MODERNIZATION OF IRRIGATION SYSTEM WITH ICT, BIG DATA, AND MACHINE LEARNING TECHNOLOGY IN KOREA

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ABSTRACT

Information & Communication Technology (ICT) is expected to improve the efficiency of the Korean agricultural irrigation system by facilitating advanced water monitoring and analysis. The Korean government has been making efforts to apply the latest technology for irrigation modernization. A model for linking watershed runoff into reservoir water balance and the need for water supply from agricultural lands for the water resources management has been developed, which helps to evaluate the supply safety of the reservoir under various weather conditions and irrigation supply scenarios. Long-term consumptive use change and the availability of storage patterns were analyzed under climate change scenarios by several researchers. We have developed a program that allows a hydraulic analysis of the irrigation canal operations including the opening and closing of the diversion facilities for the supply of water to the farm field. This study confirmed that it is feasible to save water by efficiently operating and managing the diversion facilities from a pilot project. In recent years, big data and machine learning techniques have been widely used to evaluate the current water management practices through and predict future water use patterns with the consideration of weather projection and irrigation management. In addition, studies demonstrated that return flow could be a feasible water resources for irrigation, and it could secure irrigation water for drought in advance while minimizing the environmental burden of developing new reservoirs.

Keywords: Irrigation system, ICT, Modernization, Machine learning

1. INTRODUCTION

Approximately half (48%) of water resources in South Korea is used for agriculture. While approximately 70% of the annual rainfall is received during the summer season, most of the agricultural water is utilized from May to June. Therefore, efficient operation of irrigation systems including reservoirs, canals, and pumps is important for sustainable irrigation and agriculture. In Korea, there are 18,000 agricultural reservoirs and 70,000 other irrigation facilities. Many of these are small, old, and scattered over wide areas. In addition, most of them do not receive good maintenance, resulting in poor water management. Seasonal variation in rainfall and other climatic factors do not allow for adequate stream flow to be maintained throughout the year. All the agricultural reservoirs face water shortages in dry years, and reservoir operation is primarily determined based on experience rather than scientific principles. For improved water use efficiency and agricultural sustainability, optimal water management based on monitoring and modeling are necessary (Pereira et al., 2007; Nam et al., 2013; Pawde et al., 2013; Nam and Choi, 2014).

Drought has been a significant agricultural problem to be overcome at the national level, and water shortage has become a social conflict factor beyond a natural-level disaster in Korea. Various measures are being taken into consideration as future water

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shortage measures such as the construction of new dams, enhancement of existing dams, rainwater harvesting, and reuse of wastewater. Particularly in rural areas where insufficient water supply is expected, water supply from agricultural reservoirs is considered as one of the main measures. Korean government promotes the transition of agricultural water development to multi-purpose projects including living and environmental water in rural areas. The government has initiated implementation plans to expand its water development and water quality conservation measures and to ensure reliable water supply in rural areas under water shortage and water pollution expected under future climate change.

Efficient water management and operation technology with the priority of saving water can be a fundamental solution. In addition, in recent years, there has been a change in the farming practice of cultivating horticultural crops in rice paddy fields. Therefore, it is necessary to improve the agricultural water supply facilities and water management technology. Moreover, as the average age of farmers and water management workers becoming also high, advances in water management is getting delayed. Effective water management and operation technologies need to be improved with data-based intelligent water management methods.

In this paper, we would like to describe the recent history and current status of irrigation modernization in Korea.

2. DECISION SUPPORT SYSTEM USING ICT-BASED IRRIGATION WATER MANAGEMENT

Due to advances in technologies, several sensors have been used to collect information; the information from the sensors as well as the decision supporting model can be used to characterize water in agricultural fields (Mateos et al., 2002). Over the past few decades, ICTs have been applied to agriculture to provide help for monitoring crops, weather, and soil moisture for use in calculating water quantity requirements. This is accomplished by integrating ICTs in order to provide real-time online access to data, environmental monitoring, irrigation scheduling, and monitoring of agricultural emergencies (Diaz et al., 2011).

ICT has been widely adopted in water management, providing numerous opportunities to apply wireless sensor, network-based, irrigation systems to optimize water management and to support the efficiency of irrigation facilities management including reservoir levels, canal levels, rainfall, pumping stations, and mobile discharge measurement sensors based on real-time information. ICT can provide better decisions in agricultural water management using better data in terms of quantity and quality over large spaces in real time. (Bazzani, 2005; Bazzani et al., 2005; Bartolini et al., 2007).

ICT can be useful as it can assist improvements in operation and management based on better decisions within an irrigation system. (Molden and Gates, 1990; Mishra et al., 2001; Goncalves et al., 2007; Reinders et al., 2013; Kanooni and Monem, 2014). ICT-based irrigation water management is an important tool that can facilitate appropriate irrigation planning and effective water management (Nam et al., 2013).

Recently, the frequency of drought is increasing due to climate change. Drought patterns are also persistent and tend to be stronger locally, which is more serious than flood damage. Current water management in agricultural reservoirs depends on experience without scientific judgment or criteria. Therefore, when a disaster such as a drought occurs, there is a variation of water supply efficiency due to local and customary water management and water manager's competence. In the case of drought, shortage of required quantity of terminal waterways such as mainline and branch line frequently occurs. In addition, there is no understanding or prediction as to whether water is properly distributed through the water supply. Studies identified the limitations of existing conventional water management systems and practices and evaluated the current status of reservoir management to suggest the optimal reservoir operation options from pilot studies. In addition, studies developed management systems for agricultural reservoirs based on the latest sciences, which is essential for the modernization of Korean irrigation system.

The Korea Rural Community Corporation (KRC) has installed an automatic water level gauges at agricultural reservoirs (1,729 out of 3406 as of 2018) and monitored water levels and storage rates in real-time. Such automatic monitoring helps us to grasp the spatio-temporal distributions of available reservoir water resources nationwide and manage irrigation systems considering the local agricultural and weather conditions (Fig. 1). Some of the main irrigation canals (21.8%) has TC / TM facilities installed, and they can be remotely controlled by cell phones using applications in an office or at fields. In addition, some of pumping and drainage stations can be operated remotely.

Figure 1. Tele-measuring of reservoir water level and storage information system with ICT.

3. RESERVOIR WATER BALANCE MODEL

Irrigation systems in South Korea have been built and maintained based on the design frequency to withstand a 10-year drought (Nam et al., 2015). Hydrologic operation model for water resources system (HOMWARS) has been developed using the Daily Irrigation Reservoir Operation Model (DIROM), which has been utilized as a tool to analyze the water balance of a reservoir (Kim and Park, 1988a, 1988b)(Fig. 2). DIROM is a simulating model for daily inflow and the release rate for irrigation reservoir composed of two modules. The first module is a Tank model to estimate inflow into reservoirs (watershed runoff), and the second is irrigation water requirement (IWR) model to release rates of the reservoir (Jang et al., 2012).

The tank model, which is a well-known conceptual rainfall-runoff model (Sugawara, 1979), was selected to simulate daily inflow rates in each reservoir for a data-scarce watershed. The model structure is simple, but it can reproduce the many types of hydrographs in an area of mixed land use area, including paddy fields. In the HOMWARS model, runoff in a reservoir watershed (reservoir inflow) is estimated using the modified tank model suggested by Kim and Park (1988a). Considering the characteristics of agricultural reservoirs in Korea, this model was simplified from a 4-stage to a 3-stage tank by eliminating the fourth tank, which considered surface runoff, intermediate runoff, and base flow, respectively (Kim and Park, 1988a). The model parameters are usually estimated using an empirical formula that relates the watershed characteristics such as drainage area, land uses including paddy, upland, and forest, and the characteristics of agricultural reservoirs to the parameter values.

The daily IWR is defined as the depth of water needed to counteract the water loss that occurs through the crop evapotranspiration (ETc) of a stress-free crop growing in large fields and to achieve the full production potential in the given growth environment (Yoo et al., 2008). The IWR for paddy rice is calculated using a water-balance concept as described by Jensen et al. (1990). The required amount of irrigation water was estimated by considering the amount of effective rainfall, crop consumptive use (evapotranspiration and infiltration) and operation loss during the growing season. Evapotranspiration amount was determined with Penman-Monteith equation. The IWR model also includes the water requirement for transplanting and the minimum release for maintaining canal flow (conveyance losses) (Kim and Park, 1988b).

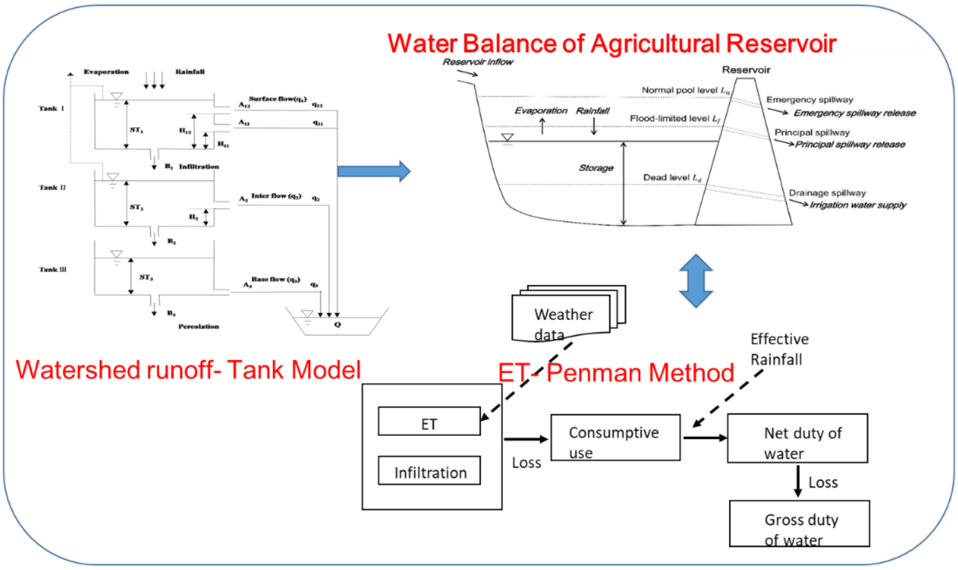

Figure 2. Components of hydrologic operation model for water resources system (HOMWARS).

The HOMWARS has been used to determine the size of a new reservoir, evaluate the supply potential of an existing reservoir, implement a drought analysis under climate change scenarios, design the size of a delivery canal system, analyze irrigation supply for a new cropping pattern, analyze potential environmental flow supply from reservoirs, analyze the potential of drinking water supply for rural areas from agricultural reservoirs(Jang et al., 2004 ; Kim et al., 2011 ; Park et al., 2009a ; Park et al., 2009b).

Agriculture is directly affected by climate conditions and their changes. It is necessary to understand the effects of climate change on agricultural water resources and to minimize its negative effects to achieve stable and sustainable crop production. Climate change affects not only crop water requirements but also various aspects of rice cultivation systems including cultivation land and crop-growing season. Yoo et al. (2013) analyzed the impact of climate change on the water requirements of agricultural reservoirs using the HOMWARS model, the paddy rice growing season, and land uses. The results showed that due to increasing temperature, transplanting and heading dates would be delayed by 5–25 days and 0–10 days, respectively, in comparison to the baseline.

The decreasing rates of irrigation water requirements (IWRs) were predicted. The major causes of this decrease in IWRs were crop evapotranspiration and percolation followed by a shortened growing period.

4. WEB BASED IRRIGATION CANAL TELEMETERING SYSTEM

ICTs were applied to irrigation canal water management, thereby providing real-time information and knowledge about the current state of the water supply of irrigation canals and, consequently, enhancing the performance of the agricultural water system (Hong et al., 2016). Irrigation water management using web-based decision support systems is necessary to resolve water efficiency problems. Automatic water gauges were installed at the main and secondary irrigation canals in Dongjin-River Basin, South Korea. The water levels in each canal were monitored, and the irrigation water supply was calculated. An irrigation model considering intermittent irrigation was developed to compare the estimated irrigation demands to the actual supplies for decision making and demand strategies. Using this model and water level data, a risk-based decision support system for the operation and management of the agricultural water was developed and evaluated. Fig 3. shows designed flow depth and current flow depth of cross-section at each branch. Such system helps field canal managers to operate distribution facilities properly.

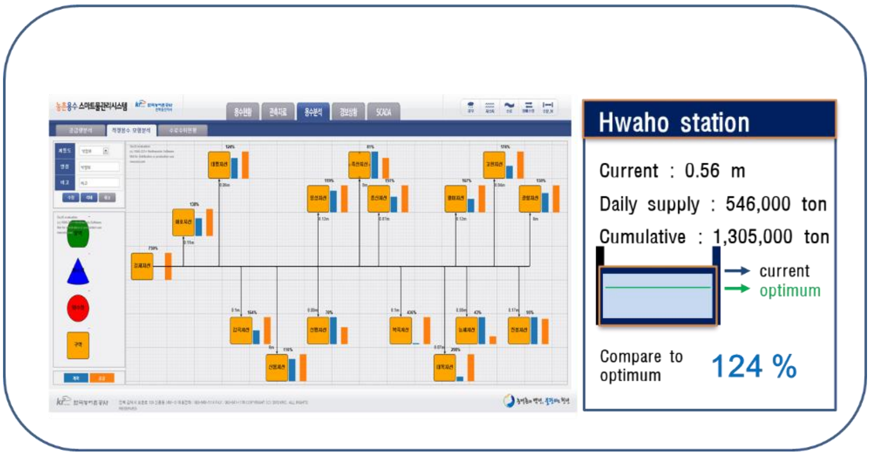

Figure 3. Irrigation canal water delivery monitoring system.

5. HYDRAULIC MODEL FOR IRRGATION CANAL MANAGEMENT

There has been a management problem caused by the infrequent maintenance of a designed canal capacity and the empirical operation practices of an irrigation system. For successful agricultural water management, it is essential to determine the proper distribution of crop water requirements and improve irrigation system operation and water allocation in an irrigation canal network flow analysis.

In South Korea, HOMWRS, a reservoir operation model, has been frequently used for managing irrigation systems. However, a canal flow simulation model has not often been used to achieve higher distribution efficiency and proper irrigation water allocation. Therefore, a decision-making support system based on a hydraulic simulation model is needed to improve agricultural water management and to allow decision makers and stakeholders to implement appropriate operational strategies. Traditionally, hydraulic simulation models of an irrigation area are used for water resources planning and management (Al-amin and Abdul-aziz, 2013; Shrestha et al.,

2013) and for determining proper irrigation and drainage strategies (Bayat et al., 2011; Karamouz et al., 2011).

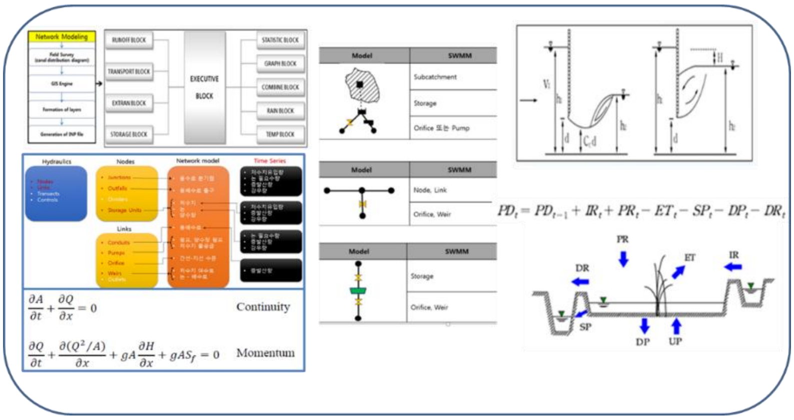

Figure 4. Components of a hydraulic model for irrigation water distribution system.

Kim et al. (2016) combined network modeling and paddy water balance simulation functions to develop a hydraulic analysis model for irrigation canal flow by using the Storm Water Management Model (SWMM) module, which provides a hydraulic analysis for rainfall and water flow in canals of the urban area. A set of nodes and links was used to form the irrigation network for the network modeling process, and the irrigation block data, including the area, soil and crop characteristics, were prepared for the model input. The developed model was applied to Daesan Irrigation District, located in the western part of South Korea, where there was a rice paddy field rehabilitation project area.

This hydraulic model can assist with accurate irrigation scheduling based on its simulation results, such as flow travel time, water level, and flow amount depending on sluice gate control. Thus, we recommend the model for control of the water supply from the start to the endpoints of irrigation canals to prevent invalid discharge and water waste. It is worth pointing out that some limitations of this hydraulic model remain and deserve further study. Water diversion and pumping data are critical model inputs, but they usually have low spatial and temporal resolution and involve significant uncertainty. Accurate field data are essential for model calibration, validation, and improvement.

6. MACHINE LEARNING FOR IRRIGATION DELIVERY SYSTEM

We planned to apply ICT / IoT-based sensing, modeling, and unsupervised learning techniques to the pilot field to realize data-based autonomous learning water management technology for water saving and efficient use of water. The focus of this study was to improve the function of irrigation facilities such as waterway, diversion, and intake check in the process of supplying agricultural water from the water source to the water supply area. In addition, the study derived a model for data-based water management. The current agricultural water supply system analysis results show that agricultural water loss is mostly caused by the distribution management generated by the spill type irrigation system and the cross-section of the canal that were designed based on the maximum potential discharge.

ICT / IoT and self-learning techniques is expected to bring a significant improvement in terms of prevention of excessive water loss. However, since there is no field application yet, it is necessary to develop not only key technologies but also test and demonstration processes. To clarify the goal of improvement of autonomous learning water management, it is necessary to further study the performance of the process technology through trial production of technology based on field-based tests. The expected effect of this study is the reduction of labor force along with securing the water saving technology. It is also expected to create new jobs for specialists called "Specialist Managers" that are needed by applying the 4th industrial revolution technology to traditional water management.

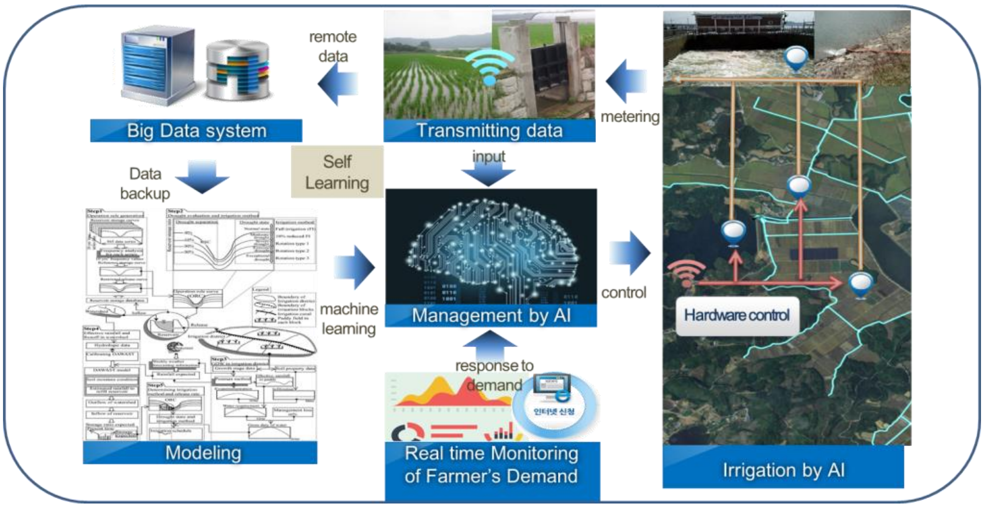

Figure 5. Intelligent irrigation system with machine learning technology analyzing farmer's irrigation practice.

7. RECYCLING RETURN FLOW SYSTEM FOR COUNTER MEASURE OF DROUGHT

As a result of agriculture policy focused on rice farming in Korea, 80% of the paddy fields secure water for ten-year frequency drought. However, there are still many areas vulnerable to drought in the period from March to June, the period of irrigation. Generally, the drought damage of crops depends on the duration of drought and the timing of recovery of irrigation capacity. As the drought damage caused by water shortage is frequent, there is a need for water management method for reducing loss through optimal water management and reusing water to be returned to a downstream river through a drainage canal.

In order to compensate for the insufficient supply of water from the main agricultural reservoir, the restoration of reservoir water through recharging water by pumping up stream or river water or repeated use of irrigation return flow in an irrigation period. However, practical and detailed guidelines are rare. Recently, the agricultural water management system equipped with the SWMM (Storm Water Management Model) model, which is able to quantify various supply phenomena by quantifying the water supply phase from the water source field to the field and analyzing the water consumption patterns by the field. The model can reflect quantitative results of channel network analysis that cannot be derived through using existing water balance models. It is possible to analyze the process of water supply in the field during the period of drought and to develop a recyclable supply capacity estimation model that can derive the amount of discharge, the required quantity and the target ponding depths of paddy fields.

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