



K-water's Integrated Water Resources Management System

(K-HIT, K-water Hydro Intelligent Toolkit)

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 South Korea

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Summary

Water management is a challenge in Korea due to limiting geographical features, such as short watercourses, and high rainfall variability across the regions and seasons. Korea also faces regular water-related disasters such as extreme flooding and droughts, increasing in intensity due to the change in climate thus creating increased necessity for national water management and security.

To address this, Korea has placed great effort to resolve temporal and regional variability through the construction of multi-purpose dams and multi-regional water supply systems. Such an investment in water resources in Korea has increased the water supply for industrial and domestic use alongside supporting Korea's national economic development.

K-water is responsible for managing flood water and for supplying water through the operation of water resources infrastructure including: 34 multipurpose and water supply dams, 4 flood control dams and reservoirs, 16 weirs, and one estuary barrage (similar to a low dam wall). Of these, the multi-purpose dams operated by K-water account for 62% of total dam supply and 94% of flood control capacity.

In order to protect the people from drought and flood disasters through more efficient water resource management, K-water has constructed a scientific river operation system which links the rivers in the connecting watersheds. The aim of this system is to implement integrated water resource management technology in rivers for the purpose of increasing water quantity and water quality concurrently.

In 2002, the K-water Hydro Intelligent Toolkit (K-HIT) was introduced, to provide an integrated water management system based on Information and Communication Technology (ICT). K-HIT has five functions including real-time hydrological data acquisition, precipitation forecasting, flood analysis, reservoir water supply, and hydropower generation. By using K-HIT, K-water can minimize the flood damages by storing more water during the flood season and can prevent droughts by supplying stored water during the dry season through the use of scientific and effective operation of this system.

Through the introduction of K-HIT, K-water have been able to effectively deal with floods that occurred in 2012, 2013 and 2015. In this way K-HIT also contributes to the achievement of sustainable development goals including SDG 6 (availability and sustainable management of water) and SDG 11 (making cities inclusive, safe, resilience and sustainable) by preventing disasters such as floods and securing water in droughts.

1. Background

1.1 Climate and Water Management Characteristics of Korea

1.1.1 Topography and Precipitation Features

Water management in Korea is broadly divided into 6 zones: the Han River in the Seoul metropolitan area and Gyeonggi, Geum River in Chungcheong, Seomjin River and Yeongsan River in Jeolla, Nakdong River in Gyeongsang and Jeju/Ulleung islands (see Figure 1).



Figure 1. Six zones in Korea

Rivers in Korea experience severe fluctuations in terms of river flow throughout the seasons, with rainy season in particular creating an extreme challenge for water management due to the high flood levels and runoff. In contrast, the dry season results in very low river levels, which creates its own water management challenges. As shown in Figure 2, Korea experiences highly concentrated rainfall in the summer (June - August) while precipitation is very scarce in the winter (October - January).

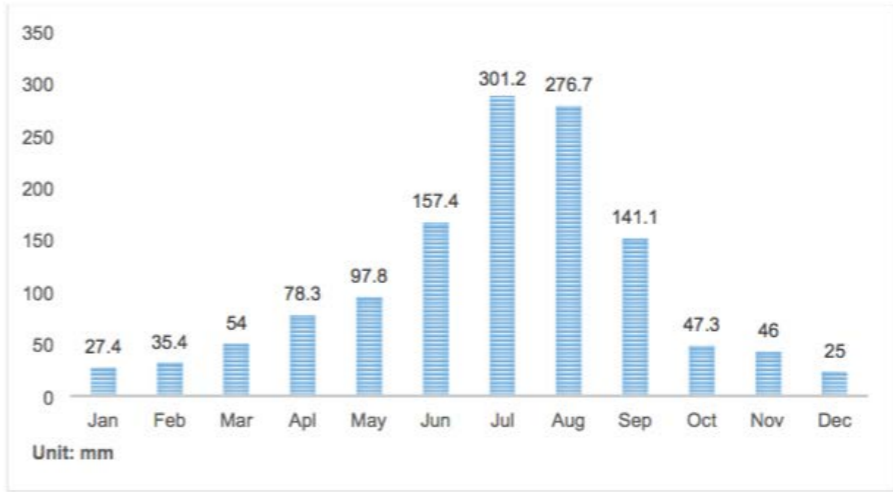


Figure 2. Monthly Rainfall in Korea
(Source : MoLIT (2017), The 4th Long-term Comprehensive Plan for Water Resources (2001~2020), 3rd revision.)

Table 1 shows a comparison of flow variation coefficients between major rivers in Korea and in other countries.

Table 1. Flow Variation Coefficients in Rivers

River	Flow Variation Coefficients	River (Country)	Flow Variation Coefficients
Han River	90 (390)	Tone (Japan)	115
Nakdong River	260 (372)	Seine (France)	34
Geum River	190 (300)	Rhine (Germany)	18
Seomjin River	270 (390)	Nile (Egypt)	30
Yeongsan River	130 (320)	Mississippi (U.S.A)	3

* Note: figures in parenthesis refers to coefficients before multi-purpose dams were constructed
Source : MoLIT (2017), The 4th Long-term Comprehensive Plan for Water Resources (2001~2020), 3rd revision.

An analysis of the patterns of precipitation change, as shown in Figure 3, indicates that the average rainfall over a 10 year period is increasing (by approximately 4% since the 1970s) and rainfall variability has been gradually increasing from the 1990s. The annual average rainfall over the past 100 years shows a large range of variability, from the minimum of 754mm (in 1939) to a maximum of 1,756mm (in 2003). In careful consideration of these natural precipitation characteristics, Korea has placed great effort to resolve temporal and regional variability through the construction of multi-purpose dams and multi-regional water supply systems.

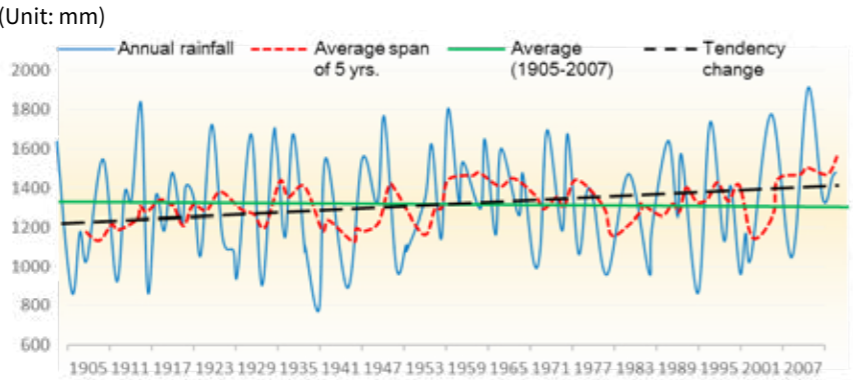


Figure 3. Average Rainfall in Korea (1905-2007)
Source : MoLIT (2017), The 4th Long-term Comprehensive Plan for Water Resources (2001~2020), 3rd revision.

Furthermore, weather anomalies such as extreme floods and droughts, which seem to be intensifying due to climate change, are occurring more frequently. Recently, Korea has been suffering from a severe drought. As Table 2 indicates, annual rainfall in 2013 was 11% lower than the average annual rainfall, and in 2014 it was 10% lower. By August 2015, the annual rainfall was only 64% of the annual average. Due to the increasing frequency of extreme weather conditions, Korea faces many challenges in terms of managing water resources and ensuring water security.

Table 2. Annual Rainfall (2006-2015)

	2006	2010	2011	2012	2013	2014	2015.8
Rainfall(mm)	1,424.3	1,444.9	1,622.6	1,479.1	1,162.9	1,173.7	659.4
Percentage compared to the average annual rate	109%	110%	124%	113%	89%	90%	64%

Source : MoLIT (2017), The 4th Long-term Comprehensive Plan for Water Resources (2001~2020), 3rd revision.

1.1.2 Water Resources Availability

The average annual rainfall rate in Korea is 1,274mm (calculated between 1973-2011), 1.6 times the world annual average. However, due to high population density in Korea, the average annual rainfall per capita is only 2,660 m³, approximately 16% of the world average. Per year, Korea has a total water supply of 132.3 billion m³. In 2007, the total amount of water-use was 37.2 billion m³ (dam 20.9 billion, groundwater 4.1 billion, river 12.2 billion), which accounts for 28% of the total amount of water resources available. Total water-use is 1.8 times the normal water runoff (runoff that occurs outside the rainy season; 21.2 billion m³), and thus flood runoff (runoff that occurs during the rainy season of June to September) is reserved in impoundments such as dams and other reservoirs to be used when necessary. The total water-use for domestic, industrial and agricultural water is about 25.5 billion m³ per year, which is approximately 34% of the total available water resources.

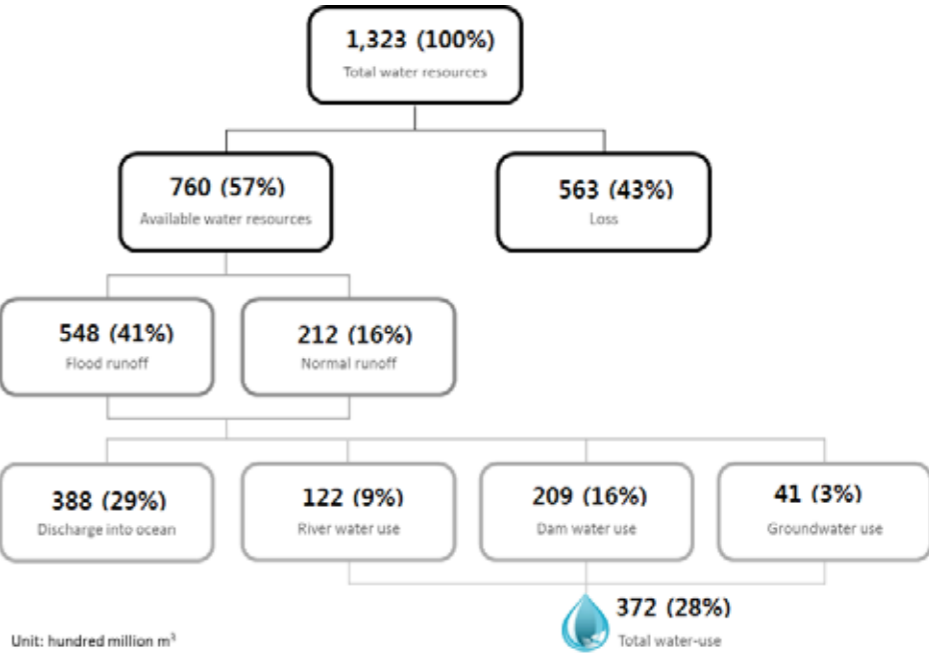


Figure 4. Water Availability in Korea
Source : MoLIT (2017), The 4th Long-term Comprehensive Plan for Water Resources (2001~2020), 3rd revision.

1.1.3 Water-Use by Purpose

In terms of water-use by purpose (see Figure 5), agricultural water accounts for the largest proportion at 48% of the total water-use, followed by domestic water 23%, then river maintenance water 23% and industrial water-use accounts for 6%. It is also notable to mention that river maintenance flow continues to increase over time. As aforementioned, the total water-use for domestic, industrial and agricultural purpose accounts for 25.5 billion m³ per year.

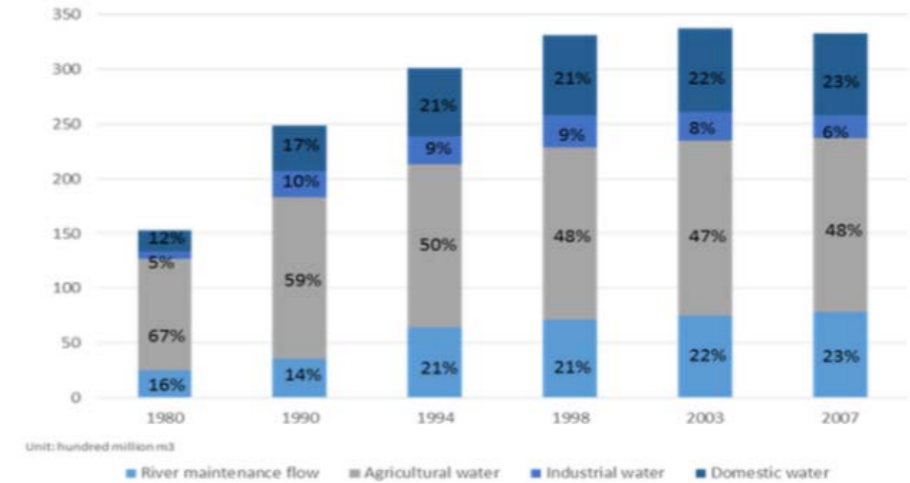


Figure 5. Water-use by Purpose
Source : MoLIT (2017), The 4th Long-term Comprehensive Plan for Water Resources (2001~2020), 3rd revision.

The water abstraction rate for domestic, industrial and agricultural purposes stands at 34%, which confirms the categorisation that Korea is a “water-stressed” country (Table 3). The high abstraction rate creates a greater vulnerability for water security, and excessive water abstraction increases the difficulties in managing water quality and conserving river ecosystems.

Table 3. Water Stress Level by Country

Abstraction Rate	Degree of Water Stress	Country
Below 10%	Low	New Zealand, Canada, Russia
10-20%	Middle	Japan, U.S.A., U.K., France, Turkey
20-40%	Mid-high	Korea, China, India, Italy, South Africa
40%	High	Iraq, Egypt

Source : MoLIT (2017), The 4th Long-term Comprehensive Plan for Water Resources (2001~2020), 3rd revision.

1.1.4 Flood Risks

It is essential to take preemptive measures and preparation in order to mitigate the effects of natural disasters given that weather anomalies and vulnerability driven by climate change are aggravated in Korea.

Approximately 70 to 80% of the total annual rainfall is concentrated in the summer making Korea highly vulnerable to water-related disasters. The average annual damage caused by water-related disasters over the last 10 years is estimated at 2,084.5 billion KRW (USD 1.895 billion). As Figure 6 notes, Korea's flood risk index is much higher than other countries resulting in the need for systematic and proactive responses in order to prevent extensive damages caused by disasters and climate change.

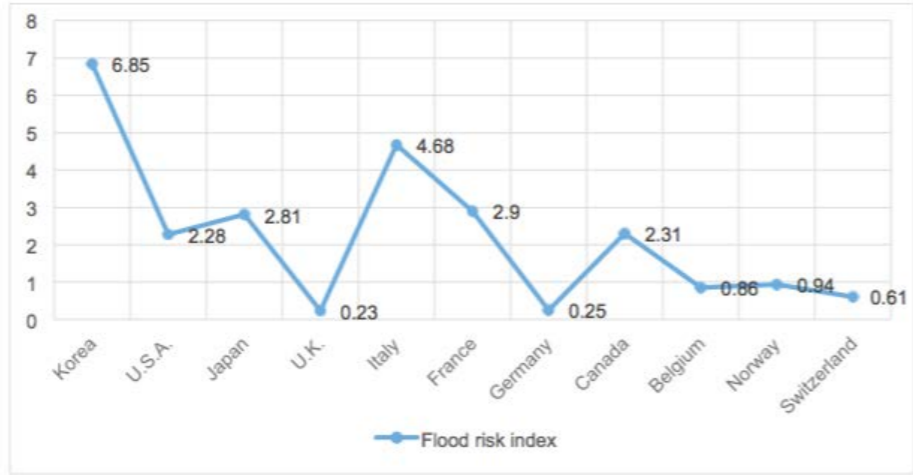


Figure 6. Flood Risk Index by Country
Source : Based on UNDP (2004), Reducing Disaster Risk. A Challenge for Development

1.2 Economic Growth

Box 1. Economic Growth in Korea
Over the past 50 years Korea has transformed from an agricultural country to industrialised country with rapid urbanisation. The per capita GDP grew by an average 10.95% of a year (USD 253 in 1970 to USD 27,805 in 2015), and the urbanisation rate reached 81.9% in 2011 from 40.7% in 1970. The agriculture and forestry industry was the largest industry with 28.9% in 1970 but sharply decreased to 2.3% in 2015 and the manufacturing industry grew from 29.5% to 148.8%.

Table 4. GDP and Urbanisation Rate

Year	1970	1975	1980	1990	2001	2011	2015
GDP (Billion)	2,795	10,505	39,471	197,712	688,165	1,332,681	1,564,124
Urbanisation Rate (%)	40.7	48.0	56.7	73.8	79.6	81.9 (2010)	

Source: Analysis of the effects of water resources development in Korea's economic development process, Dec. 2016, Choi Han-ju

Table 5. Industrial Structure (%)

	1970	1975	1980	1990	2001	2011	2015
Agriculture and Fisheries	28.9	26.9	15.9	8.4	4.1	2.5	2.3
Mining and Manufacturing	20.4	23.4	25.6	28.0	27.8	31.6	29.7
(Manufacturing)	18.8	21.9	24.3	27.3	27.6	31.4	29.5
Electricity, Gas and Water Supply Business	1.4	1.2	2.2	2.2	2.9	2.0	3.2
Construction Industry	5.0	4.5	7.6	9.5	6.1	4.8	5.1
Service Industry	44.3	44.1	48.7	51.9	59.0	59.1	59.7

Source: Analysis of the effects of water resources development in Korea's economic development process, Dec. 2016, Choi Han-ju

1.3 Water Resources Investment

Korea's investment in water resources has increased alongside its national economic development. Figure 7 shows the annual investment (based on construction amount) and the trend of gross domestic product (GDP) for water facilities from 1977 to 2014 based on a construction industry survey. Water investment has increased, though irregularly, as GDP growth continues.

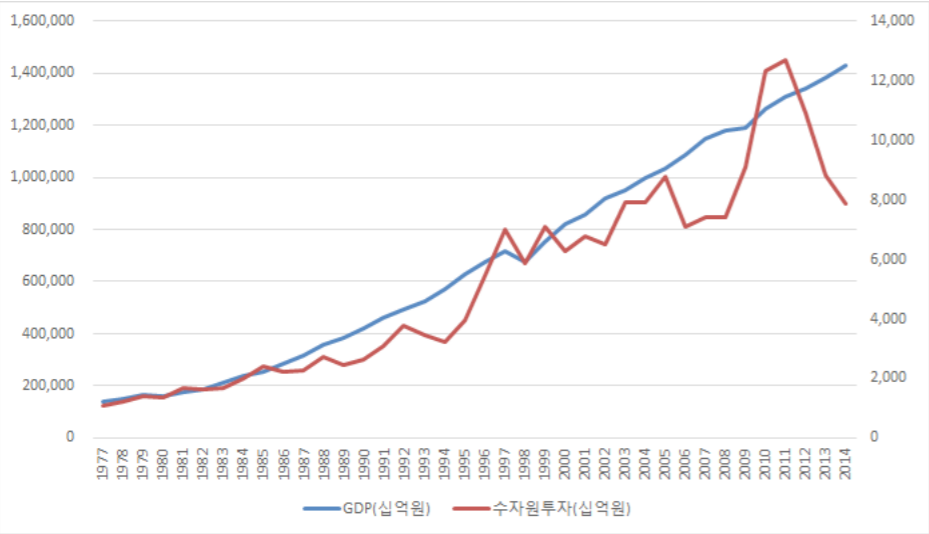


Figure 7. Water Investment and Gross Domestic Product Trend (1977~2014, yearly basis)
Source: Analysis of the effects of water resources development in Korea's economic development process, Choi Han-ju, K-water Researcher, 2016

Box 2. Water Resources Investment in Korea

Economic Development Period (1960 ~ 1980)

Water development during this period was actively promoted to support economic development. It was designed to meet a variety of demands such as supplying electricity using hydroelectric power, supplying stable industrial water, and establishing industrialisation and urbanisation bases through flood control. Andong Dam (1976), which is a multi-purpose dam, was constructed in order to provide a stable supply of industrial water and domestic water. Over this period, water usage tripled from 5.12 billion m³ to 15.3 billion m³ in 1980, and the water supply rate increased from 16.9% in 1960 to 54.6% in 1980.

Economic Growth Period (1980 ~ 2000)

The construction of multi-purpose dams, which had been sluggish due to the government's tightened budgets in the early 1980s, has increased rapidly since the mid to late 1980s due to the expansion of social overhead capital. Between 1980 and 2000, ten multi-purpose dams were constructed to secure a total volume of 3.7 billion m³ and to supply 3.3 billion m³ of water for industry, agriculture and domestic use. However, despite the increase in the number of multi-purpose dams constructed at this time, the size of the dams has been reduced compared to the total capacity of the 5 dams that were previously built for the purpose of flood control. Since the 1980s, multi-purpose dams have been constructed with a focus on water supply.

The main goal of water resource development in the 1980s was to respond to the surge in water demand due to industrialisation and urbanisation. In 1980, the urban population ratio was 68.7%, while the water supply rate was only 54.6%. By 2000, the water supply rate increased to 87.1%, which is close to the urban population ratio of 88.3%.

Economic Growth Period (2000 ~ present)

Water resources development has also been transformed from quantitative development based on supply to qualitative diversification with an emphasis on water quality, river ecology and environment. The increase in the cost of construction of dams, such as the exhaustion of land and compensation for resettlement due to the large areas of land required for reservoirs, and the increase in public demand for water quality and environment have made the dam construction conditions more difficult. During this period, only 5 small to medium-sized dams were constructed and the development of new water sources such as sewage reuse was actively promoted.

In 2009, the Four Major River Restoration Project (4MRRP) was promoted as part of the Korean-style Green New Deal for green growth, in which the central government sought fundamental preemptive measures to mitigate flood and drought damages caused by climate change. Unlike a single-purpose river project, the aim of 4MRRP was to contribute to the revitalisation of the rivers and economic revitalisation through the development of water resources infrastructure, increased water storage capacity for enhanced flood and drought management, improvement of water quality, and the creation of new waterfront leisure and culture spaces. With a total investment of 22.2 trillion won, 520 million m³ of underwater dredging was conducted, 16 weirs were built in the main rivers and flood control areas and riverbed reservoirs were constructed to secure 11.7 billion m³ of water resources to improve dimensional safety and water utilisation.

1.4 Population and Water Supply Rate

The population of Korea increased from 31,435,000 in 1970 to 52,419,000 in 2014. In that time the water supply rate increased greatly from 31.2% (10,430,000 people) in 1970 to 96.1% (31,372,000 people) in 2014.

Table 6. Population and Supply of Water (Unit: Capita, %)

year	1970	1975	1980	1990	2001	2011	2014
Population (thousand)	31,435	34,709	38,124	43,520	48,289	51,717	52,419
People of water supply(thousand)	10,430	14,961	20,809	33,631	42,402	48,938	50,373
Water supply rate(%)	31.2	43.1	54.6	77.3	87.8	94.6	96.1

Source: Analysis of the effects of water resources development in Korea's economic development process, Dec. 2016, Choi Han-ju

1.5 National Water Resources Management System

Box 3. Stakeholders

The Ministry of Land, Infrastructure and Transport (MoLIT) is responsible for water quantity management such as flood control, the instream flow of rivers, and the development of water resources. Whereas, the Ministry of Environment is responsible for water pollution regulations and water quality management such as drinking water and wastewater. K-water is responsible for managing flood water through dam operations and requires approval from the Flood Control Office, which is in charge of river flood control, to open the gates of dams. When the gates are opened, stakeholders and local governments must be notified of discharging information.

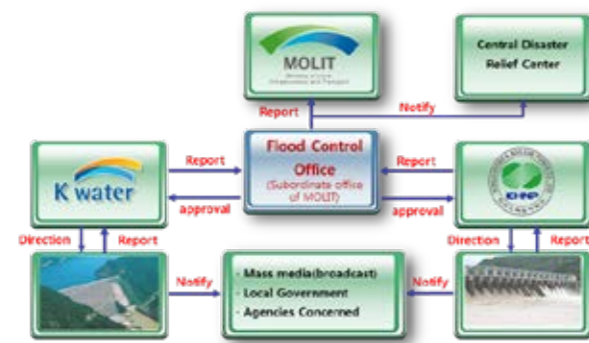


Figure 8. Dam operation procedures in Korea



Figure 9. Water Management Center of K-water

Korea has 17,759 dams in total. These dams supply 18.8 billion m³ of water annually, 56% of Korea's annual water use (of 33.3 billion m³), and they control floods with a capacity of 5.3 billion m³. Of these, the multi-purpose dams operated by K-water account for 62% (117 billion m³) of total dam supply in Korea and 94% (5 billion m³) of flood control capacity.

The flood control process of multi-purpose dams is based on the rainfall data from the hydrological data management system connected with the weather information system and the real-time online network of the dam basins of K-water. K-water also performs rainfall-runoff analysis through the flood analysis system. This system is used to make full use of the flood control capacity by determining the appropriate controlled discharge amount and timing. To do this K-water consider the capacity of the dam downstream of the river, and conduct flood control of the entire water system in consultation with the related organisations such as the Flood Control Office.

K-water operates and manages important water resources infrastructures including 34 multi-purpose and water supply dams, 4 flood control dams and reservoirs, 16 weirs, 1 estuary barrage (see Figure 10), all of which are government assets.

The basin areas managed by K-water account for 48% of the nation's total land area, 95% of the nation's entire flood control capacity and 65% of the total water usage. As the number of dams K-water manages continues to increase, K-water needs to consider ways to combine dam operations to effectively conduct water resources management in river basins.



Figure 10. Dams and Weirs of K-water

2. Challenge Description

Increasing Frequency and Severity of Water Related Disasters

The frequency of severe floods and droughts in Korea has increased in recent years due to the changing climate. The measurement of this phenomenon is difficult to calculate due to a broad range of uncertainties, however the increase in water related disasters such as intensive precipitation and irregular drought cycles are significant and urgent issues that Korea is now facing.

The financial cost of the damage caused by natural disasters over the past 10 years in Korea, 87% of which were water related, was 1.7 trillion won per year (USD 1.55 billion), 5.3 times greater than in the 1980s and 3.1 times greater than in the 1990s. The annual restoration cost was even higher (approximately 2 trillion won; USD 1.82 billion). In addition, as 62% of dam facilities are over 30 years old, water management hazards are rapidly increasing creating a further serious water management and safety issue.

For example, four typhoons (including three in close succession at the end of the rainy season) struck the Korean Peninsula in 2012 for the first time since 1962 causing precipitation almost twice the monthly average from the middle of August to the middle of September. In 2013 the rainy season was the longest on record since weather observation data was first collected

in 1904 with heavy rain in the middle region of Korea, while insufficient rain in the southern region of Korea resulted in a regional deviation of over 200mm. The most severely impacted was Jeju Island, which experienced approximately USD 300 million in drought damages, for the first time in 90 years. According to the 4th assessment report of the Intergovernmental Panel on Climate Change, it is expected that the risks of flooding and drought disasters in high latitude countries in the northern hemisphere, such as Korea, as well as the intensiveness and fluctuation of rain will continue to increase significantly.

Significant change of water management conditions after the Four Major Rivers (restoration) Project

In addition, the water management condition in Korea changed significantly as a result of the *Four Major Rivers (restoration) Project*, which was completed in 2012. K-water used to control floods and water-level control with linked operation among more than 30 multipurpose and water supply dam and river stations in the past. After the project, the changes made to river facilities (e.g. weirs and river-crossing sections) affected the stream flow of the river, increasing the consideration factors for flood control and algae bloom.

Box 4. Water cycle management in weirs and dams

Water has a hydrological cycle starting from precipitation to evaporation then eventually runoff. Thus, a water management system that is able to accurately analyse the water cycle is the key for successful water management. This is especially true for the effective operations in dams and weirs, which are an important element of many multi-objective water resources systems, an must ultimately create a balance between flood risks and other system objectives such as water supply or hydropower production.

3. Smart Water Management Solution

3.1 Input

3.1.1 Economic Factors

The (Smart) Water Management Center for the Integrated Operation of Dams and Weirs
In 2002, K-water established the Water Management Center, with 39 experts on water resources including water management, ICT, power generation, and weather. With the opening of a comprehensive water control room, K-water greatly enhanced its water resource management capabilities by integrating the operation of dams. The Water Management Center expanded its management staff to 55 people in 2010 and 67 people in 2016 due to the expansion of management facilities and functions.

The Water Management Center performs the following step-by-step work during normal and floods times.

- Normal stage: one person is on duty after working hours (18:00 – 09:00) if there are no forecasted weather issues
- Caution stage: If the national rainfall forecast requires the operation of dams and weirs for flood control, 8 people will operate the facilities (in groups of four)
- Alert stage: If weather report is issued and water discharge is needed to carry out flood control, 13 people will operate (in three groups)
- Serious stage: If nationwide floods and massive flood damage occur, 24 people (split into two groups) will be operate the system

Flood Control Capacity Enhancement Project

The Flood Control Capacity Enhancement Project on existing dams is the project for prevention of disasters from excessive flood due to changes in the climate and thus protects lives and property damage by increasing the safety of dams.

To prepare for the increasing frequency of heavy rain due to recent climate changes, the standard of design flood¹ has been changed from frequency of flooding (100/200yrs) to Probable Maximum Flood (PMF). PMF is the amount of flood that results from the maximum possible amount of water, which is the theoretical maximum precipitation that can physically occur in any given period of the year for a given watershed area at a given location over a given time duration. Therefore, the design flood has been enlarged due to this change.

The amount of inflow into dams is much higher than the designed capacities when dams were initially constructed. As a result, flood control capacity enhancement is required to guarantee the permanent safety of dams. The types of measures include spillway expansion, auxiliary spillways and parapet walls.

The Flood Control Capability Enhancement Project for 24 dams, which was first implemented in 2003, is still in progress. As of 2017, 17 dam projects have already been completed, three dams are under construction and four dams are being planned.

3.1.2 Policy Factors

Establishment of Operational Regulations for Dam-weir Operation

In order to integrate the water facilities' operation with the existing dam management regulations, regulations on linked operation between the dams and the weirs have been developed to ensure the water resources facilities can be more efficiently managed.

Scientific and systematic operation is implemented to both secure additional water resources for the future, and to allow water facilities to preemptively discharge water for the purpose of flood control.

For the management of weirs, it is necessary to operate with consideration for river inflow situations, discharge situations of upstream dams, and river water quality.

Drought Response Guideline

A step-by-step 'Drought Response Guideline' has also been developed for dam operators to enable them to preemptively prepare for drought situations and to carry out the necessary measures required to manage the water supply. The Guidelines ensure the proper water supply is provided during droughts in order to minimise any social impacts including public inconvenience.

The 'standard' daily storage volume required for the dams to stably supply water for the next year is set in the Guideline. If at any time the actual storage volume is lower than the standard volume, the amount of water discharged from the dams is reduced in stages in accordance with the advice of relevant agencies.

- Ordinary season: water supply reductions are flexibly implemented to supply water through conjunctive dam operation in the river basin based on the capacity of each dam.
- Shortage for Water Supply: If conjunctive dam operation is unable to satisfy the water demand, dam water supply is reduced in order to prevent the interruption of daily or industrial water supply in the future.

1. The design flood is the engineering design standard for the river facilities considering the characteristics of the flood, frequency of occurrence of flood, potential damage due to flood, and economic factors.

In Korea, monthly operation plans for multi-purpose dams are confirmed by the prior approval of a joint committee called the ‘Collaborative Operation Committee with Dams and Weirs’.

Drought response stages and major action plan in each stage are as follows:

- 1. Notice stage: adjustment of water supply to contracted quantity, real-time monitoring and progress sharing with relevant agencies.
- 2. Caution stage: reduction of river maintenance water, support water supply to the public such as bottled water and campaign of water saving by media
- 3. Alert stage: Reduction of irrigational water and structural countermeasures such as development of underground well, leakage improvement
- 4. Serious stage: restrict domestic and industrial water supply and develop sustainable countermeasures including building new dams and diversification of water sources.

- Applied Model : SAMS(Stochastic Analysis Modeling and Simulation) 2007
- Extension of inflow maintaining statistical characteristics using the observed data

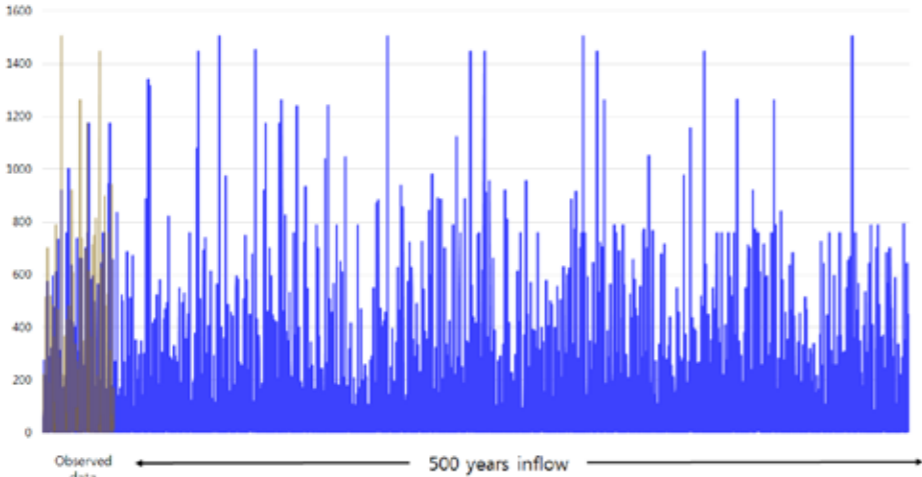


Figure 10. Estimation of long-term inflow for 500 years by stochastic analysis
Source : K-water

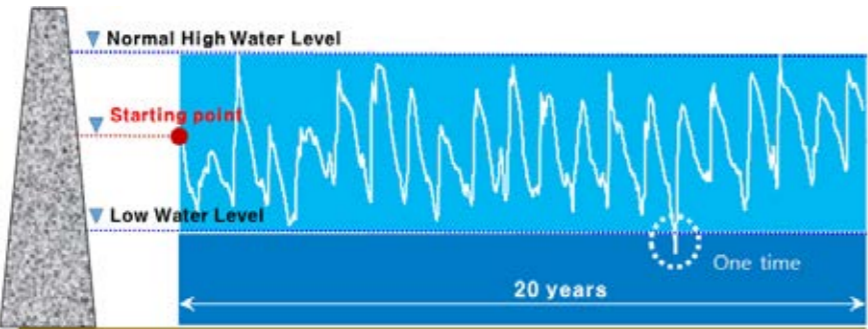


Figure 11. 95% safety for water supply (1 year shortage out of 20 years)
Source : K-water

The standard storage volume is the minimum volume required to supply water in accordance with the drought stage, as estimated by trial and error methods considering safety for water supply (95%, 475yrs out of 500yrs).

If a dam storage approaches the standard storage volume, the reduction of water supply will be implemented in accordance with the drought response guideline after approval of ‘Collaborative operation committee with dams and weirs’. The order of reduction is primarily river maintenance, irrigational, domestic and industrial water as shown in Table 8.

Table 8. Required reduction in stages

Stage	Required Reductions
Notice	Surplus water (only contracted water quantity provides)
Caution	River maintenance water
Alert	River maintenance water + Irrigation water
Serious	River maintenance water + Irrigation water + (Domestic & Industrial water) ratio

If the water supply reaches the caution stage during the reduction process, the reduction will continue until it exceeds the normal stage (with exceptions at the request of the relevant agencies). If the dam storage exceeds the normal stage, the water supply should be recovered up to the contracted water quantity volume in consultation with the relevant organisations.

3.1.3 Technical Factors

The development of the IWRM System

Korea relies heavily on the supply of surface water by rivers and dams for 90% of the total annual water resources supply (approximately 33.7 billion m³). During most of the year (except during the flood season), a number of major rivers, including the Han River, are controlled by the supply volume of multipurpose reservoir groups located in the upper middle area of the basin. Therefore, in order to protect the local people from drought and flood disasters through more efficient water resource management, it is essential to construct a multi-purpose dam with a reservoir and a scientific river operation system in a watershed or a metropolitan watershed which links the rivers.

K-water has constructed this system in three steps with the aim of implementing integrated water resource management technology in rivers for the purpose of increasing water quantity and water quality at the same time.

- 1. Phase 1 (2001 - 2004): Development of the 'real-time watershed management system' - a database-based modularised analysis system consisting of simulation models of reservoir groups and watershed runoff, and Integrated Water Resources Management System (IWRMS).
- 2. Phase 2 (2004 - 2007): A Geographic information system (GIS) and a real-time Reservoir Turbidity Monitoring and Modeling System (RTMMS) implemented in parallel with the calibration of the elemental technologies developed in Phase 1 by applying the Geum River and Nakdong River basins.
- 3. Phase 3 (2007 - 2011): Research and Business Development (R&BD) level technology developed through generalisation and commercialisation of various technologies and systems for analysing water quality and to improve the water resource management capacity of dams and rivers connected in a watershed with consideration for water ecology and ecosystems.

Box 5. The system construction phases

Phase 1) Build infrastructure for water management technology

To acquire stable data such as hydrological data generation, processing, transmission, etc., it is necessary to replace old sensors such as water gauge and rain gauge with the latest products and install power and lightning protection facilities, data acquisition, storage and transmission functions such as the Smart-TM Configuration. The Smart-TM system also has a single structure for small dams and rivers, and redundancy for large and medium-sized dams and rivers, depending on the dam and river size.

*Smart-TM (Tele-meter) is an intelligent hydrologic observation system for installing power and lightning protection facilities and data acquisition, storage and transmission functions for stable production data by replacing sensors such as water gauge and rain gauge Configuration

Phase 2) Construction of real-time hydrological information and image system

Establishment of an integrated database of dam hydrological data, production of data through a system that includes data verification and correction, real-time hydrological information (RHDAPS) based on user-customised Graphic User Interface (GUI), and real-time video system to support decision making

Phase 3) Building a decision-making system

Water management technologies such as flood analysis, water supply, drought information, safety management shall be constructed considering the situation of water use and water control by country. In addition, flood analysis model and early flood warning system through integrated Database analysis shall be established and monitoring and warning criteria are settled by visualisation of expected water level and flood range in conjunction with GIS

Phase 4) Integrated Water Management Center with ICT

The Integrated Water Management Center is designed to integrate the collected data and to respond quickly to major situations through real-time hydrological information such as hydrological data and CCTV images and decision-making systems. In case of Generation Integrated Operation System (GIOS), independent and integrated according to the level of independent operation and communication infrastructure of plant facilities are as follows.

- Independent configuration: It is adopted when independent operation is advantageous, or when there is a lack of communication infrastructure.
- Partially integrated configuration: if several power plants are operated in one area, partial integration in the area or center will be implemented.
- Integrated configuration: Considering the integrated operation of power plant operation from the remote center in the central center, the national communication infrastructure should be good and the operator's skill level should be high.

3.2 Outputs

3.2.1 K-HIT, K-water Hydro Intelligent Toolkit

The main aim of this project was to maximise efficient water supply and to minimise flood disasters. To achieve this we developed the K-water Hydro Intelligent Toolkit (K-HIT), an integrated water management system based on Information and Communication Technology (ICT). The multiple functions of this system can be operated by anyone, anywhere, at anytime. This system is also sharable and smart-phone compatible. K-HIT consists of 5 sub-systems including 1) real-time hydrological data acquisition, 2) precipitation forecasting, 3) flood analysis, 4) reservoir water supply, and 5) hydropower generation.



Figure 12. K-water's water resources management procedures based on K-HIT
Source : K-water

The K-HIT procedures are applied in several steps to operate our dams, weirs and hydro power plants. First we gather and process the data from our observatories using the Real-time Hydrological Data Acquisition and Processing System (RHDAPS). Then we forecast the rainfall for dam and weir basins using the Precipitation Forecasting System (PFS). These observed and forecasted data are used for flood control and water supply. Then, based on the results of the Flood Analysis System (FAS) and the Reservoir Water Supply System (RWSS), we decide the volume of dam discharge, the gate opening time, and withdrawal of the water from dams. Finally, we use the Generation Integrated Operation System (GIOS) to efficiently operate the hydropower generation facilities to consider the discharge from the dams and weirs into our water management operation.

3.2.2 Precipitation Forecasting System (PFS)

The Precipitation Forecasting System (PFS) was developed by K-water to forecast the average precipitation levels of the dam and weir basins. The Korea Meteorological Administration (KMA) and the National Oceanic and Atmospheric Administration (U.S.) (NOAA) provide the initial data including temperature, humidity and wind speed and these data are then used as input data for K-PPM, a 3km×3km high spatial resolution forecasting model.

PFS provides precipitation forecast information for the following five days, updated four times a day, using a HPC (High Performance Computer) and makes various weather maps including rainfall prediction maps. In addition, it analyses the predicted rainfall for each basin with the resulting data applied to the flood analysis model.

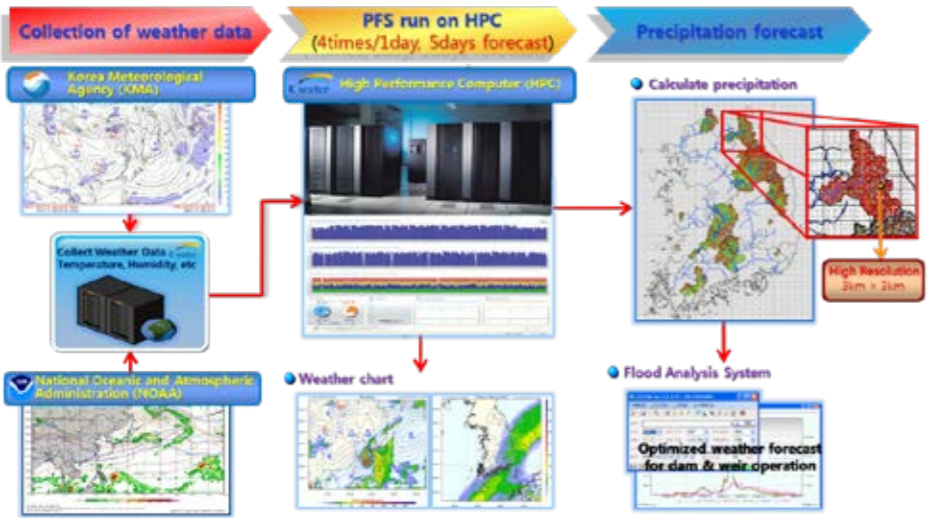


Figure 13. Precipitation Forecasting System (PFS) for Dam and Weir Operation
Source : K-water

3.2.3 Real-time Hydrological Data Acquisition and Processing System (RHDAPS)

All data related to dam operations and precipitation, water level and hydraulics are saved in the Database server at the Water Management Center and are managed by the Real-time Hydrological Data Acquisition and Processing System (RHDAPS), as shown in Figure 15. Real-time hydrological data such as rainfall, water level, inflow and outflow is collected every two seconds from over four hundred observatories. RHDAPS then produces user-friendly operational data in one, 10 and 30 minute intervals. As such, this system enables our operators to be familiar with key data on inflow, outflow and the operational status of the hydro-structures. To increase the safety and reliability of data gathering, a dual communication network has been established using both satellite and Code Division Multiple Access² (CDMA).



Figure 14. Real-time Hydrological Data Acquisition and Processing System (RHDAPS)
Source : K-water

3.2.4 Flood Analysis System (FAS)

K-water built the Flood Analysis System (FAS), for flood control and dam and weir operation. FAS performs flood analyses using rainfall forecasting data provided by PFS and hydrological information obtained through RHDAPS. As the first step, the system decides the opera-

2. CDMA is an example of multiple access, where several transmitters can send information simultaneously over a single communication channel. It is used as the access method in many mobile phone standards.

tion methods for each reservoir through rainfall-runoff analysis using storage function and hydrological channel tracking. Next, PFS operates a joint operation model for the reservoir system to prevent flood damages by minimising peak flow downstream. At this time, discharge is decided upon using optimisation techniques. Simulations are preformed to determine the optimum discharge plan to be performed with consideration to the field site constraints. After this simulation, the discharge plan is revised and the hydraulic model is operated by applying the reservoir operation plan and tide level. After the assessment on whether or not the flooding of rivers will occur, a final discharge decision is made. Through these processes, an optimal release plan is realised.

After determining the optimal release schedule, the dam's discharge schedule is disseminated to the local government, broad casting companies and people who live in the downstream area of the dam at least three hours before the gates are opened. After completing the flood control measures, we also evaluate and communicate the result of the release plan to make people aware of the positive effects of the dam operation.

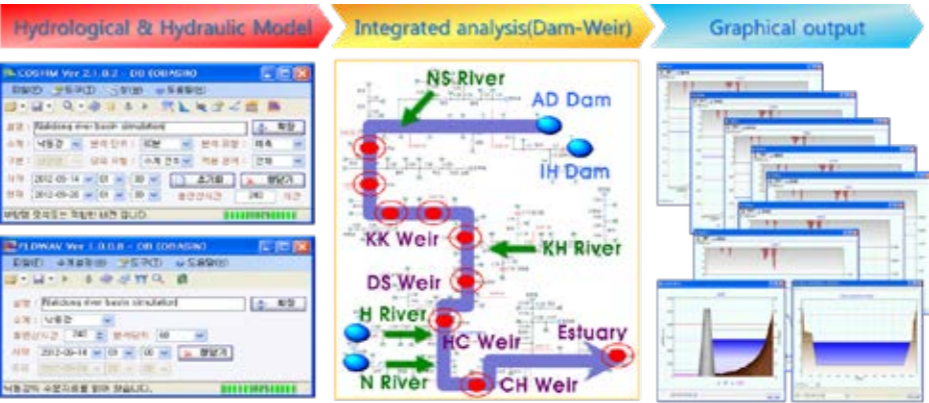


Figure 15. Flood Analysis System (FAS)
Source : K-water

The rainfall-runoff simulation in FAS is applied to the storage function model, which is a non-linear and concentrated model. A one-dimensional numerical model considering dynamic waves is also applied to the hydraulic analyses in FAS. Using these models we are able to operate a detailed simulation of dam-weir coordinated operations.

Box 6. Establishment of integrated flood management system for municipalities

Due to the warming of the Korean peninsula, precipitation and stormy days (more than 80mm / day) are continuously increasing. With 85% of natural disaster damage caused by floods, small rivers are the most impacted by the damage. Between 2007 and 2011, 98.7% of flood damages occurred in small, local rivers.

TABLE 9. Flood Disaster Status
Unit: KRW million (Divide by 1000 for approx. value in USD)

Rivers	Total	2007	2008	2009	2010	2011
National rivers	5,439 (1.3%)			962		4,477
Local rivers	230,172 (53.8%)	26,435	5,274	49,667	32,260	116,536
Small rivers	192,169 (44.9%)	24,480	9,120	43,109	27,290	87,810
Total	427,780	51,275	14,394	93,738	59,550	208,823

Source: Problems and Improvement Tasks of River Disaster Management Project ('12.8, National Assembly Budget Policy Department)

The Korean government's preventive investment has increased rapidly to the level of developed countries, but the safety of individual residents is still insufficient. Between 2008 and 2012, the average disaster prevention investment ratio compared to the government budget of Korea was 2.0% (greater than that of Japan at 1.7%). However, the preliminary response to the safety measure of the individual was less than 40.9% (2014, NEMA). In particular, municipalities only invest 90 million won (USD 82 thousand) annually in order to establish a preemptive disaster recovery system.

In Korea, the management laws and administrative departments of national, provincial, and small basins are very diverse, resulting in inefficiency and difficulties to implement integrated water management. While the proportion of local rivers (49%) managed by local governments is lower than that of national rivers (81%), there is a lack of national investment. Developed countries recognise that there is a limit to structural measures when coping with localised floods, and so are changing the paradigm of flood disaster management by implementing unstructured measures. It is therefore essential to prepare a preventative flood response system by using science and technology since current flood management is predominately focused on the recovery after the flood damages occur, instead of proactive measures to prevent the damage in the first place.

Flood integration management project for local governments

The purpose of this project is to build a system that can optimise the best decision making alternatives by observing and analysing flood information in real-time, while considering the characteristics of local governments. As of 2017, the project has been implemented in five municipalities with 27 additional municipalities currently in the process of implementation.



FIGURE 16. Integrated flood management system concept (Source : K-water)

1. Real-time situation monitoring and remote control (water level, rainfall, CCTV) and remote control of repair facilities (drainage pumping station, water gate and storm water storage).
2. Link with relevant organizational data
K-water, Flood Control Office, Meteorological Agency, and other local governments to manage floods including the upstream and downstream of the jurisdiction
3. Establish flood analysis and response standards
Prevent flood damage by establishing flood countermeasures optimised for small and medium streams by using past weather and hydrological data to conduct flood analysis

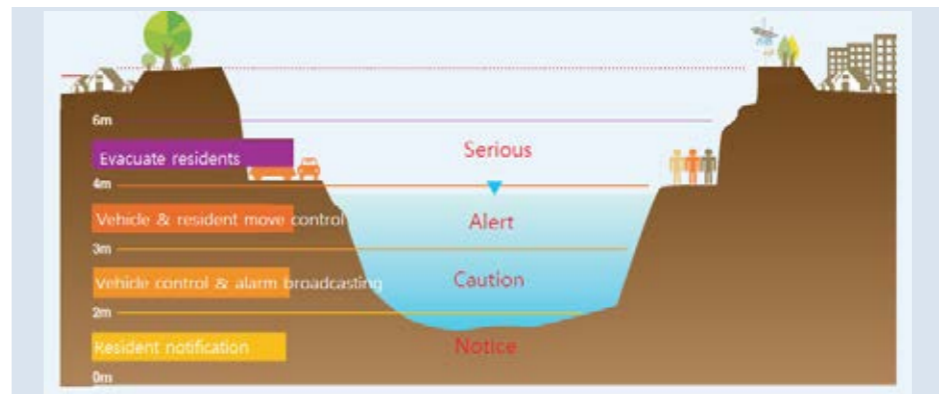


FIGURE 17. Establishing flood response standards (Source : K-water)

K-water has concluded a contract to transfer accumulated flood management technology to local governments, establishing customised flood disaster monitoring systems (diagnosis and construction of flood disaster monitoring facilities, and integrated monitoring systems) for disasters and damage patterns in basins.

3.2.5 Reservoir Water Supply System (RWSS)

Water management during the dry season is based on a system for stable water supply during an unexpected drought.

The Reservoir Water Supply System (RWSS) was developed to make optimal water supply plans from reservoirs considering water demand, water balance and water quality. First, long-term rainfall-runoff is analysed for the entire basin, including the consideration of long-term predicted rainfall. Then, medium- and long-term operation plans are made based on analysed runoff situations and water demand. With this operation plan, water quality in rivers and weirs is examined and if it does not meet the criteria, the operation plan is re-produced. Once the water quality meets the criteria, the plan is given to the joint operation council after consultation with interagency organisations. The council then comes to a decision based on the consideration of general water resources usage in entire basins and operation situations, and the final operation plan on water resources facilities for stable water supply is completed. For reservoirs, the operating plan by RWSS is checked by water level standards. Guidelines are set in advance for unexpected severe droughts, with regular severe droughts anticipated every 20 years.

By applying the 'sequent peak method' (a method used to determine the reservoir capacity required to meet demand over a given period) monthly water level guidelines are calculated to supply water stably taking into consideration the design drought inflow (expected inflow in drought). If water levels in the guideline are higher than the restricted water levels of reservoirs, inflow and water supply resume.

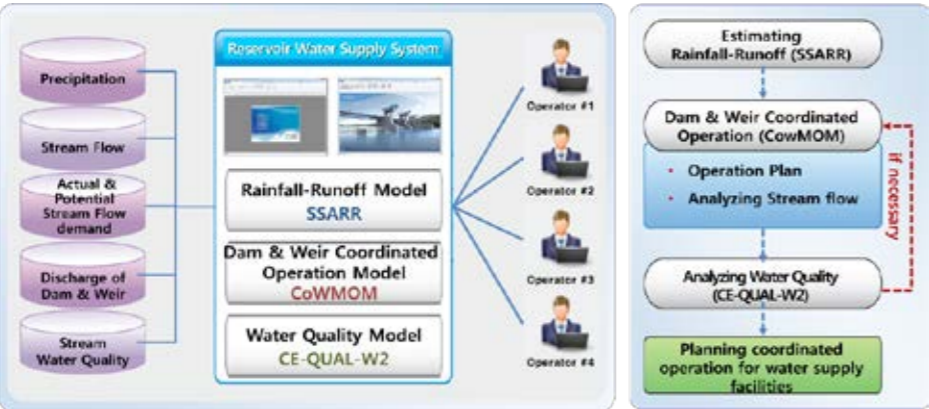


Figure 18. Reservoir Water Supply System (RWSS)
(Source : K-water)

3.2.6 GIOS, Generation Integrated Operation System

K-water developed Generation Integrated Operation System (GIOS), to enhance competitiveness in the electric power market in 2005. Using GIOS 25 hydropower plants (and 78 generators) are remotely operated and monitored from the Water Management Center on a real-time basis. While hydroelectric energy is small in regards to the total amount, it contributes to the stable electricity supply since it plays a pivotal role when managing peak demand situations. In peak demand, the GIOS automatically reacts to ensure energy demands using hydropower. To ensure the system is protected against breakdown or cyber terrorism, GIOS has a failover function and security system, alongside dual servers and networks to ensure continuous service and an anti-virus program and surveillance cameras for system security.

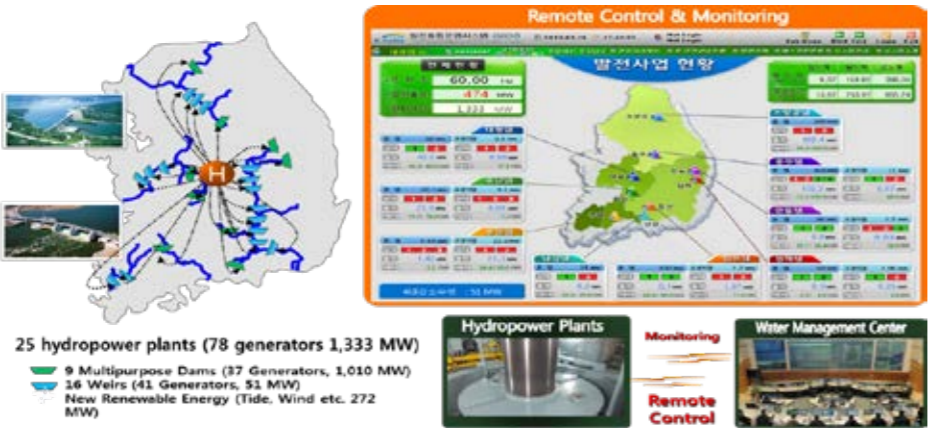


Figure 19. Generation Integrated Operation System (GIOS)
(Source : K-water)

4 Outcomes & Impact

4.1 Operation of dams against floods

4.1.1 Flood control in 2012 and 2013

Due to insufficient precipitation in June 2012, the rainy season started later than usual (July instead of June) and it finished earlier than usual. After the rainy season ended, precipitation

was significantly higher than usual due to the passing of continuous troughs of low pressure and three consecutive typhoons, which occurred for the first time in meteorological observation history. Accumulated precipitation nationwide in multipurpose dam basins in 2012 was 1,402mm, approximately 110% the annual average, 967mm of which occurred during the rainy season.

Due to the close cooperation system between the upstream and downstream facilities, K-water only needed to release 29% of the total inflow through the floodgates during this period, which played a major role in the reduction of flood damages. In other words, K-water stored most of the inflow in dams and only released water when the flood discharge of downstream decreased, so the water level at the main point downstream decreased down to the required maximum of 5.1m.

Table 10. Flood control effects in 2012

Main stations		Without dam		With dam		Reduction effect	
		Flood (m³/sec)	Water level (EL.m)	Flood (m³/sec)	Water level (EL.m)	Flood (m³/sec)	Water level (EL.m)
Han River	Yeoju	9,075	35.7	6,305	34.4	2,770	1.3
Nakdong River	Jindong	20,350	14.3	13,230	11.3	7,120	3.0
Geum River	Geumnam	6,374	18.0	1,851	12.9	4,523	5.1
Seomjin River	Gurye	3,304	5.3	1,484	3.7	1,550	1.6

Source : K-water

Overall, K-water minimised the flood damages through the use of scientific and effective dam operation, storing 0.6 million m³ of water during the rainy season and by discharging 0.8million m³ of the total inflow (1.4million m³). Discharge (excluding the amount required for water supply, instream maintenance and irrigation) in this period was approximately 38% of the total discharge and 23% of the total inflow. This approach contributed to ensuring stable flood control as well as securing the storage water needed for supplying water during the dry season and for improving the quality of the water quality supplied.

In 2013, despite only 80-90% of the annual average precipitation occurring in most basins, (with the exception of the Han River basin), the Geum River basin secured the average annual level of water storage, with other basins securing more than the average, due to K-water's previous efforts to secure additional water in preparation for insufficient rain before the rainy season. As a result, K-water secured 119% of the average water storage and 105% of the goal at the end of rainy season. In addition these efforts securing water for dry seasons, by storing water prior to the rainy season K-water also decreased the water level of each river by 3.2m in the Han River, 2.1m in the Nakdong River, 1.2m in the Geum River and Seomjin River as shown in Table 11, reducing the water discharge during the rainy season and thereby reducing the potential for flooding.

Table 11. Dam flood control effects

River systems	Rainfall event	Precipitation(mm)	Flood control effect(m)
Han River	12th~17th Jul.	128	3.2
Nakdong River	2nd~8th Jul.	137	2.1
Geum River		90	1.2
Seomjin River		225	1.2
Yeongsan River		252	Dam does not exist

Source : K-water

Prevention of drought damages

Water reservoirs provide a stable water supply by setting the monthly operation level of the dam water before the rainy season (end of June) against the backdrop that severe droughts occur on average every 20 years and climate change could increase the frequency.

The method of operating the dams' water supply has shifted from determining the discharge amount for each individual dam separately, to considering the hydrological situation of the upstream dams and the water demand required when determining discharge volumes. To this end, a 'real-time water management system' was constructed to take into consideration the hydrological situation of the water system, the reservoir water volume, the inflow and outflow status, the power system condition and water quality and demand. The operating system includes a watershed analysis model, a river water quality prediction model, and an optimal operation model, so that runoff analysis and reservoir operations are systematically carried out.

Existing flood-related dam operations were initially focused on flood control and securing control capacity and would manage this by emptying the reservoir completely and gradually recovering the water level in the latter half of the rainy season. This approach can have an impact on the quality of life of the inhabitants around the dams, and the ecosystems within the basin areas. Therefore, the focus for dam operations now includes social and environmental considerations to ensure the increase in quality of life and the preservation of ecosystems.

As the rivers, and the factors impacting them (such as green algae) are all highly connected, an integrated approach is needed to operate the dams as weirs in order to preemptively cope with increased drought and the occurrence of green algae in the summer months due to the changing climate.

For this reason, the regulations for dam operation were improved as follows. First, by setting the target level of the dam water to ensure dam stability and downstream flood control is not affected in the first half of the flood season (at the end of July), it becomes possible to increase the water storage capacity. In the latter half of the rainy season, when flood control is the highest priority, additional water storage can be ensured by setting a stable flood control level (in relation to the flood level limit) through power generation discharge without discharging flood water. This ensures that each dam is closely connected to other dams, allowing integrated water management in the basin while also ensuring adequate water supply and water quality throughout the year.

In July 2012, there was a severe drought in the central region of Korea, the most severe in 104 years. K-water followed the operating procedure for drought in advance with the rainfall and runoff forecasting provided by PFS and RWSS. This enabled us to plan the reservoir operation for the drought and to supply 11 billion m³ of water from multipurpose dams, 5% more than we would have been able to had we not followed this procedure.

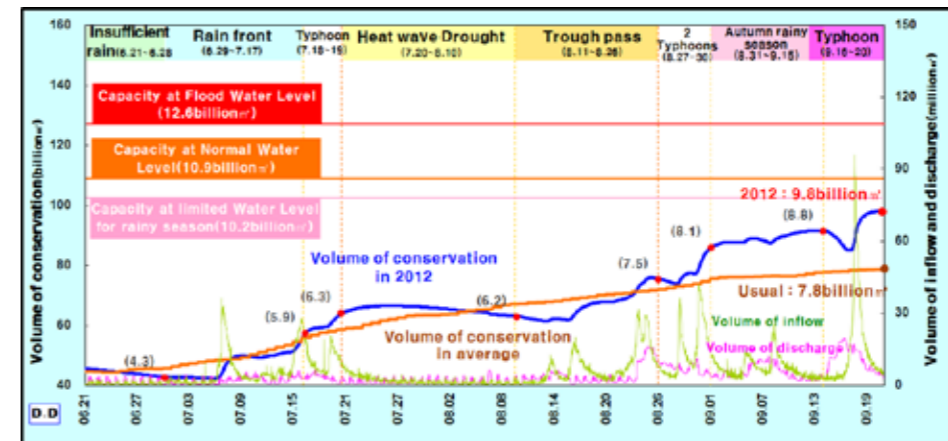


Figure 21. Status of volume conservation in 2012
(Source : K-water)

A total of 8.6 million m³ water was supplied additionally to drought prone areas in advance for the prevention of drought damages, with the flexible operation of the weirs allowing stable intakes despite of the severe drought conditions. We also supplied 2.7 million m³ of emergency water to 29 municipals by way of waterworks. Moreover, K-water played a key role in water governance by hosting periodic meetings with related organisations and water users. With these efforts, there were no damages despite the severity of the drought.

In 2015, rainfall and water levels of major dams in Korea marked the lowest record in history, and has since been described as the record-breaking drought. While a 20-year frequency drought inflow has traditionally been used to design the dam storage volume for water supply, in 2015 most inflow into the dams was less than the 20-year frequency drought inflow, officially classifying it as a natural disaster. Continuous drought conditions since 2014 have threatened normal dam operations.

In order to efficiently cope with the drought, water supply adjustment criteria for times of drought were established by K-water.

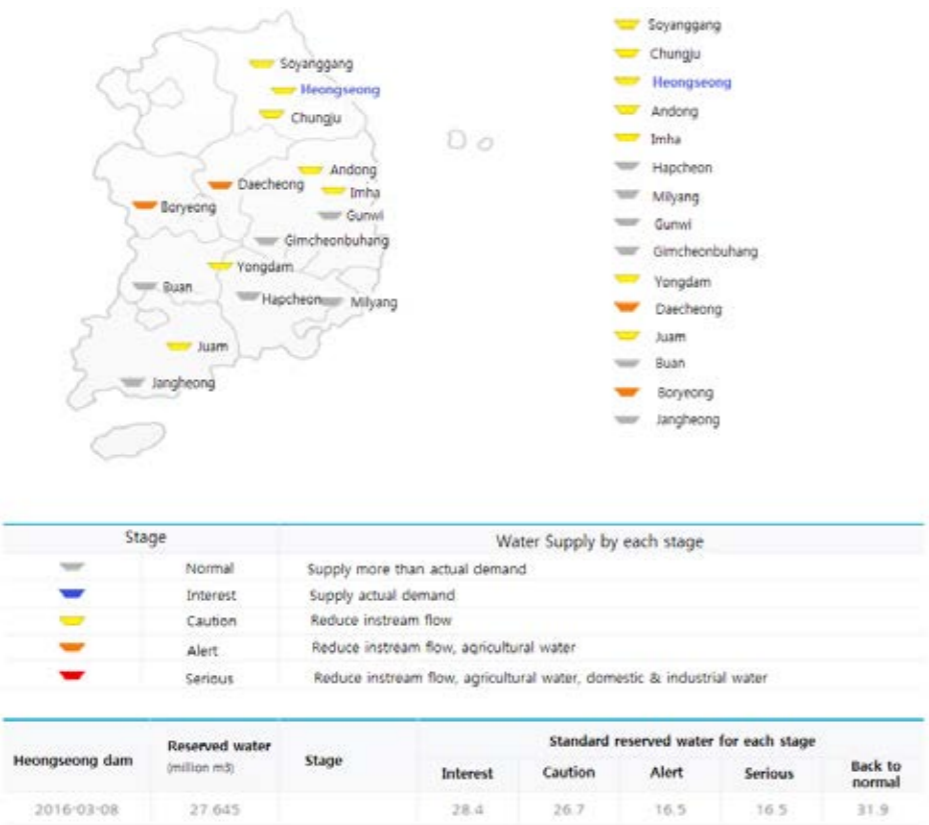


Figure 22. Example of real-time drought information on K-water's homepage. Top) Drought level of multi-purpose dams; Bottom) Water supply adjustment plan according to the drought stage

Source : K-water

There are four uses of water supply from a multi-purposed dam, 1) domestic, 2) industrial, 3) irrigational, and 4) instream flow, in order of priority. K-water made an effort to preferentially secure the domestic, industrial and irrigational water by reducing instream flow as the first three directly relate to the economy and the public daily life. In order to increase public awareness of the drought, real-time drought situations for each K-water dam are presented on K-water's website (see Figure 22).

Despite an unprecedented extreme drought spreading across the country, K-water has been able to stably supply water to the public through the use of comprehensive countermeasures. If K-water had hesitated to carry out these anticipatory actions, interruption of water supply would have likely occurred. With anticipatory and active actions against drought, an additional storage volume ($2.4 \times 10^9 \text{ m}^3$) was secured among nine dams and drought damage was mitigated.

4.1.2 Improvement of water quality and efficiency

Water quality improvement

Improvement of water quality by way of water discharges in Korea first started in 1991 due to a phenol accident. In March 1991, the Nakdong River Gumi Industrial Complex was flooded with phenol from the Nakdong River to the Dasa Water Supply Plant in the Daegu Metropolitan City. As a result, approximately 7 million m³ of water from Andong Dam was discharged over four days to improve the river water quality. In the case of the phenol spill, Gamcheon, Andong Dam, Imha Dam and Hapcheon Dam were operated in conjunction with the discharge of

26 million tons. This was seen again in 2011 and 2012 when approximately 185 million tons of water was discharged from the Soyonggang Dam and Chungju Dam to improve water quality in Paldang Lake.

Since the Four Rivers Restoration Project (December 2008 to April 2012), there has been a need for a more sophisticated water quality management response system due to changes in the physical environment of the rivers and the water management environment due to the introduction of new river facilities. Public interest in water quality and aquatic ecosystems also continues to grow due to algal blooms and has become a social issue.

In an effort to prevent algal blooms from worsening, K-water opened the gates of the weirs and discharged river water simultaneously or sequentially where the green algae had generated. It should be noted that these operations were carried out by considering the water supply capacity and discharge amount of the dam located in the upstream.

As it was found that the increase of discharge through dam-linkage operation is effective for water quality improvement, we had planned for the scientific water management system of K-HIT to examine the water quantity of dams and weirs, to establish a linkage management system between dam-weir, weir-weir and dam-dam to secure an additional 98 million tons of water to be supplied for the improvement of water quality, resulting in Chl-a reduction of up to 25%.

When water is abundant in the rivers, dam and reservoir water is discharged (every 1 - 5 days) for the purpose of reducing green algae, and the water level of the weirs is maintained (with the water level not affecting the surrounding ground water), it is predicted that the cyanobacteria will decrease by 22-36% in the Nakdong River, by 21-23% in the Yeongsan River and in case of the Nakdong River, the number of days in which green algae occur will be decreased to a quarter (average 3.8 → 1.0 day) and the number of days exceeding the alert level (more than 10,000 cells / mL) will also decrease slightly 51 → 44 days)³.

Table 12. Example of dam-weir linked operation against green algae

Time	Reason for Increase Discharge	Amount to Increase
2013.7.19	Nakdong River, green algae	Sangju Weir, Nakdan Weir 2.9 million m ³
2013.7.25	Nakdong River, green algae	Sangju Weir, Nakdan Weir, Gumi Weir 17.1 million m ³
2013.8.2~4	Haman Weir, Algae alert stage	Namgang dam 10 million m ³ , Nakdong River 8 weirs 9 million m ³
2013.9.10.~13	Haman Weir, Algae alert stage	Namgang dam 8 million m ³ , Haman weir 15 million m ³
2013.9.13~15	Haman Weir, Water quality forecast, alert stage	Dalseong Weir, Changnyeong Weir, Haman Weir 25 million m ³
2014.6.28	Haman Weir, Algae alert stage Changnyeong Weir, Water quality forecast, alert stage	Gumi Weir, Chilgok Weir 11 million m ³

Source : K-water

4.1.3 Improvement in efficiency in Management

By adopting a system such as K-HIT, an increase in efficiency is also gained as dams and weirs can be operated with fewer people. For example, the hydropower plants are now operated by 1/5th of staff previously required. This result can be see across the whole operation of the dams and weirs.

3. Announcement of the result of the research service "Operation plan of dam- and weir connection", Ministry of Environment Press release

4.2 Link with Sustainable Development Goals

The ultimate goal of Smart Water Management is to achieve sustainable development. This case is mainly linked to SDG 6 and SDG 11 to prevent disasters such as floods and to secure water in case of droughts systematically through the integrated management of dams and weirs in rivers. SDG 6 (to ensure the availability and sustainable management of water and sanitation for all) relates to securing the availability and sustainability of water resources through water management, and SDG 11 (to make cities and human settlements inclusive, safe, resilient and sustainable are safe and sustainable) is associated with water-related disaster prevention.

Table 13. A list of the SDGs and their specific targets that relate to K-HIT

Sustainable Development Goals and Targets	
SDG 4: Increase opportunities and job creation	
Ensure inclusive and equitable education and promote lifelong learning opportunities for all	
4.4	By 2030, substantially increase the number of youth and adults who have relevant skills, including technical and vocational skills, for employment, decent jobs and entrepreneurship
SDG 6: Clean water and sanitation	
Ensure availability and sustainable management of water and sanitation for all	
6.1	By 2030, achieve universal and equitable access to safe and affordable drinking water for all
6.4	By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity
SDG 11: Resilient and sustainable cities	
Make cities and human settlements inclusive, safe, resilient and sustainable	
11.5	By 2030, significantly reduce the number of deaths and the number of people affected and substantially decrease the direct economic losses relative to global gross domestic product caused by disasters, including water-related disasters, with a focus on protecting the poor and people in vulnerable situations
SDG 12: Sustainable consumption	
Ensure sustainable consumption and production patterns	
12.2	By 2030, achieve the sustainable management and efficient use of natural resources

Specifically, if we look at the goals for SDG implementation, Target 6.1 of SDG 6 ensures a universal and equitable approach to safe and available drinking water, and is an indicator for measuring the proportion of the population receiving safe and controlled drinking water. Target 6.4 also aims to reduce the number of people suffering from water shortages by providing sustainable water intake and water in response to water shortages. In this case, the percentage of safe drinking water supplied through K-HIT was not confirmed. However, in the case of severe drought in 2012 and 2015, case studies showed that the dams and the weirs were operated in conjunction to supply water to a province that was experiencing water shortage, thus contributing to this goal.

This case also relates to the integrated management of Target 6.5 of SDG 6, which relates to Integrated Water Resource Management (IWRM). IWRM is a process that promotes the coordinated development and management of water, land and related resources, in order to maximise the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems (2000, GWP). Integrated water management therefore involves integrating upstream and downstream interests that are influenced by flood control as well as the integration of water quality and water quantity. Thus, as in this case, integrating the management of quantity and quality of rivers in basins can be seen as part of integrated management. Target 6.5 presents the realisation of integrated water management and the degree of integrated water resources management implementation as an indicator.

The goal of SDG 11 is to make cities and human habitats inclusive, safe, resilient and sustainable. In this regard, Target 11.5 aims to reduce the number of casualties and direct economic losses due to water disaster. More specifically, Indicator 11.5.1 measures the number of casualties, missing persons and affected persons per 100,000 people. Indicator 11.5.2 also indicates economic losses due to disasters (damage to critical infrastructure, number of disruptions to basic services). The flood mitigation action from 2012 and 2013 are examples of times when the loss of life or property due to floods were prevented.

In this way, K-HIT contributes to the achievement of sustainable development goals by efficiently supplying water to drought areas by applying ICT to water management and minimizing damages caused by water disasters in preparation for floods.

5. Lessons Learned

The role of the public sector is important in implementing SWM

Actual data and new technology are the most basic elements for realising integrated water management, and it is possible to design short- and medium-term plans based on information on the water management situations in the field. Even though these actual data and new technologies cannot be completed in a short period of time, their importance and develop should be recognised through steady investment.

K-HIT is a system for realising integrated water management, which requires long-term investment and budgeting. While private investment could be a possibility for SWM implementation, the OECD (2011) notes that market mechanisms alone will not provide an appropriate amount of support for eco-innovation, such as SWM technology, at the right time. This is because the private sector would be unable to reap all of the benefits of their innovations, and environmental benefits may not always be appropriately valued. As this is the case policy interventions and public sector support are required⁴.

As the profit from K-HIT has a public nature, due to providing flood prevention and the reliable supply of water, it is also in the interest of the public sector to support these innovations. This is beneficial, however this public nature also limits the private sectors role in the construction of the system, which can be limiting for expanding and replicating SWM technologies.

Step-by-step system construction is more financially efficient and worth considering based on the economic situations of each country

Since a large amount of money is needed to build an integrated water management system, it is necessary to build a system step-by-step in order to apply the integrated water management system after each improvement of the existing water management system in consideration of the economic conditions and budget of the relevant country. As a result of this K-water has developed a successful approach to implementing the system construction in several phases (see Box 5). SWM also relies on extensive coverage of ICT and the capacity to maintain and operate the system. A recent OECD report (2017) confirms that while this may be possible in developed countries such as Korea, this may create difficulties in developing countries where capacity and availability to technology may differ, and therefore when implementing SWM systems in other countries it is important to take into account the social and economic context of each country to ensure its success.

4. OECD (2017), OECD Studies on Water, Enhancing Water Use Efficiency in Korea.

In order to efficiently and effectively cope with the drought collaboratively in an integrated approach, it is also important to establish a step-by-step action plan

Having a shared action plan with easily recognizable criteria for each drought stage provides the relevant stakeholders (including all dam operators) with the tools needed to identify the particular standard water levels for an entire year and also provides a step-by-step water supply adjustment plan according to the drought stage. As a result of this criteria, the speed of the decision making process, such as reducing the water supply, has become much faster, and dam operators can now work together collaboratively to ensure a successful, integrated water management approach.

To prevent the drought getting worse, it is necessary to set up measures appropriate to the characteristics of each basin

Despite of anticipatory actions, various countermeasures were carried out as the drought condition expanded across the whole country and the situation was getting worse. In the Han River basin, which is the main water source of the Seoul metropolitan area, water from a hydro-power dam was substituted as a domestic water supply source instead of multipurpose dam water due to the gradual drop of the multipurpose dam's water level. Furthermore, essential water was only provided by joint investigation with the government ministry and relevant local government authorities for actual downstream extraction.



Figure 23. Additional countermeasures during the severe stage of drought
Source : K-water

In the Nakdong and Geum River basins, irrigation water from dams had been supplied based on actual demand since September 2015. In addition, dam water discharges were minimized while maintaining the water level downstream without interruption to the extraction of water by conjunctive operation among dams, weirs and barrage. In the Seomjin River basin, a hydro-power dam used to produce power generation by diverting water to another area with high head had changed its release direction to the main stream in order to fill the downstream dam storage volume. In order to prevent water supply stoppage from the dam, various and urgent projects are sometimes required, to prevent the drought from worsening. Despite this, with effective management plans, integrated SWM tools and collaborative stakeholders, these additional measures can be significantly reduced.

Reflecting on the successes and challenges of past, the project can effectively accomplish the integrated approach of SWM technologies

In order to cope with the continual changing water management situation, the flood analysis system was extended from the existing four major rivers to five major rivers including the Yangsan River basin, and the flood analysis points in the existing 124 rivers were expanded to 164. In particular, since K-water committed itself to the integrated operation and management of weirs in 2012, river management is more focused on overall river management in comparison to focusing on dam-oriented operation. In order to improve the accuracy of the water level - flow curves, data were collected in connection with sensors, meters and so on were carried out based on the results of the flow survey team. The system has been improved by reflecting on the performance of the Four Major River Restoration Project (4MRRP) and on the expansion of its function.

6. Conclusions

In Korea, two thirds of the annual rainfall is concentrated in the summer, thus floods are more frequent and efficient water supply is essential to protect and supply water for the growing population and to continue economic development. Therefore, for decades, we have worked on the establishment of facilities including dams and weirs in rivers and the introduction of efficient water management. In recent years, since the frequency of heavy rainfall and drought are increasing due to climate change, the need to effectively manage water resources has increased. To address this, it has become essential to secure the optimal operation of water gates for continuous measurements and analysis of information or rainfall inflow and outflow weather conditions and water quality. In accordance with this need, K-HIT was introduced in 2002, and since then, the system has been upgraded continuously to expand the management of rivers and functions.

K-water's flood control capacity accounts for 95% of the gross domestic flood control capacity or 4.9 billion m³ a year, with K-water's water supply capacity comprising 66% of the gross domestic water supply capacity or 12.4 billion m³ a year. Through the introduction of smart water management and the establishment of countermeasures against floods and droughts, we have been able to effectively deal with floods that occurred in 2012, 2013 and 2015. Consequently, the capacity to operate and manage that system effectively determines Korea's resilience to water risks. SWM can enhance that capacity by collecting and sharing real-time data on water use, expected rainfalls and available room in reservoirs. This application enhances K-water's capacity to deliver its mandate on water quantity management and prevention of scarcity and flood risks (OECD, 2017).

In this way, K-HIT has systematically implemented SWM by introducing information and communication technology to flood management, water supply and hydroelectric power generation thus improving the efficiency of water management in the watershed by enhancing decision making capabilities. In addition, we have also been able to improve productivity through efficient power generation operations. Finally, we can increase profits by reducing the staff required to manage the system and by improving efficiency with the centralization of hydrology and power generation controls.

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SDG Indicators Metadata repository <https://unstats.un.org/sdgs/metadata/>

Appendix

As over 65% of the national territory is mountainous, river gradients are relatively steep.

The topography of Korean mountain ranges show that eastern mountain slopes are sharp whereas western slopes are gentle; rivers along the eastern coast side have short and steep watercourses whereas rivers along the western coast side have long and gradual watercourses

The rainy season in 2013 was the longest rainy season in recorded meteorology observation history. Starting in the middle region of Korea for the first time in 32 years, regional heavy rain occurred several times resulting in large regional deviations.

Average precipitation during the 2013 rainy season was 489mm for all multipurpose dams, which is 107% of the annual average, but the data was biased since it was centered on dams located in a specific river system, namely the Han River. The average precipitation rate in other river systems ranged from 80 to 90% of the average. Especially, average precipitation of water supply dams located in southern areas was only 69% of the annual average.

Most of the 16 multipurpose dams, except for 3 dams, which discharged flood by opening floodgates, were operated centered on securing a reserved amount of water. About 60% of total inflow was discharged and flood control by way of floodgate operation was only 6.6% of the total inflow and 11% of total discharge, as shown in Figure 21.

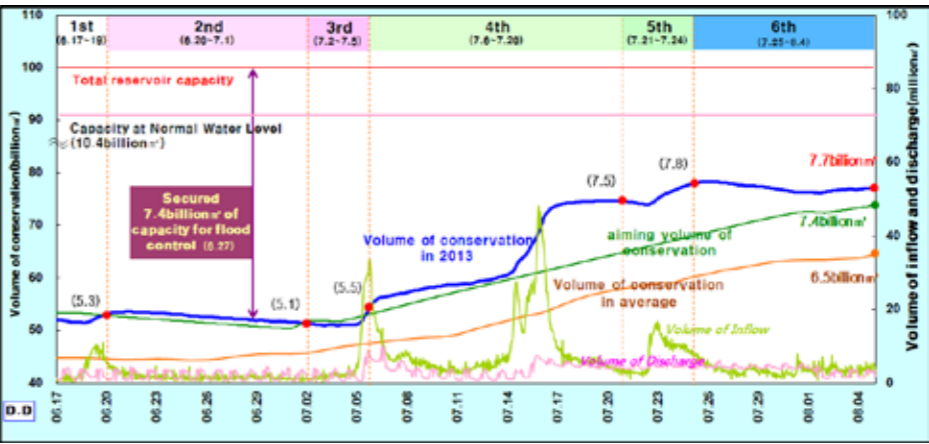
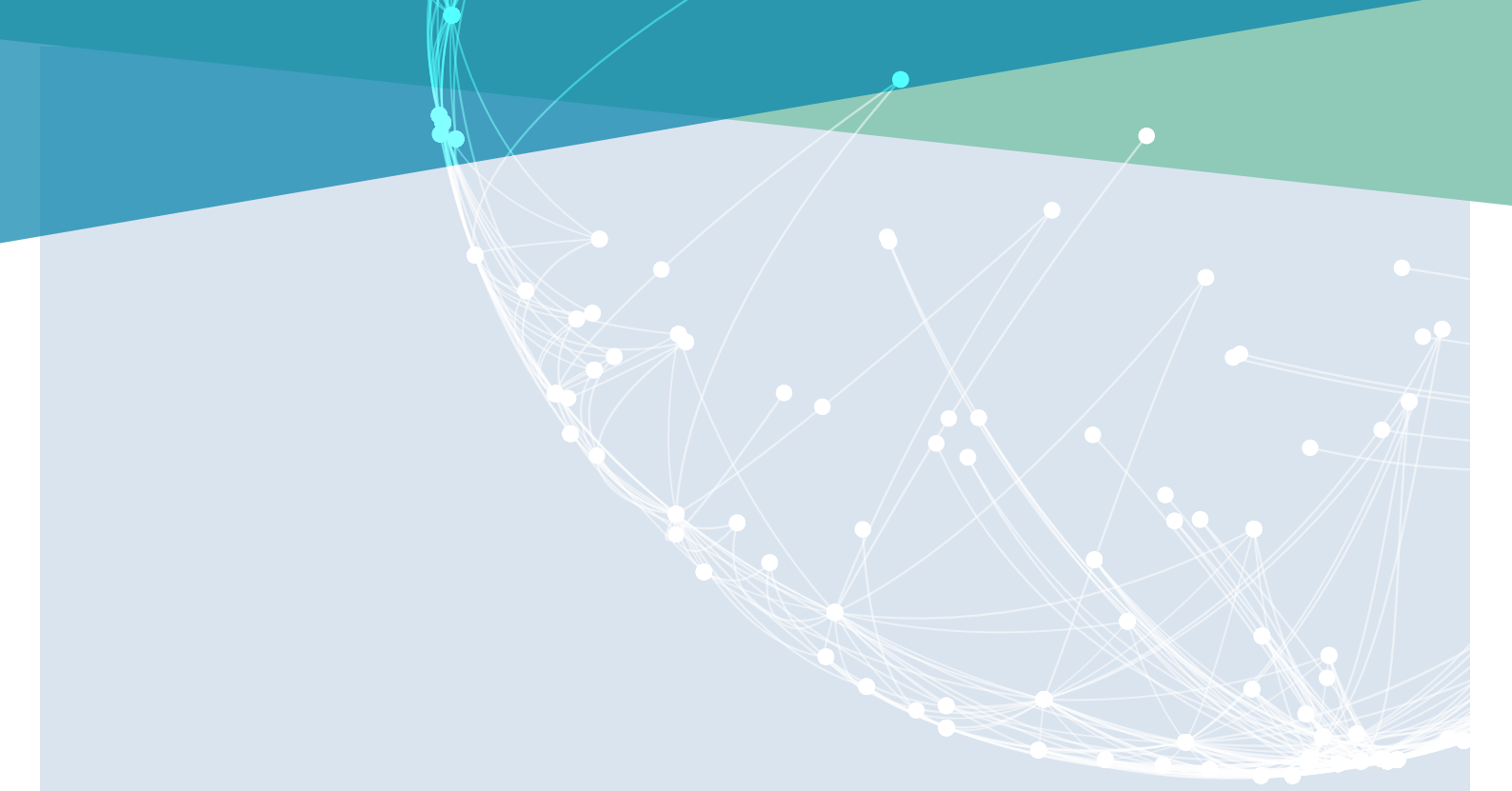


Figure 20. Status of volume conservation in 2013
Source : K-water

We can assess the degree of implementation of IWRM through surveys. Surveys on IWRM are structured in 4 components as follows:

1. Enabling environment: Includes policies, laws, plans and strategies that create an environment for integrated water management.
2. Organisation: Includes the size and role of political, social, economic and administrative bodies that support the realisation of integrated water management.
3. Administrative tools: Tools and activities that enable decision-makers and users to make decisions based on informed and alternative choices
4. Finance: Budget and finance for the development and management of water resources in various sources.

Within each component there are questions with defined response options giving scores of 0-100. Questions scores are aggregated to the component level, and each component score is equally weighted to give an aggregated indicator score of 0-100.



K-water (the Korean Water Resources Corporation)
is the governmental agency for comprehensive water resource development in the Republic of Korea, with a large pool of practical engineering expertise regarding water resources that has been championing Smart Water Management for the past decade.

IWRA (the International Water Resources Association)
are a non-profit, non-governmental, educational organisation established in 1971, providing a global knowledge based forum for bridging disciplines and geographies by connecting professionals, students, individuals, corporations and institutions concerned with the sustainable use of the world's water resources.

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