The Development of Water Safety Plans in Korea

Written by K-Water, Republic of Korea

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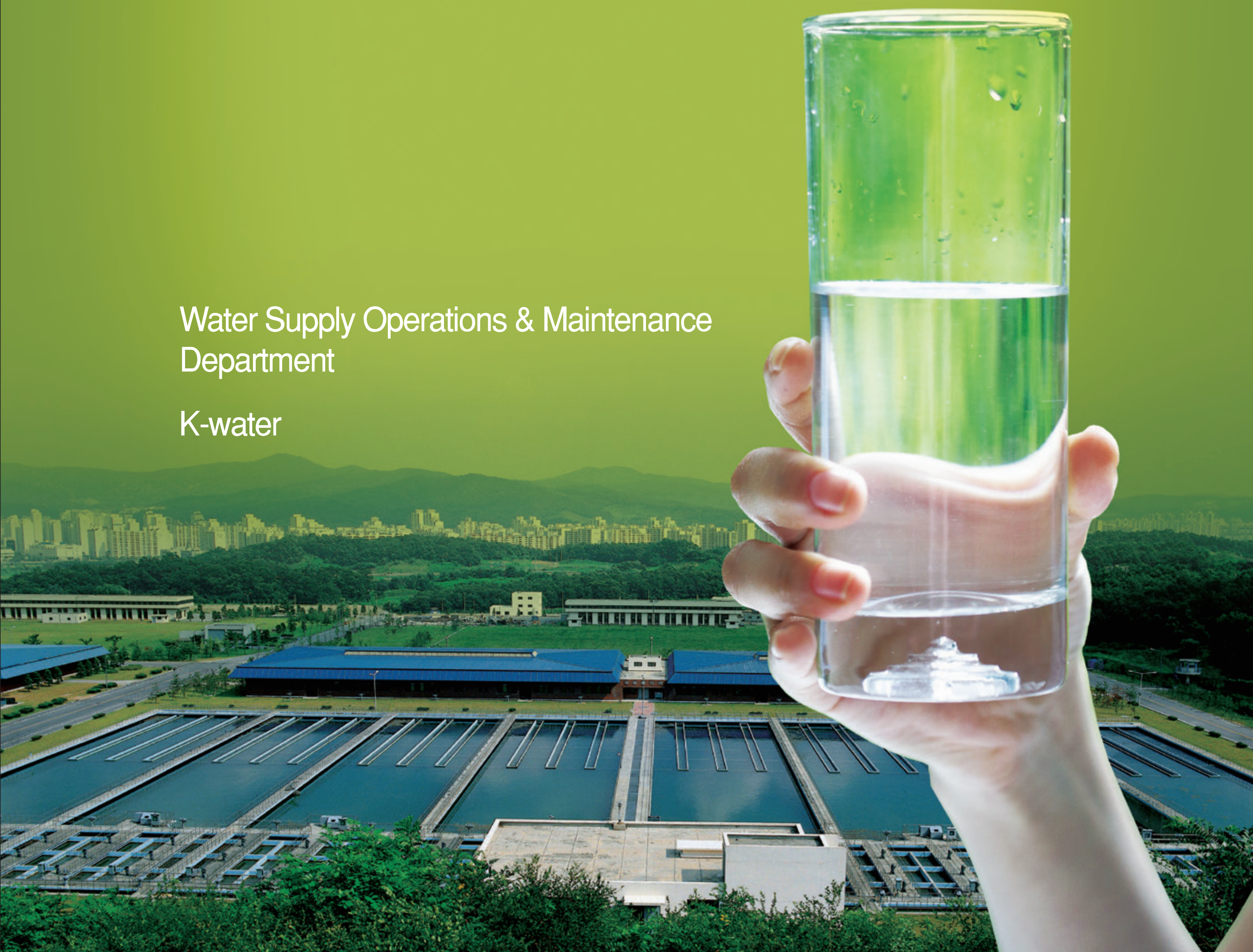

Water Supply Operations & Maintenance Department

K-water

Foreword

I'd wholeheartedly like to thank our customers for supporting K-water, which makes the world more abundant and happier by water, and I am also glad to publish the WSP introduction report about sustainable management activities and achievements of K-water. It was established in 1967 as the only comprehensive water service corporation in Korea. K-water is now operating and managing 16 multi-functional dams, 39 water supply and 10 sewerage systems across the nation including metropolitan areas. Over the last 50 years, it is taking the lead in improving the quality of people's lives by reliably supplying clean and safe water.

With the increase of various emerging issues, K-water is trying to develop a new approach for integrated water quality management by improving the water system's safety and performance from catchment to customers. The first round of application of the WSP was successfully done at K-water's 36 state-owned waterworks in December 2012. It was a meaningful challenge to upgrade the requirements for managing hazards and hazardous events precautionary in water system. It was also likely to be a milestone during a century when the first modern style water system in Korea was developed at 1908. K-water is committed to doing its best to produce and deliver clean and safe drinking water through a multi-faceted and comprehensive system and plan to control hazards and hazardous events.

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Acknowledgments

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Research on the introduction of the WSP approach and system was conducted by Dr. Kim Jin Keun of Jeju National University in 2011. A seminar and special training program for WSP engineers was conducted by Dr. Kim and Dr. Mark D. Sobsey of University of North Carolina at Chapel Hill in September 2012. Peer review for this report was performed by Dr. Mark D. Sobsey. Principal contributors to WSP development are Kim Han Su, Lee Beong Doo, Shin Chang Soo, Song Young Il, Cho Hyuk Jin, Jeon Hong Jin, Lee Jae Sung, Lee Hee Suk and Hong Sung Gyun.

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1. Introduction

One of the most essential factors for ensuring public health is the production and supply of clean and safe drinking-water. Surface water accounts for half of the available source water capacity in Korea and can be used to make drinking-water. However, it is relatively vulnerable to water contamination since surface water is exposed to all types of non-point source pollutants. There is a high potential for the deterioration in drinking water quality including excess turbidity and microbes due to insufficient treatment during flooding events. Advanced waterworks management is strongly required because water contamination occurs in the holistic water system from catchment to tap. A lack of sufficient response action based on a systematic approach in the event of water deterioration can lead to interruptions in water production and supply as well as cause serious public health problems. As well, an insufficient response in the early stage of deteriorating water resource situations or inadequate response to increased risks of drinking-water contamination could arouse people's distrust of water quality when the response and remediation is completed. In previous case studies, people are also likely to be more hesitant to drinking tap water because of unpleasant memories of past events. Therefore, individual waterworks should identify hazards and hazardous events in the holistic water system and conduct risk assessment using various methods. They should establish and conduct monitoring and improvement plans based on the findings to prevent water contamination. They also should do their best to produce and supply clean and safe tap water through multi-faceted and comprehensive control of hazards and hazardous events. For these reasons, there is a strong necessity to introduce and carry out a Water Safety Plan, which is the kind of risk management technique suggested by the World Health Organization in order to effectively prevent and control hazards and hazardous events in waterworks. This report contains the WSP framework which was developed over a period of 2 years from 2011 to 2012 as well as its major features, intended outcomes and future plans in Korea.

2. Community Water Systems of Korea

Water Supply

About 50,638,000 people, which comprise 97.9% of the total population, are supplied by 162 local governmental waterworks and 36 state-owned waterworks managed by K-water as of late December, 2011 (Table 1). Local governmental waterworks are comprised of 7 in metropolitan cities, 1 in a special self-governing province, 73 in cities and 81 in provinces. As a State-owned water company, K-water operates 36 waterworks to supply water to multi-regional areas in the county. As shown in Table 1, daily water supply per person excluding water for industrial use only was 335L in 2011, which is similar to that of 2010 (333L) and the previous year's shown.

Table 1. Status of waterworks supply by year

Year	2004	2005	2006	2007	2008	2009	2010	2011
Total Population (thousand)	49,053	49,268	49,599	50,034	50,394	50,644	51,435	51,717
Number of People Supplied with Water (thousand)	44,187	44,671	45,270	46,057	46,733	47,336	50,264	50,638
Water Supply Rate (%)	95.1	95.4	95.9	96.4	96.8	97.4	97.7	97.9
Daily Water Supply per Person(L)	353	351	346	340	337	332	333	335

Figure 1. The first modern style water plant, Dook-do, was built in 1908. It supplied water to about 125,000 people at the moment.

Water Intake Facilities

The total capacity of water intake facilities is 37,160,000㎥/day as of late 2011: 18,571,000㎥/day (4.2%) of surface water, 16,048,000㎥/day (43.2%) at dams, 1,567,000㎥/day (4.2%) of riverbed water, 602,000㎥/day (1.6%) of underground water, and 372,000㎥/day (1.0%) from other reservoirs (Table 2).

Table 2. Capacity of water resource based on type of source for total, local and state-owned systems

Type of Water Resource	Surface Water	Riverbank Filtration Water	Dam Reservoirs	Other Reservoirs	Underground Water	Total
Total	18,571 (50.0%)	1,567 (4.2%)	16,048 (43.2%)	372 (1.0%)	602 (1.6%)	37,160 (100%)
Local Governmental Waterworks	14,261 (72.4%)	1,567 (8.0%)	2,896 (14.7%)	372 (1.9%)	602 (3.1%)	19,698 (100%)
State-owned Waterworks	4,310 (24.7%)	- (0%)	13,152 (75.3%)	- (0%)	- (0%)	17,462 (100%)

Figure 2. Dae-cheong dam reservoir (left) and Nak-dong river and its weir (right)

Water Treatment Facilities

The total number of water treatment plants in Korea was 550 as of December, 2011. The total capacity of facilities is 30,944,000㎥/day including industrial water: 9,097,000㎥/day for state-owned waterworks, and 21,847,000㎥/day for local waterworks (Table 3). Of these, the capacity of conventional water treatment using rapid filtration is 22,464,000㎥/day (72.6%). The capacity of advanced water treatment methods such as ozone and granular activated carbon is 5,474,000㎥/day (17.7%). The capacity of other water treatment methods is 1,949,000㎥/day (6.3%). The capacity of water treatment using slow sand filtration is 638,000㎥/day (2.1%). The capacity of water treatment performing disinfection only is 372,000㎥/day (1.2%). The capacity of water treatment using membrane filtration is 47,000㎥/day (0.2%).

Table 3. Capacity (m3/day) of systems using different water treatment methods

Treatment Method	Disinfection only1	Slow Filtration	Rapid Filtration	Membrane Filtration	Advanced Treatment such as Ozone and GAC	Other Methods[2]	Total
The Number of Systems	20	172	315	13	25	5	550
Total Capacity	372 (1.2%)	638 (2.1%)	22,464 (72.6%)	47 (0.2%)	5,474 (17.7%)	1,949 (6.3%)	30,944 (100%)
Local Governmental Waterworks	372 (1.7%)	638 (2.9%)	15,344 (70.2%)	17 (0.1%)	4,976 (22.8%)	501 (2.3%)	21,847 (100%)
State-owned Waterworks	- (0%)	- (0%)	7,120 (78.3%)	30 (0.3%)	498 (5.5%)	1,449 (15.9%)	9,097 (100%)

1. Disinfection only systems are using for ground water sources only.
2. Other method is coagulation and sedimentation only for industrial water usage.

Source Water Conveyance and Distribution Systems (Networks)

As shown in Table 4, the total length of the water pipelines for all water service is 173,014㎞. Conveyance pipes, which carry raw water from intake stations to water plants, are 3,257㎞(1.9%) in length. Water pipes which deliver treated water from treatment plants to water reservoirs are 10,717㎞(6.2%) in length. Water pipes which transport drinking-water from reservoirs to water supply areas via distribution systems or networks are 89,903㎞(52%) in length. Water pipes linked to each household are 69,137㎞(39.9%) in length. Water pipes are mainly made of ductile cast iron, PVC , PE, stainless steel, and cast iron.

Table 4. Length of water pipelines for different service functions

Type of pipe	Total length of Water Pipelines	Local Governmental Water Pipelines	State-owned Water Pipelines
Source Conveyance Pipe (km)	3,257	1,701	1,556
Water Pipe from Treatment Plants to Reservoirs(km)	10,717	7,316	3,401
Distribution (Network) System Pipe (km)	89,903	89,903	-
Water Feed Pipe to Households(km)	69,137	69,137	-
Total (km)	173,014	168,057	4,957

State-owned Waterworks

K-water, which is in charge of managing state-owned waterworks nationally, operates 24 water intake facilities and 40 water treatment plants (36 for residential purposes, 4 for industrial purposes). The percentage of total water supplied by K-water is 47.6% (17,462,000㎥/day) throughout the country. It is also in charge of managing 45 local governmental waterworks on a consignment basis. K-water is upgrading system operational efficiency by reducing water leakage and improving treatment facilities. The running rate of water treatment plants is 71.2%, and the water revenue of state-owned waterworks and consignment of local waterworks is 99.9% and 80.6%, respectively. The total length of pipelines which are controlled by K-water consists of 4,957km of state-owned waterworks and 14,239km of the consigned local waterworks.

Figure 3. K-water's state-owned waterworks

3. Recent Progress of Water Safety Plan Development and Application

Policies and Laws

The Korean government has several laws to manage waterworks and strengthen water safety. Representatively, there are the Waterworks Law, the Drinking Water Management Law, and the Drinking Water Quality Criteria and Test Regulation. The Waterworks Law, which was first enacted in 1961, aims to enhance public hygiene and improve the living environment through the reasonable setup and management of waterworks based on comprehensive planning for waterworks in Korea. The Drinking Water Management Law, which was enacted in 1995, aims to contribute to national health promotion through the rational management of drinking-water quality and hygiene. The Drinking Water Quality Criteria and Test Regulation, which is a subordinate regulation of the Waterworks and Drinking Water Management Law, describes the national primary water quality standards and test procedures for 84 compounds.

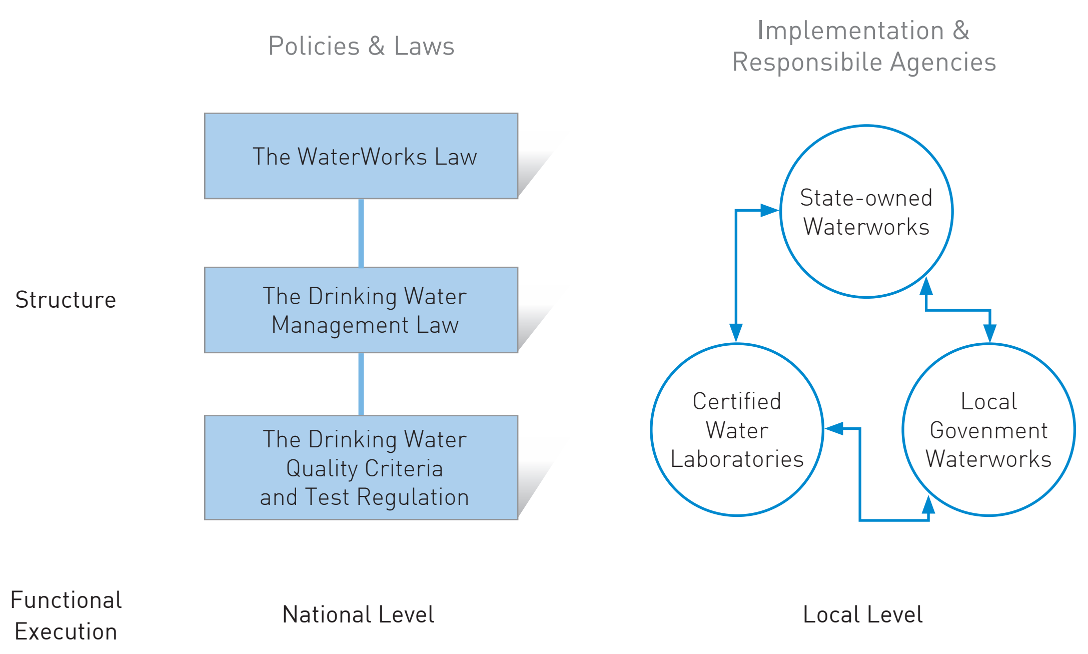


Figure 4. Structure and functional execution of policies and laws and the responsible agencies

National Water Safety Supervisory Regulation

The trend of more extreme weather phenomena such as localized heavy rainfall and huge typhoons are likely to increase due to global warming. As a result, large amounts of silt, suspended solids, and nonpoint source pollutants are flowing into source water with rainfall. These conditions and events can be serious risk factors for water quality management. For these reasons, the Waterworks Law, which was amended in 2012, specifies drinking-water safety management under the responsibility of individual waterworks. It also states that an assessment by the Korean government should be conducted on a regular basis for the current operation and management of water treatment plants, which is consistent with the independent surveillance component of the WHO-recommended framework for safe drinking water. In accordance with the Waterworks law, K-water collaborated with Jeju National University in 2011 to conduct research on the introduction of the WSP approach for strengthening water safety and hygiene. The primary goals of the research were to understand WSP guidelines, suggest a WSP framework considering the current waterworks conditions, draw up a checklist of hazards and hazardous events throughout the national water system, and develop a WSP model for Korean waterworks. As a result of the research, the establishment of an introduction and implementation scheme for the WSP approach in Korea was done in April 2012.

Milestones

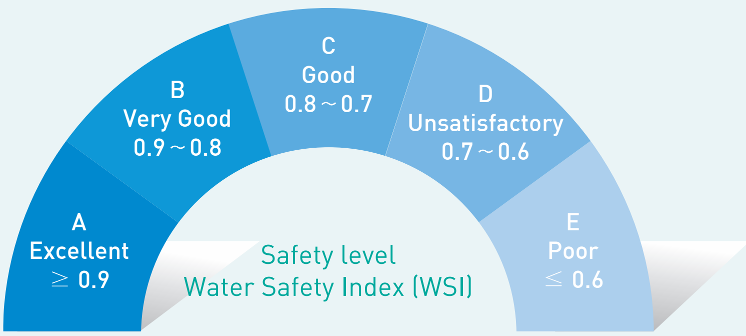
- **April 2011** : Initiated WSP development research in Korea that was performed by Jeju National University
- **April 2012** : Successful completion of WSP development research
- **May-July 2012** : Testing of WSP's applicability for several waterworks (1st: Gu-cheon, 2nd: Cheon-an, Go-san, Ham-pyeong, Go-ryeong)
- **August 2012** : Planned a WSP scheme for K-water's waterworks and selected WSP experts to do risk assessments for their water plants
- **September 2012** : Conducted a seminar and special training program for WSP by Mark D. Sobsey who is a professor in the University of North Carolina at Chapel Hill
- **December 2012** : Completed application of WSP approach for 36 state-owned waterworks
- **January 2013** : Held a technical meeting for WSP output adjustments in order to carry out risk assessments following the same developed approach
- **March 2013** : Report on the results of WSP application to 36 state-owned waterworks was completed
- **April 2013** : Held the first working-level WSP workshop for WSP action team engineers by K-water itself.

The Characteristics of a Water Safety Plan in Korea

The established Korean WSP system faithfully complies with the original WSP guidelines jointly developed by WHO and IWA. It takes into account the specific conditions and features of Korean waterworks. First of all, the check-list of 160 hazards and hazardous events, which can be generally applied to Korean waterworks, was made in advance to allow easier risk assessments of hazards and hazardous events. Secondly, the Water Safety Index (WSI) which measures the safety level of drinking-water depending on the risk rating measured by risk assessment was newly developed and added. The WSI is believed to be very useful, with its advantage of quick understanding of the drinking water safety level of a water plant and its vulnerabilities or weak points. Lastly, a water treatment specialist pool (35 experts) was organized to aid WSP experts so that they enhance risk assessments on the basis of identifying and addressing hazards and hazardous events with specialty skills and a balanced approach.

※ Water Safety Index

The activation of WSPs mainly aims to identify and assess risk ratings of hazards and hazardous events present in within community water systems. The primary operational characteristic of the Korean WSP is the provision of a water safety index (WSI) which identifies drinking-water safety levels using a five-point Likert Scale and risk ratings system. The WSI outcome consists of five safety grades such as Excellent (≥0.9, A grade), Very Good (0.9~0.8, B grade), Good (0.8~0.7, C grade), Unsatisfactory (0.7~0.6, D grade) and Poor (≤ 0.6, E grade). The maximum value of the WSI is 1.0 and the closer a value is to 1.0 in the Water Safety Index, the higher the safety grade. The WSI is considered to be a very useful indicator with its advantage of quick understanding of the drinking-water safety level of a water plant and an objective and structured system to identify its weak points or vulnerabilities.



* The closer a value in the Water Safety Index is to 1, the higher its safety grade.

※ How to calculate Water Safety Index
(WSI) = (Safety Rating Ratio) - (Risk Rating Ratio)

- Safety Rating Ratio = Total number of Low Rating Item ÷ N
- Risk Rating Ratio = (Medium ratio) + (High ratio) + (Very high ratio)
  - ✓ Medium Rating Ratio = (Total number of Medium Rating Item / N)÷3
  - ✓ High Rating Ratio = (Total number of High Rating Item / N)÷2
  - ✓ Very High Rating Ratio = (Total number of Very High Rating Item / N)
- N = Total number of assessed WSP check-list items)

Progress in Implementing and Applying the Structure and Organization of the WSP Process

The structure, organization and operating plan for the Korean WSP system established is summarized in Figure 5. Based on this system, WSP action teams at each waterworks were organized and given the authority to execute WSP activities. Generally, a WSP action team consists of 7 engineers. The total number of WSP action team members for 36 waterworks is 270 engineers. A special training workshop for all WSP experts, including the water treatment specialty group, was held in September, 2012. This workshop mainly delivered the basic educational information about WSPs, including a special lecture given by Professor Mark D. Sobsey (University of North Carolina at Chapel Hill), which included content from WSP experts at WHO headquarters (Geneva, Switzerland) and the Asia region (The Philippines). In particular, the special lecture enhanced the basic understanding of and the necessity of having a WSP with respect to the conduct of holistic and systematic pro-active actions to identify and control unexpected hazards. After the selection of the WSP action teams and special training, the WSP approach was primarily applied to K-water's 36 waterworks that supply drinking water to multi-regional areas. In total, 27 specialists and 270 WSP action members were involved in the first risk assessment which lasted 2 months. Risk assessments were conducted in various forms at each waterworks: document evaluations, field evaluations and interviews with operators. The results documented that the WSI (water safety index) of K-water's 36 waterworks had an average level of 0.778, which is rated "Good" and in the middle of the ratings scale. In particular, it was found that there are potential hazards and hazardous events in areas pertaining to water resources, while water treatment and supply processes remain effective and stable and are rated generally favorable. K-water plans to lower the risk level of hazards and hazardous events identified by these WSP activities through the use of intensive observation and continuous management, depending on the risk ratings. In particular, budgets and all types of technical support required to control hazards and hazardous events should be preferentially allocated to achieve substantial improvement. The second risk assessment of 22 consignment local waterworks is scheduled to take placed in 2013. This task has focused on the establishment and use of the hazard identification and management system of the WSP system and approach and is now in progress.

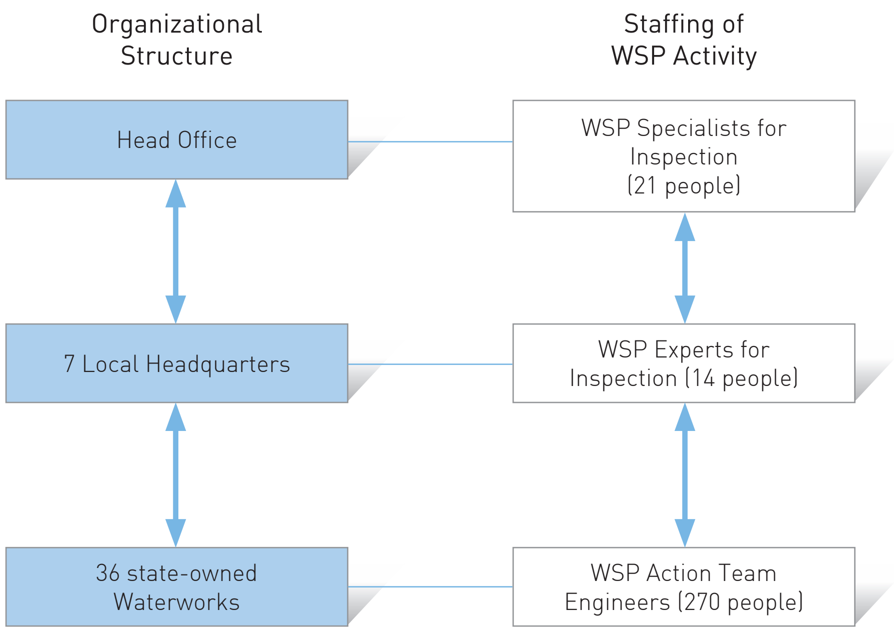


Figure 5. Structure, organization and staffing of the K-Water WSP activity

4. Outline Description of the Water Safety Plan System Developed for Korea

Purpose

The Korean WSP system has two purposes: 1) to attain management efficiency through objective budget investment in order to prevent hazards & achieve proactive risk control using WSP activities that are based on the WHO global standard of risk assessment & management; 2) to maintain and enhance drinking-water safety.

WSP Activity Process and Participants

The WSP activity process consists of three steps: 1) the identification and quantification of hazards & hazardous events, 2) monitoring and management of risk factors identified, and 3) verification and feedback as well as surveillance for risk management. A flow diagram of the WSP activity process and its responsible participants is shown in Figure 6, below. This process has been continuously repeated for 3 years since the first application of WSPs to individual systems. A detailed inspection by the WSP specialists and experts will be performed once at the beginning of WSP activities. Regular inspections and follow-up actions will be performed by the WSP action team engineers 5 times every quarter.

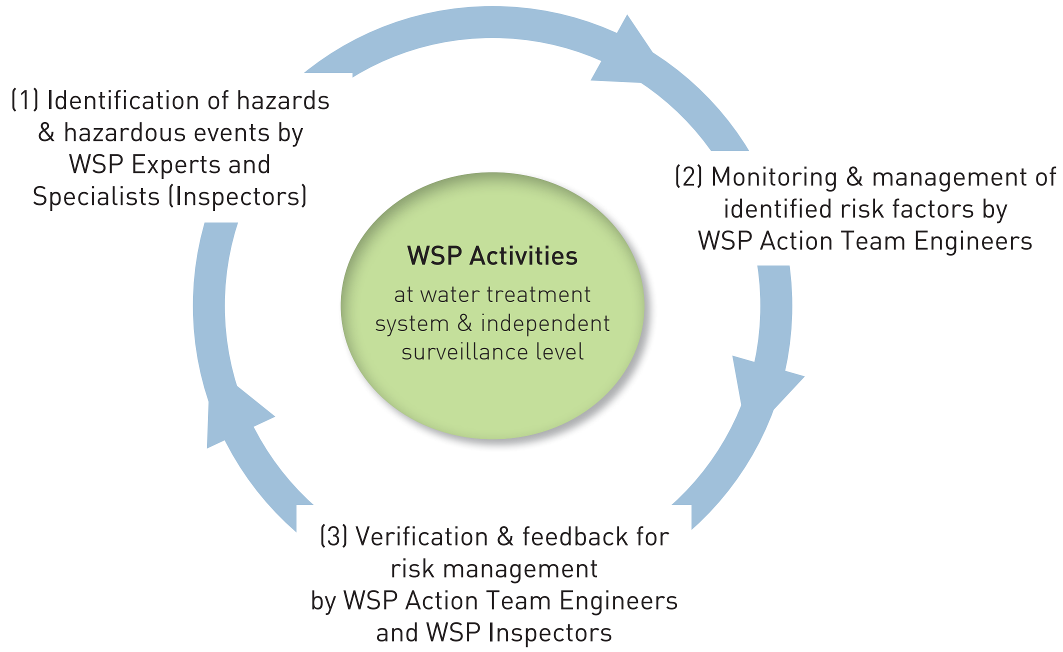


Figure 6. The process flow of WSP activities and actors (participants)

Table 5. The number of hazards and hazardous events in the Korean WSP check-list

Process Steps	Water Quality	Facilities & Instruments	Maintenance & Operation	Total
Source Water Resource	27	10	8	45
Water Treatment	23	35	13	71
Supply Delivery	15	19	10	44
Total	65	64	31	160

Check-list of Hazards and Hazardous Events

The Korean WSP Checklist was divided into three process steps which are source water resource, water treatment and supply delivery. Each step was subdivided into three categories which are water quality, facilities & instruments, and maintenance & operation. In total, the Checklist has 160 potential hazards and hazardous events. They were initially drawn up to consist of nine sections, allowing for the addition of other hazards and hazardous events through additional inspection and identification.

Risk Prioritization Methods

A semi-quantitative, qualitative risk analysis matrix and simplified qualitative approach were used as an appropriate risk ranking and prioritization method, depending on the characteristics of the hazard type. Consistent with WSP guidelines, the severity (A) and frequency (B) of hazards were each divided into 5 levels (1 to 5). Risk scores were calculated (AxB) by using a Matrix method. Risk ratings were divided into 4 levels (low, medium, high, very high). The scores for each risk level in the matrix are shown in Table 6.

Output of hazard assessment

WSP activities mainly perform a risk assessment of hazards and hazardous events present within community water systems. The primary characteristic of the Korean WSP is that it can provide a WSI (water safety index) which is used to determine drinking-water safety levels using a five-point scale and risk rating system as shown in Table 7. WSI outcomes consist of five safety grades: Excellent (≥0.9), Very Good (0.9~0.8), Good (0.8~0.7), Unsatisfactory (0.7~0.6) and Poor (≤ 0.6). The maximum value of the WSI is 1.0 and the closer a value in the Water Safety Index is to 1.0, the higher the safety grade. The WSI is believed to be a very useful scoring system with the advantage of objective and rapid assessment and understanding of the drinking water safety level of a water plant and its weak or vulnerable points.

Table 6. Semi-quantitative risk analysis matrix (Deer et al., 2001)

Risk Factor Matrix:		Severity or Consequence				
		Insignificant No impact / not detectable Rating: 1	**Minor** Compliance Impact Rating: 2	**Moderate** Aesthetic Impact Rating: 3	**Major** Regulatory Impact Rating: 4	**Catastrophic** Public Health Impact Rating: 5
Likelihood or frequency	**Almost Certain** Once a day Rating: 5	5	10	15	20	25
	Likely Once a week Rating: 4	4	8	12	16	20
	Moderate Once a month Rating: 3	3	6	9	12	15
	Unlikely Once a year Rating: 2	2	4	6	8	10
	Rare Once every 5 years Rating: 1	1	2	3	4	5

Source: Deere et al, 2001

Table 7. Water Safety Index

Water Safety Index (WSI)	**≥ 0.9**	**0.9 ~ 0.8**	**0.8 ~ 0.7**	**0.7 ~ 0.6**	**≤ 0.6**
Safety level	A	B	C	D	E
	Excellent	Very Good	Good	Unsatisfactory	Poor

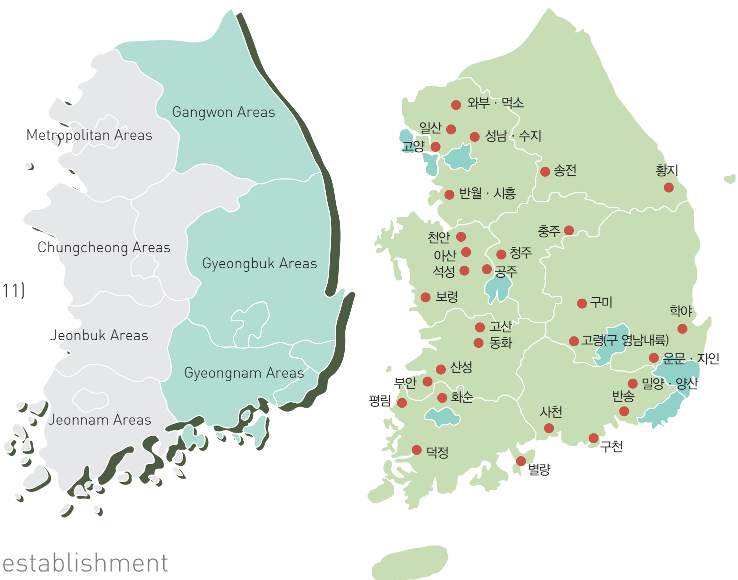
* The closer a value in the Water Safety Index is to 1, the higher the safety grade.

5. Case Study: WSP application for 36 state-owned waterworks

Overview of Water Systems and their Assessment using the WSP Approach

K-water operates a total of 81 waterworks and attached facilities throughout the country: 36 state-owned waterworks and 45 local waterworks on a consignment basis by local governments. The first successful application of K-water's WSP system was to 36 state-owned waterworks in 2012. Figure 7 below shows K-water's waterworks which have primarily adopted the WSP system. As for the specific assessment of K-water's waterworks, the water intake volume of 36 state-owned waterworks depends more on dam reservoirs (13,202,000㎥/day, 74.7%) than river surface water (4,481,000㎥/day, 25.3%). Of state-owned waterworks, there are 28 general water treatment plants (78% of all plants) that employ the treatment processes of coagulation, sedimentation, filtration, and disinfection. There are 8 advanced water treatment plants (22% of all plants) using the treatment processes of ozone, granular activated carbon, and membranes. Of these, 3 advanced water treatment plants are located in Seoul metropolitan areas. The others are located in the Gyeong-buk and Gyeong-nam areas. Most of the advanced water treatment facilities experience high concentrations of natural organic matter (NOM) and/or objectionable taste & odor compounds produced by algal blooms. Local headquarters are located in 7 administrative districts. An integrated SCADA (supervisory control and data acquisition) system was installed to network waterworks facilities within a local headquarter. They are conducting regular monitoring and control of their waterworks based on the SCADA system.

Established in the Jeonbuk Area(2005)
Established in the Chungcheong Area, Metropolitan Area(2006)
Established in the Jeonnam Area(2007)
Established in the Gangwon, Gyeongbuk and Gyeongnam Area(2010)
Opened intergrated operation in all areas(2011)



7 Areas,

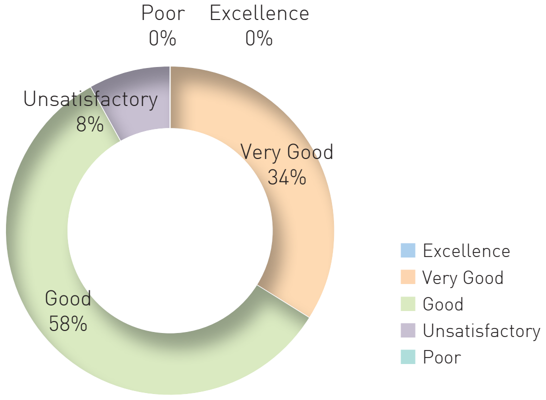
Completed all areas of K-water waterworks integated establishment

Figure 7. K-water's state-owned waterworks

Operation Scheme

K-water's head office generally manages and monitors how WSP applications and activities are doing. Local headquarters and operation managers of each waterworks actually take charge of WSP operations and carry out activities to identify and control hazards and hazardous events that are considered by and covered in the plan. In order to perform efficient independent surveillance of WSP activities and actions, 7 safety inspection teams composed of several specialists from the head office and local headquarters were formed. They are also responsible for assessing and managing waterworks facilities located in each region as the surveillance authority. The WSP action team was organized with a manager and operation engineers of each facility. They jointly identify and assess hazards and hazardous events with the safety inspection team and perform the role of monitoring, managing, and controlling those hazards.

Water Safety Index (WSI) Rating
based on 36 state-owned waterworks



Water Safety Index (WSI) Rating Distribution with respect to process steps

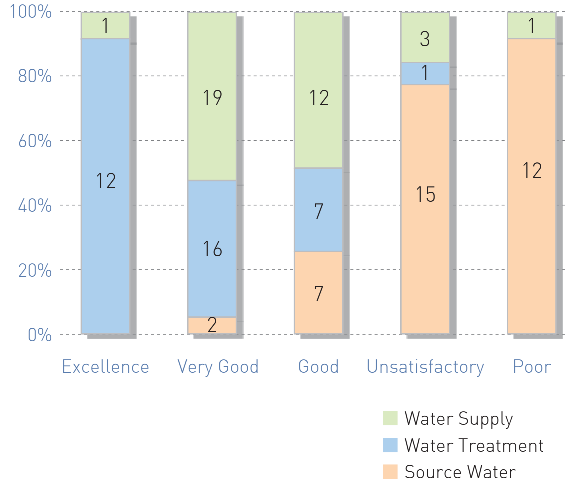


Figure 8. Water Safety Index rating and its distribution based on 36 state-owned waterworks

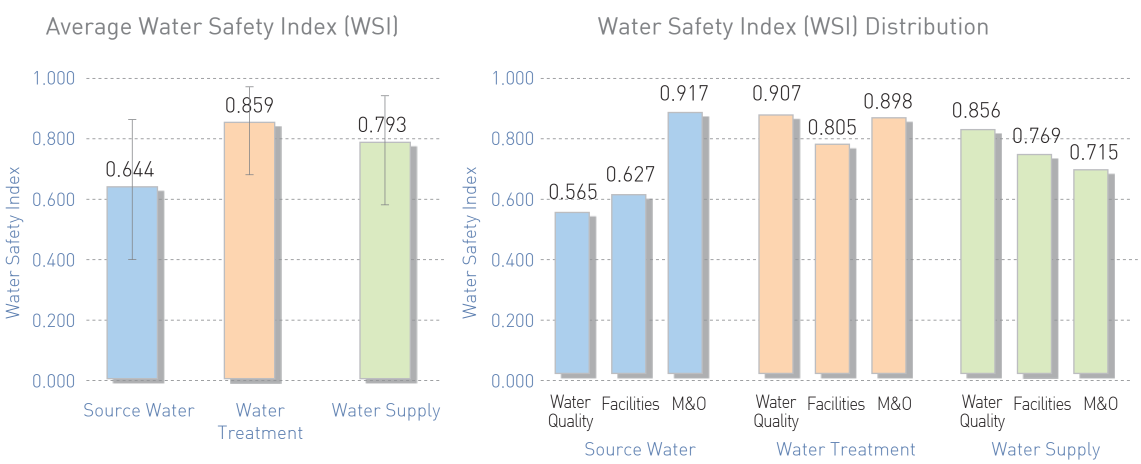
Results of WSP application to K-water waterworks

The average WSI, water safety index, of the 36 K-water waterworks was 0.778, which is classified as a Good water safety level (C grade), overall (Figure 8). With regard to WSI ratings, 33 percent (12 waterworks) were identified as having very good water safety levels (B grade) and 58 percent (21 waterworks) were identified as having Good water safety levels (C grade) (Figure 8) . Lastly, 9 percent (3 waterworks) were identified as having unsatisfactory water safety levels (D grade). To be more specific about the rating of treatment plant factors responsible for safety levels, the WSI of source water resources was classified as having unsatisfactory levels, resulting in lower than a D grade. The WSI of the treatment processes had very good scores, resulting in higher than B grade ratings. The

WSI of the water supply process category was mostly in the B-C grade range.

For the factors and conditions concerning the source water resource, water safety levels of water quality, facilities & instruments, scores were low and were rated lower than D (Figure 9 and Table 8). It is judged that the low rating is caused by various factors contributing to undesirable source water quality changes resulting from geographical conditions, weather changes, and the influx of nonpoint source pollution. Most water treatment processes were rated higher than B, which reflects very stable treatment process management and operations. On the other hand, water safety levels of the water supply distribution process category was rated C, reflecting some weaknesses in the operation and management of pipelines for water conveyance and distribution. In summary, the water treatment process category showed the highest level of safety, while source water resource showed the lowest level of safety. Therefore, more effort is required to better monitor and manage source water resources.

Figure 9 and Table 8. Average Water Safety Index values and their distribution into safety categories for 36 state-owned waterworks



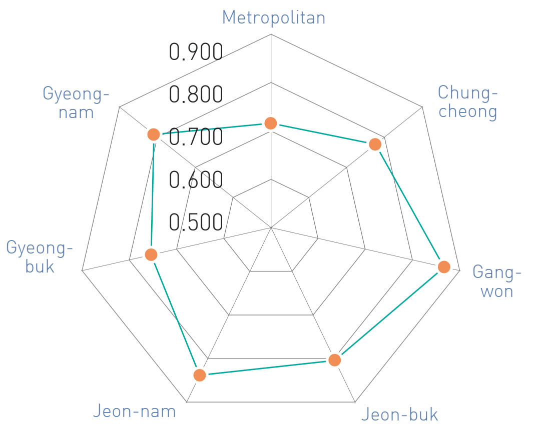
Process	WSI of Water Quality	WSI of Facilities & Instruments	WSI of Maintenance & Operation	Mean
Source Water resource	0.565 (E rating)	0.627 (D rating)	0.917 (A rating)	0.644 (D rating)
Water treatment	0.907 (A rating)	0.805 (B rating)	0.898 (B rating)	0.859 (B rating)
Water Supply Distribution	0.856 (B rating)	0.769 (C rating)	0.715 (C rating)	0.793 (C rating)
Mean	0.776	0.734	0.843	0.778

Water Safety Index Ratings of Local Headquarters

The WSI of each headquarters ranged from 0.715 at the lowest level to 0.865 at the highest level, with headquarters in metropolitan areas, the Chung-cheong region, and Gyeong-buk rated relatively low (C rating) compared to other areas. The lower ratings of certain areas were due to the characteristics and conditions of source water, such as their geographical conditions, basic water quality conditions, and atmospheric phenomena. Most source water rating scores were below 0.7 and only one was above 0.8. In particular, it was found that most source water resources were influenced by major fluctuations in water quality and the frequency of algal blooms in summer. The WSI of water quality shows that most source waters have weaknesses in terms of water safety, while water treatment and supply distribution processes are very stable and rate well, with all but one rating score above 0.85. The WSI rating of facilities and instruments show differences among regional headquarters, with most rated only Good and some others rated Very Good or Excellent, resulting in an overall WSI rating of Good.

Figure 10a and Table 9. Water Safety Index values based on local headquarters

Average Water Safety Index (WSI)
based on Local Headquarters



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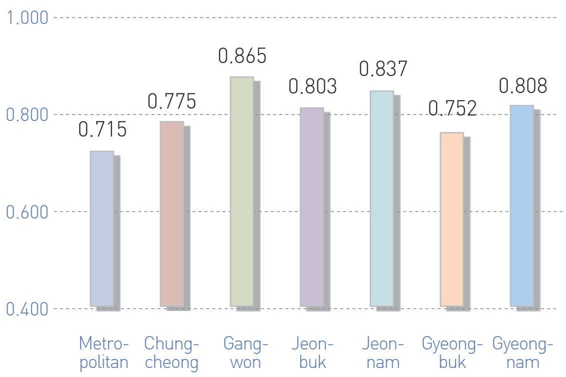
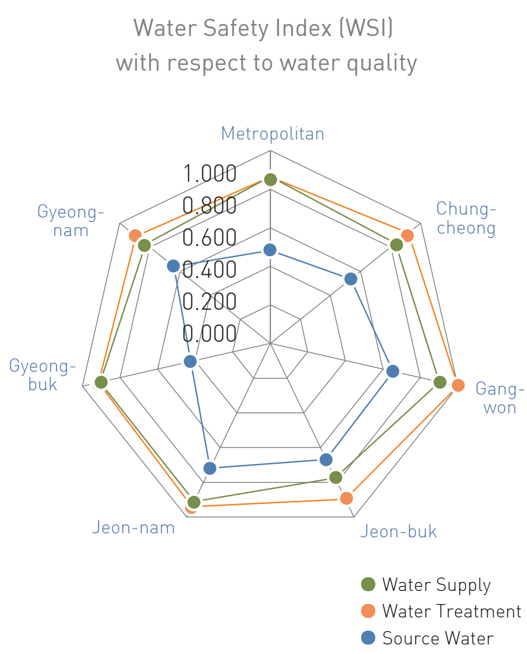
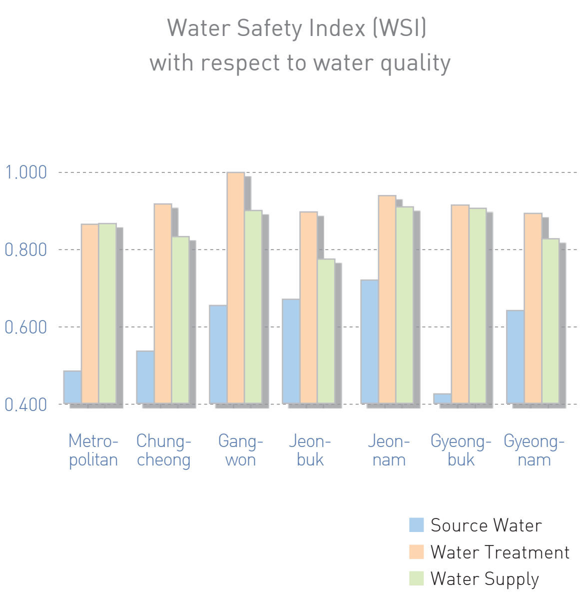
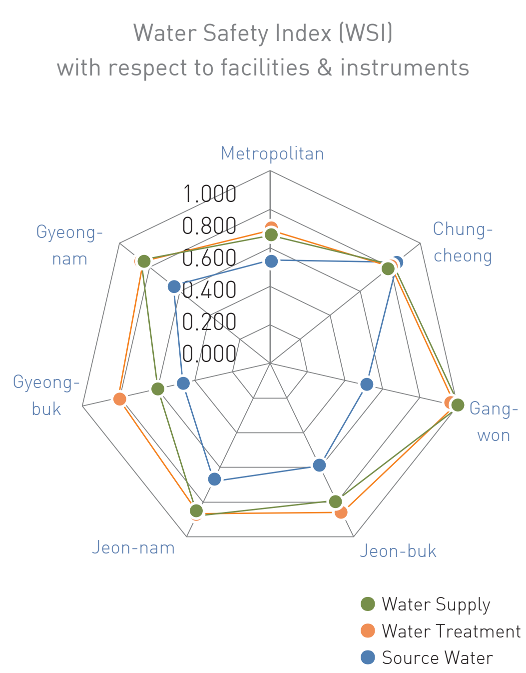


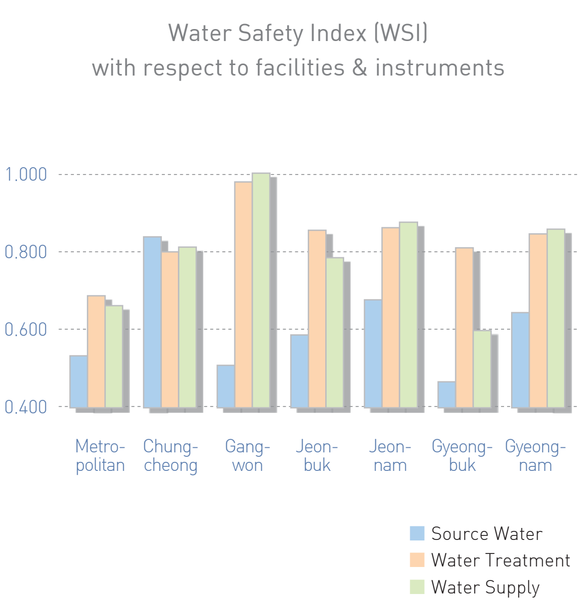
Process	Metropolitan Area	Gang-won	Chung-cheong	Jeon-buk	Jeon-nam	Gyeong-buk	Gyeong-nam	Mean
Source Water resource	0.588	0.683	0.662	0.698	0.747	0.522	0.686	0.644
Water treatment	0.780	0.970	0.857	0.881	0.897	0.878	0.880	0.859
Water Supply	0.763	0.916	0.776	0.769	0.838	0.764	0.828	0.793
Mean	0.715	0.865	0.775	0.803	0.837	0.752	0.808	0.778
WSI Rating	C	C	C	B	B	C	B	C

Figure 10b. Water Safety Index values for rated water systems based on three water supply process steps and three categories of conditions (water quality, facilities and instruments and maintenance and operation)

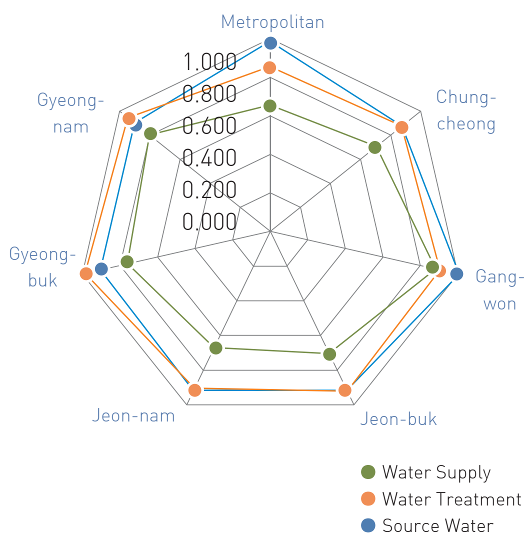




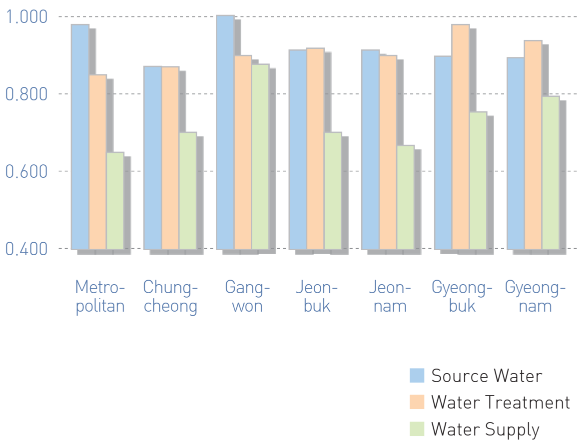




Water Safety Index (WSI)
with respect to maintenance & opration



Water Safety Index (WSI)
with respect to maintenance & opration

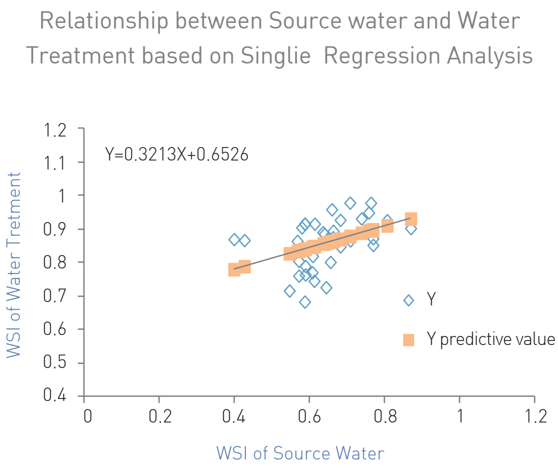


Hazards and Hazardous Events

As summarized in Figure 10 and Table 9, it was found that source water resources are vulnerable to flooding and algae blooms, experience large fluctuations in water quality such as changes in turbidity by season, and are heavily influenced by blue-green algae which produce objectionable smells and toxins. In the process of water treatment, there could be problems such as excessive or insufficient injection of liquid chemicals, hydraulic overload caused by flux changes in the water treatment, and increased frequency and magnitude of odor detection in tap water due to insufficient and ineffective treatment of algae blooms in water resources. In the water supply process, the crisis response manual was deemed to be inadequate for managing unexpected water contamination conditions. In addition, a higher level of total trihalomethanes (TTHMs) and low levels of residual disinfectants were reported at the point of consumption as compared to finished water at the treatment plants. Pipeline connections with other waterworks facilities were insufficient for supplying alternative drinking water in emergencies such as water contamination incidents or damaged pipeline facilities.

Statistical Analysis

Results of statistical analysis on WSI values found important correlations between source water resource and water treatment (Figure 11). A lower WSI value of source water resource was correlated with a lower WSI value of water treatment. Poor source water resource can negatively affect drinking-water quality and safety. A high correlation (R^2=0.9752) was also found between each variable from multiple regression analysis using the WSI values of source water resource, water treatment, and supply distribution process, resulting in a an overall linear frequency distribution.



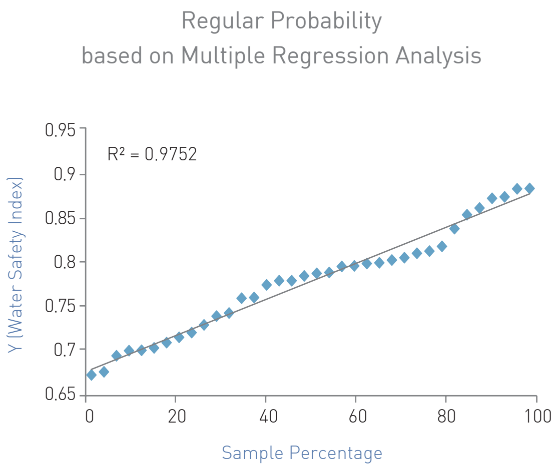


Figure 11. Relationships between source water and water treatment WSI values and probability distribution of WSI values

Proposed Actions Based on WSP Analysis K-water's Endeavor 1: Control of Source Water Contamination

Most dam reservoir catchments or river basins are vast and wide, making it is difficult to understand and characterize the causes and effects of water quality change. In addition, these catchments and basins are heavily affected by various external factors such as weather phenomena and length of water storage time. Therefore, identifying influencing factors, characterizing and monitoring conditions, and modeling key parameters for making scientific predictions of future water quality are very important to effectively manage water quality of source water. To overcome several limitations of water quality predictions, K-water has been developing various new technologies. For example, one is 3-dimensional prediction modeling and other one is water quality monitoring using artificial satellite images in 2011 (see Figure 12). In particular, 3-dimensional water quality prediction modeling has been installed at 10 dam reservoirs by 2012. It is also planned for this capacity to be expanded continuously to other dam reservoirs. In regards to green algal blooms which occur in summer season, they can cause water deterioration and be a serious obstacle to water treatment. K-water has been trying to do a variety of activities in order to improve water quality and minimize algal bloom impacts by using selective water intake equipment, water circulation systems, and algae inflow prevention curtains.

Figure 12. Integrated Information Management for Water Resources including Dam Reservoirs

K-water's Endeavor 2: Tap Water Quality Management

A system to achieve internal drinking-water quality goals of K-water was set and monthly assessments for each of the 36 waterworks are conducted regarding 7 items which can affect or reflect drinking-water quality such as turbidity, residual disinfectant, and disinfection by-products Table 10. Drinking-water quality control through the feedback from the results of these monthly assessments helps to improve the efficiency of water treatment plants and their operation.

The general excellence of K-water's drinking-water gained international recognition by acquiring 5-Star Award certification in the assessment program on water treatment plant operations management by American Water Works Association (AWWA) in 2008 (Figure 14). A 5-Star Award level of water quality control was achieved in 28 water treatment plants in 2012. Thanks to its efforts to supply the best quality of water, Tap water produced by K-water was selected as one of the global top 10 tap waters for the two consecutive years from 2011 to 2012, competing excellent tap-waters from the U.S., and Canada in the International Water Tasting and Competition. K-water has been trying to develop advanced water treatment processes such as ozone and granular activated carbon that can remove micro-pollutants, disinfection by-products, and taste & odor compounds. These constituents are generally known to be harder to remove by conventional water treatments such as coagulation and sand filtration. A total of 8 advanced water treatment facilities have been developed by 2012, and 6 more will be constructed by 2015.

Table 10. Internal drinking-water quality goals for key performance parameters

Turbidity	95% of ≤ 0.1NTU monthly ≤ 0.3NTU of turbidity maximum in a month	Disinfection by products	THMs : ≤ 80㎍/L HAA_2 : ≤ 60㎍/L CH : ≤ 30㎍/L
Residual chlorine	Max (at water plant) : 1.0mg/L Min (at the consumer's tap) : ≥ 0.1 mg/L	Manganese	≤ 0.02mg/L
CT value	≥ 1 of inactivation rate	Aluminum	Annual maximum value ≤ 0.1mg/L Annual average ≤ 0.05mg/L
Taste, odor	2-MIB, Geosmin ≤ 10ng/L	Microbes	E. coli or Fecal Coliforms : Zero/100ml Total Coliform : Zero/100ml HPC : 100CFU/ml

5-Star Level of Water Quality Management Standard

- Meet all the applicable standards of drinking water
- Individual filter effluent turbidity in 4-hour intervals
  ≥ 95% ≤ 0.1NTU per year, ≤ 0.3NTU per year

[Results of Improving Water Quality]

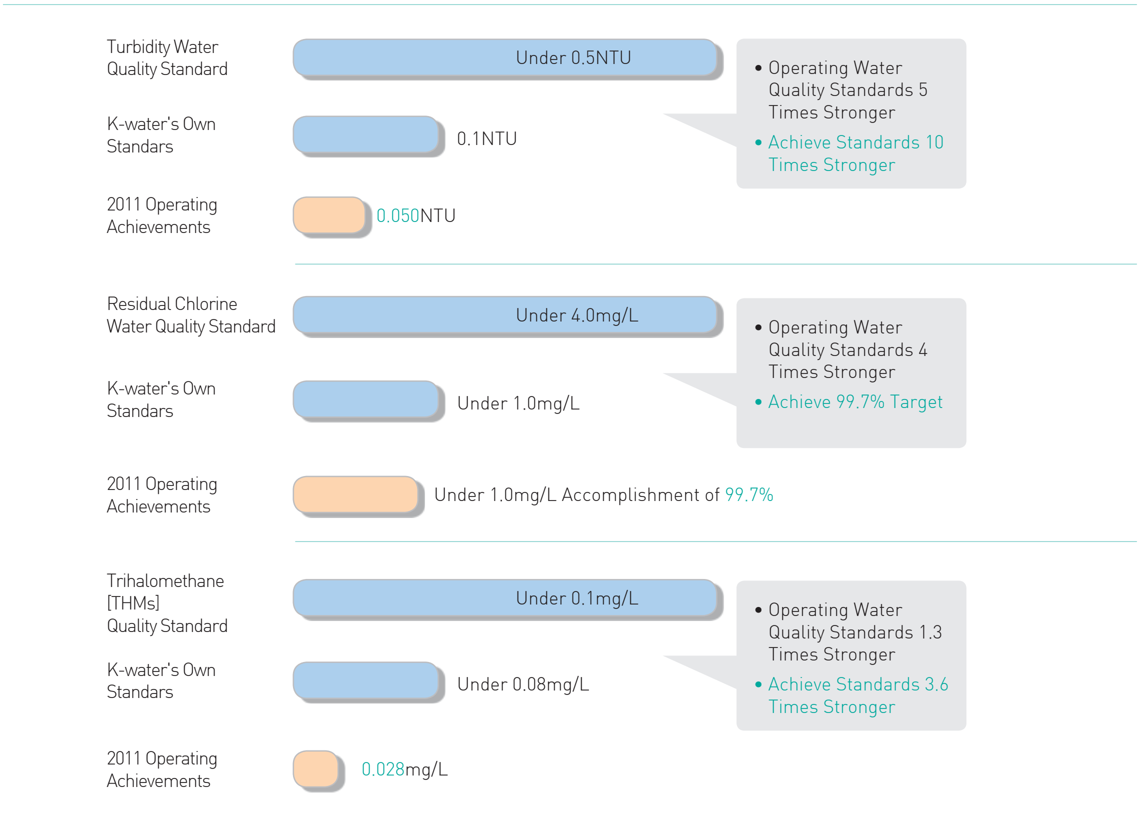


Figure 13. Results of Improving Water Quality for Key Parameters in K-water's Waterworks

Figure 14. 2008 Excellence in Water Treatment 5-Star Award by AWWA

K-water's Endeavor 3: Water Quality Analysis

Since 2002, K-water has been conducting advanced water quality testing based on having 250 water quality criteria as compared to the national primary water quality standards which is for 85 criteria. Drinking-water quality information for 164 drinking-water supply process sites are notified on the internet home page in real time as a part of an effort to provide more accurate information on drinking-water. In addition, the 2012 Global Water Quality Standard, GWQS, has newly been established and is applied at all of K-water's water treatment plants. The Global Water Quality Standard is a new kind of water quality standard which is the lowest level acquired from the comparison between permissible concentrations of WHO, USEPA, EU, Australia, Japan, and Korea, aiming to document and secure K-water's drinking-water quality on the international level. The assessment of K-water's drinking-water based on the GWQS showed that only 14 items tested (0.04%) had exceeded GWQS among 38,076 items tested.

Figure 15. K-water's Water Laboratory

6. Implementation plan

The first WSP application as described above was completed in K-water's 36 state-owned waterworks in 2011~2012. Over the next 3 years, K-water plans to lower the risk ratings of all types of hazards and hazardous events identified by WSP activities. To efficiently perform the WSP approach to management, a wide array of financial and technical support investments will be strategically and systematically provided. The second round of WSP application to K-water's program and systems is scheduled at 45 local waterworks on consignment from local governments. The water supply capacities of local waterworks are less than 10,000 m^3/day which classify them small or medium in size. The outcome of WSP activities will provide more information and feedback for water system conditions and performance and on drinking-water quality and treatment process management. In 2014, the Ministry of Environment, local governments, Korean Water & Wastewater Works Association, and K-water will make a joint effort to expand the WSP system as a specific implementation approach to create and establish a waterworks safety management system specified by the Waterworks Law. In total, the WSP system will be applied to about 450 local waterworks intentionally and on a yearly basis, with on-going, sustained efforts for holistic and responsive management of these water systems. Also, K-water wants to be an active participant in regional and international efforts to implement and apply the WSP approach and system for improved, timely and responsive managements of drinking water systems and their water quality as described and promoted both internationally and regionally by WHO.

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The Development of Water Safety Plans in Korea