects: strict standards are set at a level that limits a person's risk of getting cancer to 1 in 10,000 from each contaminant factor. Appropriate analytical techniques are indispensable for the detection of changes in water quality during distribution and for ensuring good quality drinking water at the consumers' tap. Seoul's monitoring system is designed to encompass each step of the water supply chain, from catchment to consumer. To monitor the effect of each treatment step, tests are conducted at various locations of water distribution networks based in the vicinity of 6 Arisu purification plants and 27 distribution reservoirs, including 24 distributing points, 5 points at pressurizing stations and 26 taps at pipeline extremities. Key parameters are selected for the monitoring of water quality and the efficiency of the treatment steps, and are monitored in the water leaving the works and within distribution, to verify that the water is properly treated. Seoul's key waterworks parameters are microbiology, pipe deterioration, and tertiary contamination. This criteria selection involves quarterly monitoring of 11 substances in total, including residual chlorine, copper, zinc and iron, hydrogen ion concentration, iron and copper. Based on the results of regular monitoring at all locations of the water supply chain, Seoul's tap water has satisfied all the criteria. The data on the biological and chemical water quality parameters selected provide essential information on changes in quality, changes during distribution, performance of treatment technologies, and catchment characteristics. Besides the regular monitoring, special monitoring may be necessary at locations within the supply network that are particularly vulnerable to contamination. Since 2007, regions with anticipated degradation in water quality, such as extremities of the supply line, have undergone intensive monitoring at the medium block level. Also ongoing are additional quality tests on inlets, beginning in 2009, measuring six items at 298 points every month, and the test results are reported to the public. These efforts contribute greatly to the public's confidence in Seoul's tap water.

[Figure 9. Water Quality Monitoring by Medium Blocks]

The impact of old pipes on water quality is also periodically monitored. Within the districts with a higher concentration of old pipes with a diameter over 400 mm, 12 sampling points (2 points per water system) are selected for monthly testing; the test measures 12 items such as turbidity and bacteria. Secondary contamination from old pipes and the monitoring of water quality changes in vulnerable regions are managed as priorities.

■ Seoul Water Now (SWN) System

To build an automated system for monitoring water quality from raw water to end users, Seoul Metropolitan Government launched a comprehensive plan in 2001. By the system’s completion in June 2005, KRW 4.8 billion had been invested in the cutting-edge project, which performs round-the clock monitoring of water quality during distribution. If the water quality does not meet the set criteria, the monitoring system issues an alarm to signal possible contamination. Measurement results are collected to provide the necessary indicator data required to track performance over time. Engaging the public in the surveillance of source water quality can contribute to a large extent to their trust in its high quality. The "Seoul Water Now System" is designed to perform real-time monitoring of water quality from the source to its purifying process, open the water quality information online, and automatically detect any irregularities and implement instant remedies. This system uses automatic water quality testers installed at 200 spots over the course of producing and supplying tap water, as well as a monitoring system for 5 items measured at 200 sites: pH, turbidity, chlorine residue, electricity conductivity, and water temperature.


[Figure 10. Seoul Water-Now System Website]

# Conclusion & Suggestions

Policy direction when addressing the public's demands for better water quality have to reflect the rising standard of living; it is rarely designed based on one perspective, but rather is grounded in the urgent needs of the public. Securing a reliable water supply system has long been a primary focus of Seoul's initiatives. More recently, developing advanced purification technologies has become a hot issue, not only because of its relationship to environmental issues and human health, but because of the growing calls for improvement in the taste of tap water. Seoul's highly advanced purification technologies help to remove unpleasant tastes and odors as well as providing protection from environmental pollutants. The strenuous measures taken by Seoul for a better water supply system, including facility expansion and RWR improvement projects, are not unique projects, but all correlate with each other. The capacity-building projects to increase service rates led to improvements in RWR and water quality. The raised standards for drinking water, with more factors added for monitoring, was also instrumental in achieving the international-standard level of water quality. Since 2009, the effectiveness of the system has been well demonstrated by the improvement made in turbidity (0.05 NTU), which has been significantly improved compared to the 0.43 NTU of 1991. Without meeting quantitative demands first by increasing the capacity of the purification plants and distribution facilities, the advancements made in the qualitative aspects of the water service would have been impossible. The systemic management of both the quantity and quality of water production allowed for the efficient maintenance of water mains and deteriorated pipes, which in turn led to increased RWR. Ultimately, the improvement made in RWR created a virtuous cycle as the enhanced efficiency in the water distribution system led to better quality and greater capacity of the waterworks.

# Time of Policy Implementation

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

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

Improvement of RWR can be directly related to the streamlining of management.

# Situational Background for Policy Implementation

Water systems go back to the earliest history of human beings, as we need water to live. The archeological evidence tells us that the history of water systems in Korea goes back to the 7th century. The system was a very basic one to supply the citizens with groundwater and clean surface water through a pipe system made of wood and/or clay.

**Modern Waterworks Systems**

The modern waterworks system of Seoul began operation in 1908 with construction of the Tukdo WTP, which supplied the citizens with treated water. During the Japanese occupation, which began in 1910, the capacity of drinking water production and the supply system did not keep pace with population growth, as the treated water was supplied to a few select citizens only. Although Korea won its independence in 1945 with the end of World War II, political turmoil and social instability continued. Due to the chaotic conditions, few people were concerned about urban development and the operation/maintenance of social infrastructure.

**The Korean War**

The political turmoil grew due to the tragedy of the Korean War in 1950. During the war, the total number of dead, missing, and wounded soldiers was 973,000 while for civilians it was 2.1 million, or 1 in 5 family members. This was not only enormous damage for the individual and for society, but was also a national tragedy. The damage to industrial facilities was so huge that between 35 and 90% of all urban infrastructure was destroyed. It took years for Korea to recover from the damage caused by the war.

**Economic Growth**

Water demand grew rapidly with the expansion of urban areas and an explosive increase in population due to economic development in the 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 was the equivalent to building a city with a population of 300,000 every year. The city of Seoul spurred urban development to accommodate its rapidly-increasing population. Around 25% of the current urban area of Seoul was developed in the 1960's and 1970's.

**Expansion of Tap Water Production and Supply**

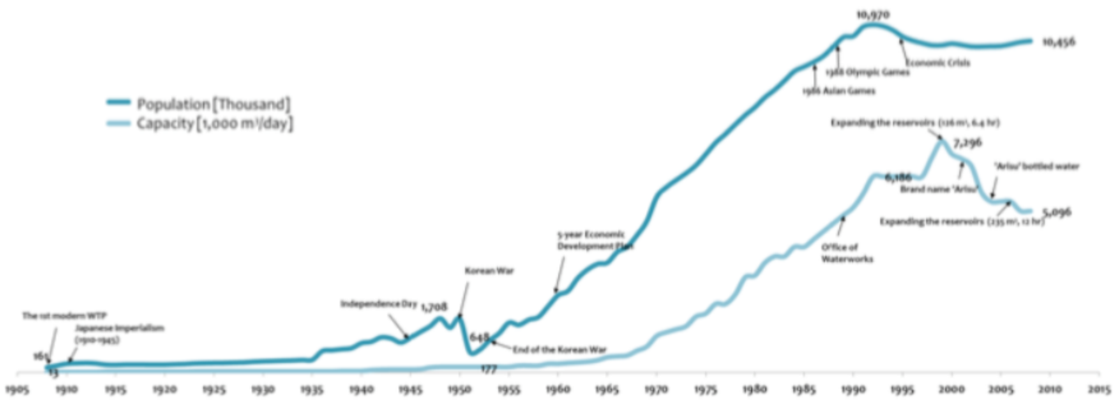
Seoul made every effort to adapt to the changes by increasing drinking water production capacity and expanding the network system for treated water. It was still not enough to cope with the explosively-increasing water demand.

310,000$m^3$ 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 its waterworks system with a 3-year plan in 1965, even with the difficulties mentioned above. The goal of the plan was replacement of old pipes and scientific leak management. The financial problems would be solved by international funding and the issuing of national bonds.

Although some parts of the plan had problems coping with the population increase, the condition of Seoul's water supply gradually improved.

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




Over 90% of all citizens could get water service in the 1980's, compared to 60% in the 1960's. As the water demand could only 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 mentioned above, there was rapid industrialization and urbanization with the implementation of the national economic development plans, coupled with a rapid increase in the demand for water with the corresponding population growth. The city focused on increasing its drinking water production capacity and improving supply systems during the 1970's and 1980's. As a result, the waterworks system of Seoul was able to provide its 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 from incomplete treatment of waste water in the early 1980's. The city had difficulties treating the dirty source water from its use of too much chemicals.

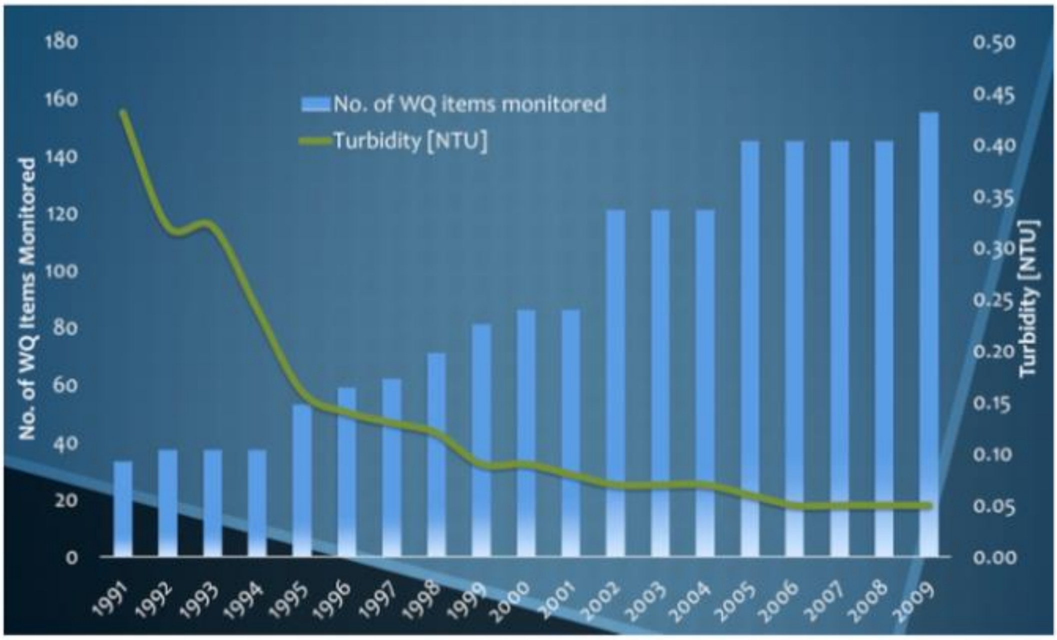
With the Asian Games in 1986 and the Olympic Games in 1988, the city made great effort to get the Han River in good condition, including building and expanding waste water treatment plants.

There were many water pollution accidents, including an increase in ammonia nitrogen concentration in local waterworks systems and phenol flowing into the Nakdong River (located in south-eastern part of the Korean peninsula). Tap water quality became a national issue as more and more citizens did not trust its quality. The central government of Korea introduced the 'Comprehensive Plan for Clean Water Supply' and launched innovation projects, including aggressive protection of water sources, prevention of water pollution, and improvement of the drinking water treatment system.

The city also made the waterworks service highly specialized by; 1) launching a research institute to research and develop water treatment technologies, scientific water quality management, and increase system efficiency, 2) streamlining the monitoring and management of source water protection areas and active cooperation, 3) improvement and replacement of old facilities in the water treatment plants, and 4) massive replacement, cleaning, and rehabilitation of old pipes in the supply network.

The launching of the Seoul Water Authority and the efforts made by the city resulted in the improvement of the quality of drinking water as well as the maintenance of source water quality at world-class levels.

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




**Improving Efficiency of Water Management**

The goal for drinking water policy changed from quality and quantity to efficiency as the city secured enough capacity for its qualitative and quantitative goals. The city was able to produce enough drinking water by increasing the capacity of the water treatment plants, and was able to supply its citizens consistently with high-quality drinking water.

A water reservoir is a water storage facility within a water supply system, and secures a consistent supply of drinking water by controlling the amount of water supplied directly to the public. The capacity of the water reservoir is critical for a consistent supply of drinking water, as well as the capacity for 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.

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 1.3 million $m^3$ in 1999, which could guarantee a continuous supply of drinking water for 6.4 hours under any conditions.

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

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

**Figure 3. International standard terms on water balance by IWA**

| | | | | |
|---|---|---|---|---|
| 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 | 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 | |

## Importance of the Policy

The water system of Seoul is quite different from other public organizations in its organizational, managerial, and financial characteristics. It 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 finances of the Seoul Water Authority are controlled as a special self-supporting system depending on the water tariff from customers only.

The mission of the Seoul Water Authority is to provide the public with clean, safe drinking water as a public service. At the same time, as a company, the Authority must achieve its goal of rationalization of administration and management.

It is very important to reduce the prime and operational costs through increasing the RWR and efficient collection of the water tariff for rationalization of water business management. It is critical to maintain sound financing by increasing the RWR (the ratio of the volume of water secured as tariff income to that of the total volume produced and supplied).

Although it's not easy to increase the RWR, it can be achieved through long-term planning for the reduction of non-revenue water by cause, and consistent implementation of the plan. The main goal of the 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 system efficiency can be a goal for the next step in the project. The city of Seoul was able to build an efficient water system through RWR-increasing projects.

As a result of these efforts, the Seoul Water Authority was able to increase its financial self-sufficiency and achieve rationalization of administration, including replacement of old pipes, renovation of water treatment plants, outsourcing of part of the operation to the private sector, and advanced redemption of high-interest debt.

The financial self-sufficiency of the Seoul Water Authority increased from 95.4% in 2002 to 100% in 2004. The debt decreased by 75% between 2002 and 2007, i.e., from KRW 600 billion in 2002 to KRW 540 billion in 2003, KRW 396 billion in 2004, KRW 325 billion in 2005, KRW 203 billion in 2006, and KRW 150 billion in 2007. The city of Seoul could have frozen the water tariff for 12 years after 2001 and returned the benefits to its customers.

High RWR is the base for a safe and sustainable water system, as it can rationalize management of the water business and provide financial stability. RWR is one of the most important factors for continuing the virtuous cycle of water systems. A system which is financially and technically stable, and can achieve the essential goal of the water business, i.e., to maintain water which is safe in quality and secure enough water to supply all needs, and also have direct advantages in water tariff. The real meaning of the policy related to higher RWR is to provide clean, safe drinking water to the public.

The RWR of Seoul was 55.2% when the Seoul Water Authority started in 1989. After continuous efforts to increase the RWR, it reached 95.2% in 2015. The results of the period between 1990 and 2013 can be summarized as a reduction of drinking water by 7.5 billion$m^3$ (which is the amount used by 10 million citizens of Seoul for 6 – 7 years) and calculated as a financial benefit of KRW 4.2 trillion. The number of leak cases was reduced by 82.5%, which enabled the city to save about KRW 1.8 trillion in budget costs. As production could be reduced as a result of the increased RWR, 4 of the 10 WTP's (total capacity of 7.3 million$m^3$/day) could be closed, i.e., 6 WTP's with a capacity of 4.4 million$m^3$/day was adequate to meet the water demand.

The WTP's closed were renovated to become parks and recreational areas for the public to increase their quality of life.

# Relationship with Other Policies

Although the policies for water supply and demand do relate to other city policies, they are not much affected by other policies, as changes in other policies do not have much impact on water policies. Policies related to RWR do not have a direct relationship to policies other than water.

**Regeneration and Rehabilitation of Urban Areas**

Regeneration and rehabilitation projects for older residential areas are closely related to the RWR project. As projects for urban rehabilitation may take more than 10 years from plan to completion, it can be difficult to replace old pipes and manage the pipe network efficiently. The project for higher RWR can be hindered by inadequate maintenance on remaining old pipes and/or abandoned pipes. Inadequate post-project measurements 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 a long time to repair the supply system after leaks develop.

It is necessary to ensure correct measurement for facilities management, including leak prevention and the closing of abandoned and forked water posts, in the early stages of an urban rehabilitation project. Systematic management using an O/M card is a good example. Detailed water demand management is enabled through the installation of water meters on the main pipes in the area where the rehabilitation project is carried out. Control over water supply and pressure is also required, to adjust to the decreased demand for water as a result of closed water posts and household moves.

**Upgrading GIS (Geographic Information System)**

It is necessary to update the GIS for systematic management of the facilities as well as for urban rehabilitation projects. Although the projects related to upgrading the 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 for increasing RWR. The project to increase RWR can be managed more efficiently by registering and managing the information related to urban regeneration projects and data related to the pipe network.

**Facilities to Control Electrolytic Corrosion**

The most important technical target for the RWR project is the pipe network, where corrosion is related to leakage. Installation of the facilities to control electrolytic corrosion can have a direct effect on RWR in locations 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 maintained considering their effect on other underground facilities.

**Urban Safety**

Leaks from water mains can cause safety problems such as road sink. The RWR project must be designed to assist with other projects, for the safety of the public.

**Other Water Policies**

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

# Target of the Policy

The RWR for Seoul is at a world-top level of 95.7% (as of August 2016). After thorough evaluation of the capacity of each local service office, including the condition 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 a goal of 97% by 2022. This level of RWR may be the maximum that a waterworks system can achieve. As investment may be greater than the returns above this level, the goal of an RWR project needs to be set systematically and scientifically.

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

# Main Contents of the Policy

The main contents of the policy include;

- Launching and operating a dedicated organization for quality management of 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 a gravity-based water reservoir system
- Scientific water management based on a water flow monitoring system
- Knowledge-sharing programs to improve RWR

The project to improve RWR was carried out in phases as follows:

The initial stage of the RWR was to increase the projects, which ran from 1989, when the Seoul Water Authority was launched, until 1995. One of the largest advancements at that time was the launching of a drinking water-dedicated organization, which was needed to carry out projects related to increasing RWR through a strategy of 'selection and concentration'.

Another goal at that time was to implement the fundamental basis for increasing 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 measure the precise water flow in and out of the system. The projects for replacement and rehabilitation of old pipes, which was carried out between 1991 and 1993 were another base of the RWR improvement project.

The second part was the stage of full-scale project promotion between 1996 and 1999.

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

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

Another important policy related to the improvement of RWR was the one concerned with urban regeneration. As discussed above, urban regeneration projects take a long time from plan to completion, and the waterworks systems within the project area could be poorly managed. This requires more concentrated and detailed management of the waterworks system. As the city has multiple urban regeneration projects, the management of waterworks systems within a project area has been managed systematically and intensively since 1999.

The third part was to focus on making the results of the previous projects sustainable. In other words, the RWR increase project has been settled in this phase from 2000 until now.

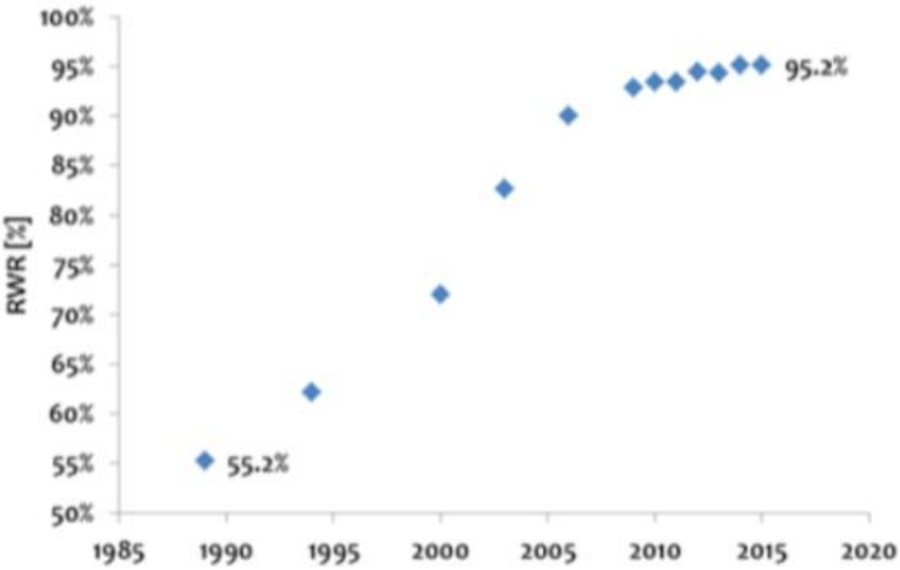
The main goal of the policy in this phase was to maintain the high RWR by constructing a production and supply system for the increase.

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

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

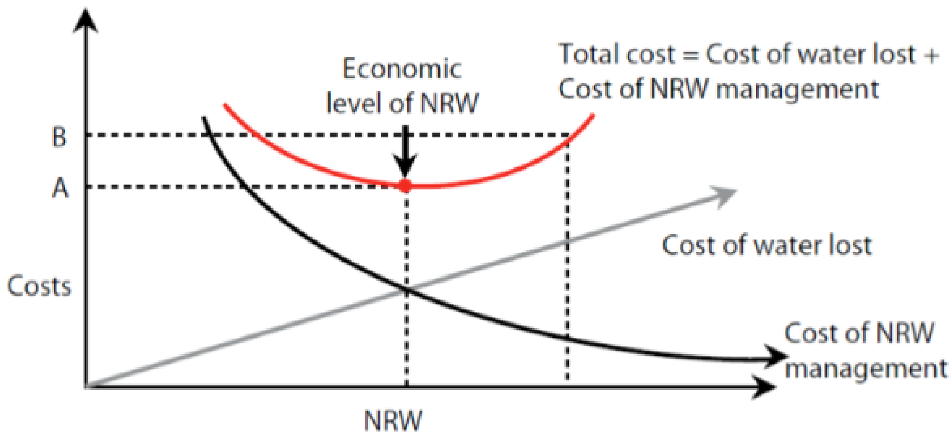
The management of the pipe network was carried out in two ways; the abandoned pipes were managed systematically and RWR was managed by mid-size block unit. For water supply management, the city began supply analysis and flow control based on the information from the flow monitoring system. The city could detect leaks in the pipe network by introducing technology called a 'multipoint leak noise correlator'. As a result of this project, the RWR of Seoul attained a world-class level of 95.2% in 2015.

**Figure 4. The RWR of Seoul**




Economic feasibility is one of the most important factors to be considered when designing 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 comes from physical loss and commercial loss. Physical loss is calculated as an operational cost such as labor, chemicals, and energy. Commercial loss is estimated from the water tariff. The cost of RWR management is defined as a cost of RWR improvement, similar to labor, equipment, and transportation. The cost of RWR management definitely increases with RWR. Although it depends on the financial and technical status of the water business in the area, RWR over 95% is close to the investment/revenue break-even point. The focus of policy for future RWR needs to be more on managing and maintaining RWR efficiently, although 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)**




# Technical Contents

**Replacement of Old Pipes**

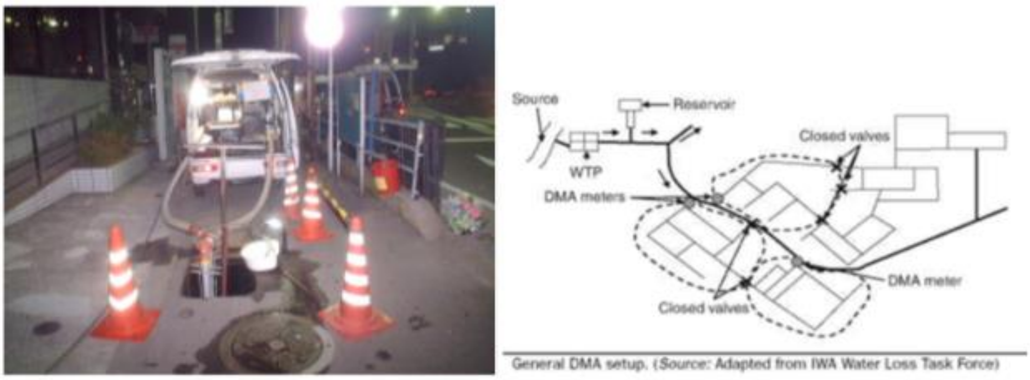
As of 2015, the total length of pipe in the Seoul network was 13,697 km, or about 1.1 times longer than the diameter of the earth (12,756 km). The most effective way to increase RWR is to replace the old pipes. The Seoul Water Authority invested KRW 1.7 trillion between 1984 and 2013 to replace 87% (11,221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

Although it differs according to pipe material and diameter, the life of a pipe asset is approximately 30 years. The replacement of old pipes is a continuous project based on technical and financial considerations. Criteria to determine the status of old pipes have 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 between midnight and 4 AM). Although the conclusion of measurement depends on the type of water supply, when the result of the flow measurement is between the minimum allowable leak of 0.5$m^3$/hr-km and 1.0$m^3$/hr-km, leak detection is carried out intensively and steps to manage leakage are taken. The city of Seoul measured the MNF at the 2,037 small-size blocks between 1998 and 2005. Currently, MNF is measured for selected blocks. It takes an overnight for 5 workers to measure the MNF of a block. After the valve installed at the boundary of blocks is fully closed to separate that block, the water flow and the water pressure into the block are measured (Figure 6). Other workers check the water meter using noise-detecting poles. Water flowing into all the manholes in the block is also visually checked. If the workers find anything suspicious, they physically get into the manhole to check for leakage.

**Figure 6. Minimum Night Flow and District Metered Area**




Source:

### Systematic Leakage Management based on the Block System

A block system is defined as a system within a water supply network which consists of separated areas, considering the characteristics of the area (altitude, roads, streams, railroads etc.) for efficient management of the water supply network and control over water supply and demand. A similar concept called District Metered Area (DMA) is used internationally. It is very effective for analyzing the changes in water supply and demand and leakage when the area of water supply is divided into small units based on the hydraulic conditions. The water supply (flow, pressure, and quality) in a block can be managed more efficiently based on the more detailed data and information, which helps to increase RWR.

As of the end of 2014, there were 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 pipe replacement, leak detection, and facility checks are carried out by the small-size block. The MNF measurement for all 2,037 small-size blocks was completed between 1999 and 2005. RWR management by small-size block is very efficient, but requires too much in terms of time, cost, and labor (Table 1). Currently, the city of Seoul manages RWR by the mid-size block. If the RWR of a mid-size block is low, the RWR is managed by the small-size block.

Table 1. Process of RWR Management by Small-size Block

| Step | Goal | Contents |
|---|---|---|
| 1st step | Fundamental investigation of the block | To determine the current condition of the block, including separation of the block, characteristics of the block, and the current condition of water supply facilities. |
| 2nd step | Block selection | Select a relatively weak block with many leak issues |
| 3rd step | Water supply and consumption measurement | Measure water supply and consumption in the small-size block three times |
| 4th step | Estimation of RWR; plans and strategies for the RWR goal | Create strategies and plans to increase RWR considering changes in water supply and consumption |

**Geographic Information System (GIS)**

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

Precise information concerning the location and status of water pipes is essential to increase RWR. GIS is a database and computerized management system which accumulates and manages graphic and attribute data for common facilities, water pipes and attached facilities. A user can search for spatial information using waterworks GIS, manage construction, and analyze and predict leakage. This can be a preemptive management utility for RWR improvement.

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

Table 2. History of GIS in Seoul

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

After the waterworks GIS was installed by the Seoul Water Authority, the number of leak cases has decreased continuously due to the precise spatial information available. The cost of repairing leaky pipes was drastically reduced as precise drilling at the point of leakage was possible. Quick and precise repair reduced the length of time when the water supply was cut off, and increased the public's satisfaction with Seoul's water service. The waterworks GIS has evolved into a decision-making support system, with scientific analysis and prediction as well as efficient support for field work.

**Water Pressure Control using the Water Reservoir System**

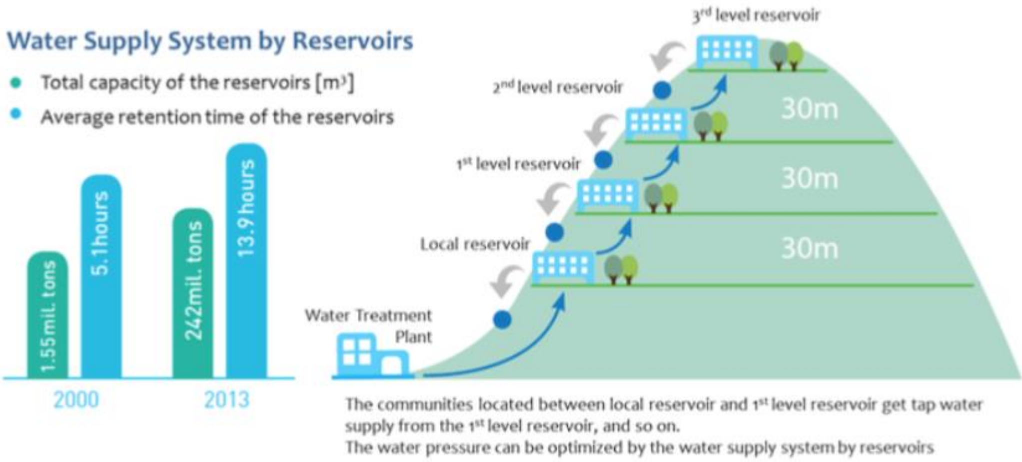
A water reservoir is a water storage facility used to supply citizens in the area with water from a water treatment plant. The drinking water supply system in a city has to maintain consistent water flow and pressure even in the case of black out or leakage. Without water reservoirs, a continuous water 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 differences, for effective water pressure management as well as effective water quality and energy management.

Seoul has constructed local, 1st and 2nd water reservoirs since 2000. As of 2015, there are a total of 120 water reservoirs in Seoul, with a total capacity of 2.4 million$m^3$. The elevation difference between the reservoirs is about 30m. A community is supplied with drinking water from the upper water reservoir (Figure 7). With this system, any excessive water pressure can be controlled at the appropriate level. It is a very effective system for reducing leakage. In addition, as the water from the WTP can be pumped to water reservoirs using relatively cheap power at night and supplied to the public using gravity by day, the cost of energy for pumping is reduced.

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

As 5% of all the water reservoirs in Seoul have a shorter retention time than 12 hours the Authority has plans to increase the capacity of these reservoirs and build new ones.

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




It is a device or a system for finding a leakage point by detecting, collecting and analyzing acoustic data about leakage from a water pipe. The device is very effective for determining leakage, with an accuracy of 80%. When there are many pipes buried in a relatively narrow space, or the water supply and consumption fluctuates greatly in an area, or if there is much structural noise, 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 that data be collected at night when water consumption and surrounding noise are at their lowest, and increase the number of data collections.

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)

# Effect of the Policy

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

As a result, the managerial efficiency of the waterworks increases and citizens can gain financial benefits in addition to trust in Seoul public services, including the drinking water service. The social benefit from the satisfaction of the public is priceless.

As the RWR of Seoul was over 80% in 2000, the city could supply its citizens with enough drinking water from the WTP's, with a total production capacity of 3.4 million $m^3$/day. The rate of WTP operation was about 60%, which was shorter than the recommended rate of 75%. As a result, in 2002, part of Gui WTP was closed, as were part of Tukdo WTP in 2003, Shin Wall WTP in 2003, and Bo Kwang WTP in 2004. Extra water due to increased RWR could be supplied to nearby cities and the city of Seoul was able to earn additional profits.

Increased public benefits due to the improved RWR were displayed in frozen water tariffs. Seoul was able to freeze the water tariff for 10 years between 2001 and 2011 because of increased financial capacity through the RWR improvement project.

Increased production costs were offset by the RWR increase and organizational reform, allowing the city to reduce the financial burden of its citizens. In 2012, the water tariff of Seoul was raised by 9.6% to allow for investment in an 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 public, and contributed to increasing the quality of public service.

The success of the RWR increase project improved the public's satisfaction with various public services in Seoul, in addition to the drinking water service by the Seoul Water Authority.

# Difficulties & Solutions

One of the largest difficulties for the RWR project was the underground facilities buried with the urbanization of Seoul, as conditions were very complicated and did not allow for effective replacement or rehabilitation of old pipes. Through the project to improve the precision of the waterworks GIS, the city was able to more accurately identify the location and status of underground waterworks facilities, including the pipe network, and this has improved continuously.

More systematic and scientific separation and management on block units has been carried out for better management of leakage.

The urban infrastructure for the Seoul waterworks system was stabilized decades ago. Another aspect of stabilization of the system is that the system got 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 when the project started in 1984 has now become old pipe which needs 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 at an outstanding level. These problems can be solved with a long-term financial investment plan and an asset management system.

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

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