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DECISION SUPPORT SYSTEM FOR THE REAL-TIME OPERATION AND MANAGEMENT OF AN AGRICULTURAL WATER SUPPLY†

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ABSTRACT

Agricultural uses are responsible for approximately 48% of the total annual water use in South Korea. 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, irrigation facilities including reservoirs, canals and pumps were installed to efficiently manage agricultural water. Efficient operation of irrigation systems is important for sustainable irrigated agriculture, which is undermined due to the low water efficiency of the irrigation systems. Irrigation water management using web-based decision support systems is necessary to resolve water efficiency problems. In this study, automatic water gauges were installed at the main and secondary irrigation canals in the Dongjin River Basin, South Korea. The water levels in each canal were monitored and the irrigation water supply calculated. An irrigation model considering intermittent irrigation was developed to compare the estimated irrigation demands with 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 agricultural water was developed and evaluated. Using this system. it is possible to optimally manage irrigation water and to make plans for efficient agricultural water operation and management. Copyright © 2015 John Wiley & Sons, Ltd.

KEY WORDS: agricultural water management; decision support system; intermittent irrigation model; irrigation canal; real-time water level

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RÉSUMÉ

Les usages agricoles représentent environ 48% de la consommation annuelle totale d'eau en Corée du Sud. Alors que près de 70% des précipitations annuelles sont reçues pendant la saison estivale, la plupart des eaux agricoles sont utilisées à partir de mai–juin. Par conséquent les systèmes d'irrigation, réservoirs, canaux, pompes, etc. ont été installés afin de gérer efficacement l'eau agricole. Le fonctionnement efficace d'un système d'irrigation est important pour l'agriculture irriguée durable. Un système d'aide à la décision basé sur le Web peut résoudre le problème de l'efficacité de l'eau. Dans cette étude, située dans le bassin de la rivière Dongjin (Corée du Sud) nous avons installé des débitmètres automatiques dans les canaux principaux et secondaires. Cette surveillance a permis de calculer depuis 2012 les besoins quotidiens, hebdomadaires, mensuels et annuels en eau d'irrigation. Un modèle d'irrigation considérant le caractère intermittent de l'irrigation a été développé pour affiner la prise de décision et la stratégie et comparer les besoins d'irrigation estimés aux approvisionnements réels. Enfin, en utilisant ce modèle et les mesures hydrométriques en temps réel, un système d'aide à la décision fondée sur les risques de l'exploitation et la gestion de l'approvisionnement en eau pour l'agriculture a été mis au point et évalué. Les résultats de l'étude suggèrent qu'il est possible de gérer au mieux l'eau d'irrigation et de faire un plan pour une gestion efficace de l'exploitation de l'eau agricole, en utilisant un système d'aide à la décision. Copyright © 2015 John Wiley & Sons, Ltd.

MOTS CLÉS: gestion de l'eau agricole; système d'aide à la décision; modèle d'irrigation intermittente; canal d'irrigation; mesures hydrométriques en temps réel

INTRODUCTION

Approximately 48% of the total water in South Korea is used for agriculture. Agricultural water problems can be divided into quantity and quality concerns. Water quantity

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problems arise due to aberrations in the occurrence and the magnitude of precipitation. They also arise due to mismanagement of water and also due to some external factors. Saving water and providing an optimal water supply for efficiency with increasing water use in various sectors are important issues to consider (Contor and Taylor, 2013; Cui *et al*., 2014; Gomo *et al*., 2014). In Korea, there are approximately 18 000 agricultural reservoirs and approximately 70 000 irrigation facilities. Many of these are small in size, very old, and scattered over a wide area. In addition, most of them do not receive enough care and maintenance, resulting in poor water management. Seasonal variation in rainfall and other climatic factors do not allow for adequate streamflow to be maintained throughout the year. Therefore, all of the agricultural reservoirs face water shortages. Rather than being based on scientific principles, reservoir operation has primarily been based on past experience, which may only apply to the small, localized regions. Therefore, optimal water management plans and scenarios based on monitoring and modelling are necessary (Riesgo and Gomez-Limon, 2006; Pereira *et al*., 2007; Nam *et al*., 2013; Pawde *et al*., 2013; Hong *et al*., 2014; Nam and Choi, 2014).

As a result of advances in technology, several sensors have been used to collect information; the information from the sensors as well as the decision support model can be used to characterize water in agricultural fields (Mateos *et al*., 2002; Amarasinghe *et al*., 2012; Aqeel-ur-Rehman *et al*., 2014). There are several models used to manage and control agricultural water. De Nys *et al*. (2008) developed the water delivery for irrigation model in order to deal with the relationship between the monitored water supply and water demand. Mateos *et al*. (2002) and Lozano and Mateos (2008) developed the FAO (United Nations Food and Agriculture Organization) Scheme Irrigation Management Information System (SIMIS) in order to manage and facilitate the planning and irrigation performance indicators. Korea needs to modernize its reservoir irrigation system the through effective use of information and communication technology (ICT) in order to improve water management through the monitoring and analysis of the monitored data. ICT can be useful as it can assist improvements in operation and management based on better decisions within an irrigation system. It can save water and increase irrigation efficiencies, and it can also help in the development of a scientific irrigation scheduling plan for different seasons and for over a large cropped area. These methods can save water and contribute positively to the improvement of agricultural productivity and food security (Molden and Gates, 1990; Mishra *et al*., 2001; Goncalves *et al*., 2007; Reinders *et al*., 2013; Kanooni and Monem, 2014).

In this study, automatic water gauges were installed at the main and branch irrigation canals in the Dongjin River Basin, South Korea. The water levels were monitored and calibrated, and the irrigation water supply and irrigation efficiencies were calculated since 2012. In addition, an irrigation model taking into consideration intermittent irrigation was developed in order to compare the estimated irrigation demands with the actual supplies to develop decision-making and demand strategies. The optimal water supply curve based on the precipitation scenario and the previous water supply curve developed through monitoring and modelling were also suggested. The model, a risk-based decision support system (DSS) for the operation and management of the agricultural water supply, was developed and evaluated in this study.

DECISION SUPPORT SYSTEM USING ICT-BASED IRRIGATION WATER MANAGEMENT

ICT-based irrigation water management is an important tool that can accelerate appropriate irrigation planning and effective water management (Nam *et al*., 2013). Over the past few decades, ICT has been applied to agriculture in order to provide help for monitoring crops, weather and soil moisture for use in calculating water quantity requirements. This is accomplished by integrating ICT in order to provide real-time online access to data, environmental monitoring, irrigation scheduling and monitoring of agricultural emergencies (Diaz *et al*., 2011). Figure 1 is a conceptual diagram of ICT-based irrigation water management. ICT has been widely adopted in water management, providing numerous opportunities to apply wireless sensor, network-based, irrigation systems in order 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, as shown in Figure 1. ICT can provide better decisions in agricultural water management using more data in terms of quantity and quality over large spaces in real time. In addition, ICT can be adapted for irrigation system operation and irrigation maintenance structures, while increasing irrigation efficiencies, and decreasing and detecting system failure to enable scientific irrigation scheduling and automated irrigation. In this study, ICT was applied to irrigation 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 (Bazzani, 2005; Bazzani *et al*., 2005; Bartolini *et al*., 2007).

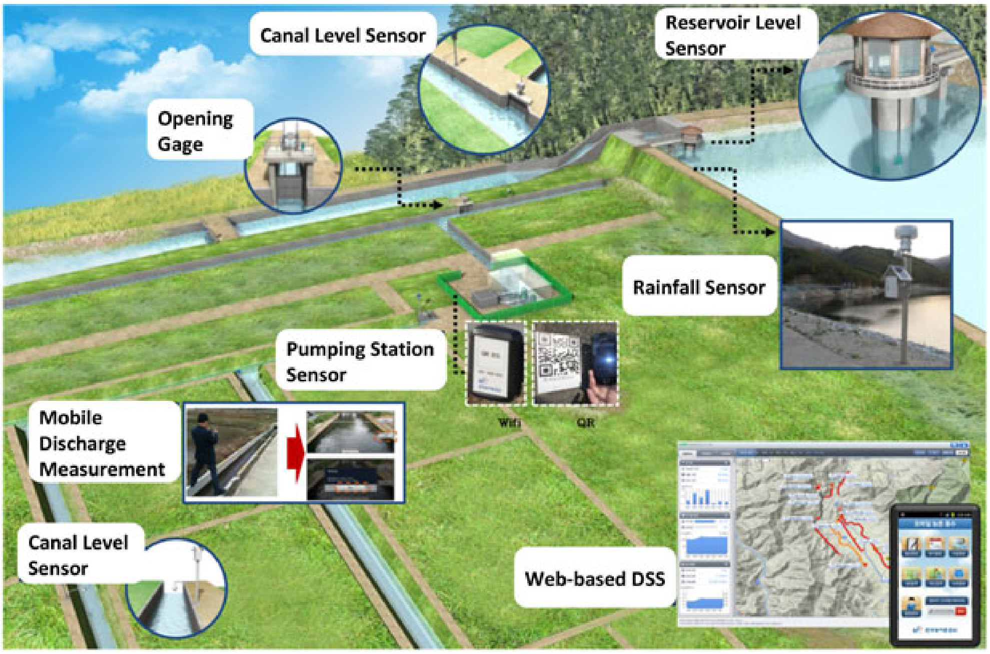

Figure 1. Conceptual diagram of ICT-based irrigation water management

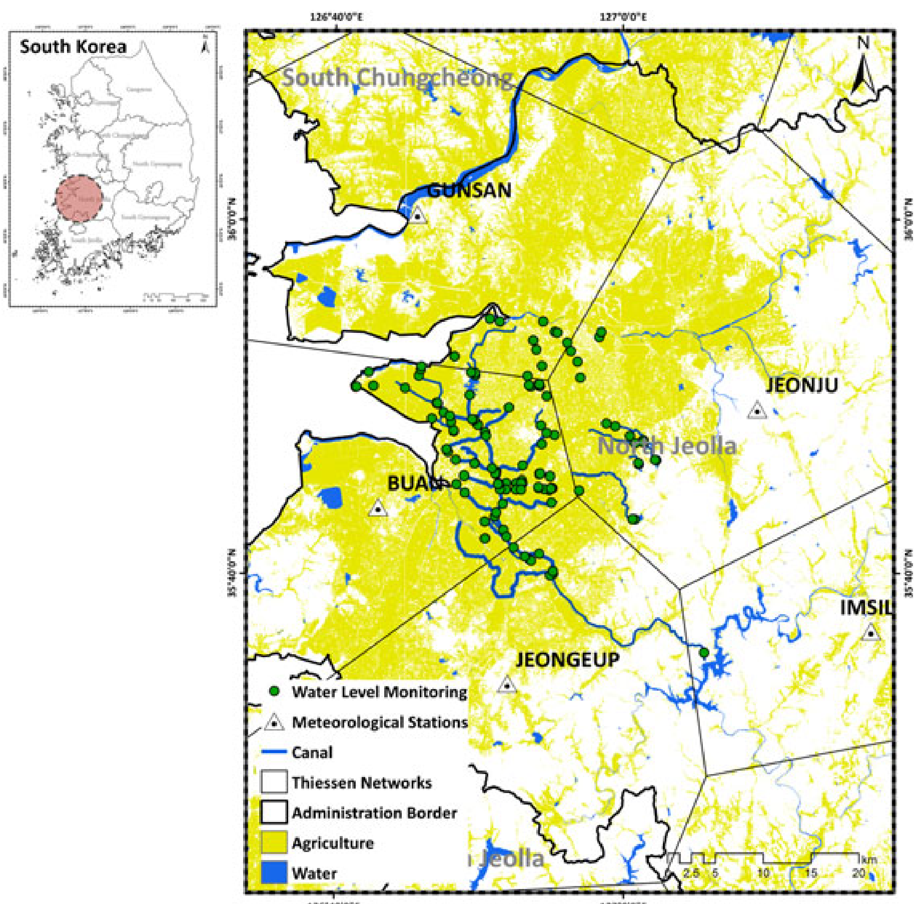

Figure 2. Location map of surveying sites in the Gimjae irrigation area

MONITORING AND MODELLING

Study area

In order to make a DSS for real-time operation and management, the Korea Rural Community (KRC) Corporation has installed automatic water-level meters since 2011 as well as developing an irrigation management system in the Donjin Basin area using ICT. The Dongjin Basin is located in the central region of South Korea (latitude 35° 21 –35° 52 N, and longitude 126° 40 –127° 07 E) and is the biggest rice paddy area of Korea as shown in Figure 2. The 30-year average annual temperature (1984–2013) near the experimental fields at the Jeonju meteorological station was 13.4 °C. The monthly high average air temperature was 26.3 °C in August and the lowest value was −0.5 °C in January. The 30-year annual average precipitation was approximately 1336.7 mm and the rainfall was primarily (approximately 67.9%) concentrated in the summer season from June to September, even though irrigation water needs were highest in the spring and early summer season. In 1988, the annual precipitation was the lowest and that in 2003 was the highest, as shown in Table I.

Table I. Dry, normal, and wet years at the Jeonju meteorological station

Rank	Dry year	Normal year	Wet year
1	1988 (707 mm)	1974 (1311 mm)	2003 (1860 mm)
2	1994 (821 mm)	1991 (1317 mm)	1985 (1732 mm)
3	1977 (824 mm)	1981 (1342 mm)	1987 (1682 mm)
4	1995 (891 mm)	1990 (1354 mm)	2000 (1637 mm)
5	1982 (934 mm)	2005 (1390 mm)	2011 (1622 mm)

Description of the irrigation system and scheduling in the Dongjin River Basin

As shown in Figure 3, irrigation water in the Dongjin River Basin is supplied through the Gimjae main canal and this is connected to 24 secondary canals. The distance from the Nakyang diversion weir, which is the starting point of the Gimjae main canal, to the Geojeon lock, which is the end of the irrigation canals, is approximately 23 km. Some irrigation water is supplied from the Seomjin reservoir in the upper watershed of the Dongin River Basin from April to October, because the Dongin River Basin does not have enough irrigation water in the Nakyang diversion weir and reservoir. In addition, the irrigation water in this area is supplied intermittently. The secondary canals are divided into an upper and lower region as shown in Table II. In the upper region, the irrigation water is primarily supplied from Thursday to Sunday, and in the lower regions, the irrigation water is primarily supplied from Monday until Thursday. The total area irrigated by the secondary canals of the Gimjae main canal in the Dongin River Basin is approximately 12 749 ha (6595 ha in the upper region and 6163 ha in the lower region).

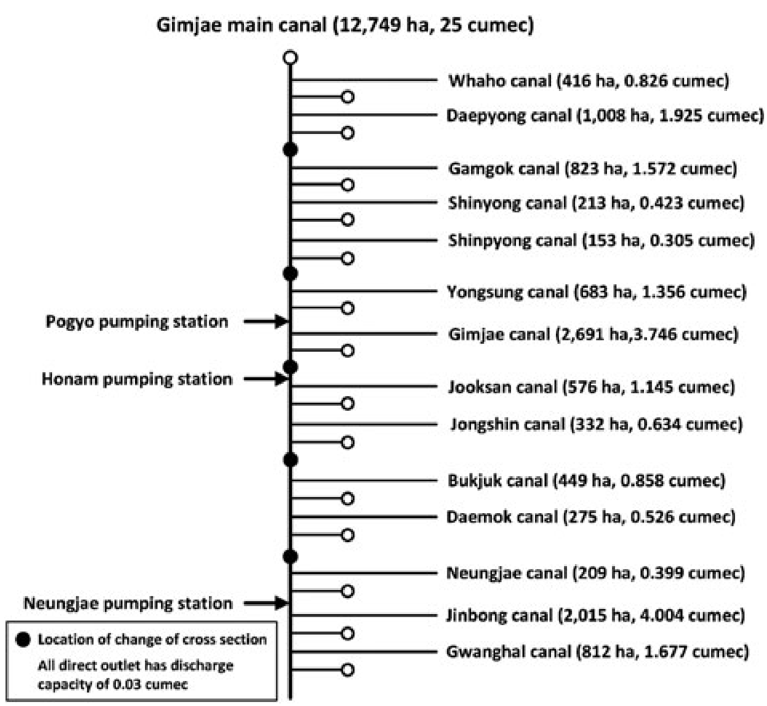

Figure 3. Water balance tree of the surveying sites in the Gimjae irrigation area

Table II. Irrigation area, length, and irrigation scheduling for the water supply of the major irrigation canals

Regions	Canal name	Irrigation area (ha)	Canal distance (km)	Day of water supply
The upper region (U)	Whaho (WH)	415.9	2.66	Thu.–Sun.
	Daepyong (DP)	1 008.0	4.22	Thu. –Sun.
	Gamgok (GG)	823.0	5.99	Fri.–Mon.
	Shinyong (SY)	212.7	2.24	Fri.–Sun.
	Shinpyong (SP)	153.4	2.39	Fri.–Sun.
	Yongsung (YS)	682.5	4.08	Wed.–Fri.
	Gimjae (GJ)	2 691.0	8.10	Mon.–Thu.
The lower region (L)	Juksan (JS)	576.3	4.16	Mon.–Thu.
	Jongshin (JH)	332.0	4.54	Mon.–Thu.
	Bukjuk (BJ)	449.0	3.87	Mon.–Thu.
	Daemok (DM)	275.2	3.27	Mon.–Thu.
	Neungjae (NG)	208.6	3.02	Fri.–Sun.
	Jinbong (JB)	2 015	6.85	Mon.–Thu.
	Gwanghal (GH)	811.8	5.05	Fri.–Sun.

Real-time water-level monitoring based on an automatic water gauge system

In this study, we constructed an auto water-level measurement system in order to estimate the amount of water delivered to the secondary canals. Nine auto water-level meters were installed in the reservoir, 2 in the regulating gate, 7 in the lock, 8 in the pumping station, 10 in the main canal, and 53 at the inlet and outlet of each secondary canal. Figure 3 shows the automatic water-level meters. Figure 4(a) shows the 20-m wide main Gimjae open canal. Figures 4(b)–(d) show the solar-powered automatic water-level meters installed at the secondary irrigation canals. The data transfer used the ZigBee and CDMA technologies. These automatic water-level data were managed by the KRC Corporation through the Rural

Figure 4. Automatic water level meters: (a) Gimjae open main canal, (b) Gimjae secondary inlet canal, (c) Jongshin secondary outlet canal, and (d) Jinbong secondary inlet canal

Infrastructure Management System (RIMS). These systems provided and recorded the real-time water levels of canals or reservoirs (Nam *et al*., 2013). The water levels were monitored every 5 min and converted into discharges using the rating curves of each of the canals (Choi *et al*., 2012).

Table III. Data and model description of the irrigation water requirement model

Data	Items
Meteorological data	Observation station data, temperature, rainfall, relative humidity, wind speed,sunshine hours
Irrigation scheduling	Date of pre-planting and transplanting, reference ponding depth by growth stages, abstraction rate, nursery bed area, rice planting water, irrigation plan (irrigation date, intermittent irrigation)
Crop and soil characteristics	Penman–Monteith equation, 10-day crop coefficients of paddy rice, infiltration
Paddy field management	Irrigation area, maximum ponding depth, minimum ponding depth, conveyance l osses

Development of the irrigation water requirement model

In order to estimate the daily water requirement in the paddy area, the paddy water balance model was constructed based on the method developed by Doorenbos and Pruitt (1977). In the conventional model, only continuous irrigation can be applied for water management (Lee and Kim, 2001; Ministry of Agriculture and Forestry (MAF), 2003). However, irrigation water is currently supplied intermittently due to irrigation water shortage. The difference between the current and the previous model is the irrigation plan. In this model, the day of the water supply was adjusted in order to apply water management of the intermittent irrigation of the water supply (Hong *et al*., 2014). Meteorological data, crop coefficients, irrigation scheduling data and many other relevant data were collected as input parameters as shown in Table III.

Using the paddy water balance model as shown in Equations (1) and (2), the daily ponding depth was estimated as shown in Equation (3). On a non-irrigating day, the irrigation water was assumed to be 0 and the ponding depth was assumed to be 0 during the midsummer drainage period. The irrigation water requirement was calculated using Equations (4) and (5), taking into consideration the effective rainfall as shown in Equation (6). The reference evapotranspiration was calculated on a daily basis using the Penman–Monteith method (Allen *et al*., 1998), and the actual crop evapotranspiration was obtained by correcting

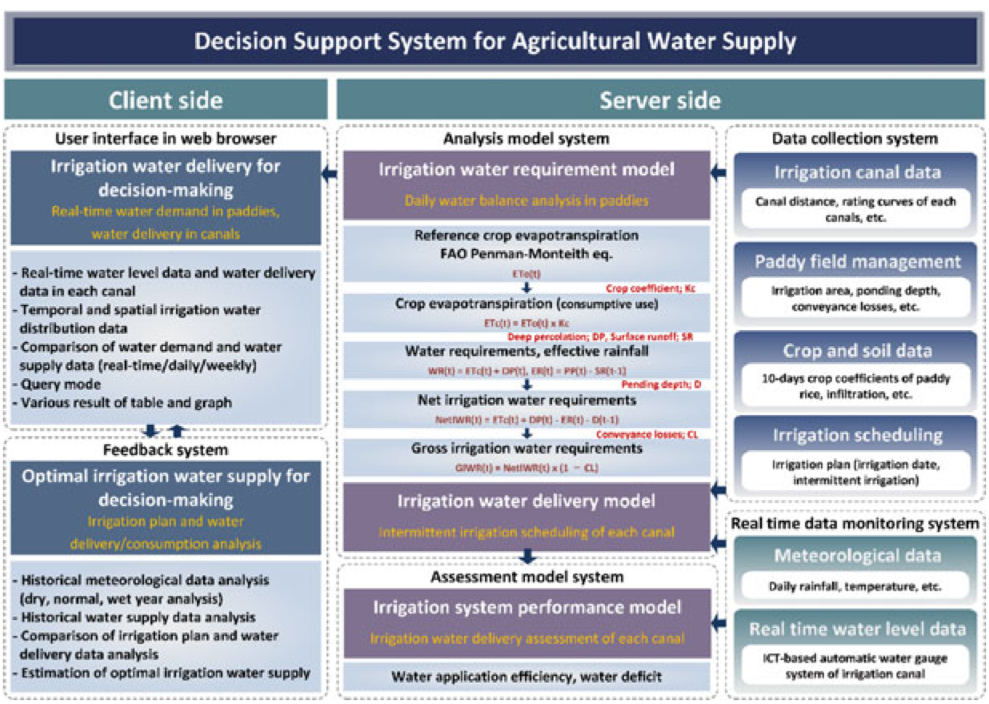

Figure 5. Schematic diagram of the decision support system for an agricultural water supply]

the reference evapotranspiration values with the crop coefficient (Hong *et al*., 2014).

$$\mathrm{IR(t)} + \mathrm{PP(t)} = \mathrm{ETa(t)} + \mathrm{DP(t)} + \mathrm{SFO(t)} + \Delta \mathrm{D(t)} \quad (1)$$

$$\Delta \mathrm{D(t)} = \mathrm{D(t)} - \mathrm{D(t-1)} \quad (2)$$

$$\mathrm{D(t)} = \mathrm{D(t-1)} - \mathrm{ETa(t)} - \mathrm{DP(t)} - \mathrm{SFO(t)} + \mathrm{IR(t)} + \mathrm{PP(t)} \quad (3)$$

$$\mathrm{REQ(t)} = \mathrm{ETa(t)} + \mathrm{DP(t)} + \mathrm{SFO(t)} - \mathrm{PP(t)} - \mathrm{D(t-1)} \quad (4)$$

$$\mathrm{ER(t)} = \mathrm{PP(t)} - \mathrm{SFO(t-1)} \quad (5)$$

$$\mathrm{REQ(t)} = \mathrm{H} - \mathrm{D(t-1)} + \mathrm{ETa(t)} + \mathrm{DP(t)} \quad (6)$$

if REQ $(t) \leq$ PP(t), ER(t) = REQ(t) andREQ $(t) >$ PP(t), ER (t) = PP(t),

where IR(t) is the amount of daily irrigation water (mm day^{-1}), PP(t) is the daily precipitation (mm/day), $\mathrm{ET_a}(t)$ is the daily crop evapotranspiration (mm), DP(t) is the daily deep percolation (mm), SFO(t) is the daily surface runoff (mm day^{-1}), ΔD(t) is the differences in the ponding depth between the tth day and the (t−1)th day.

DEVELOPMENT OF A DECISION SUPPORT SYSTEM FOR AN AGRICULTURAL WATER SUPPLY

The development of a DSS for water management is critical to provide decision makers with current water delivery information for water management (Nam *et al*., 2012b). A schematic diagram of the DSS for irrigation water

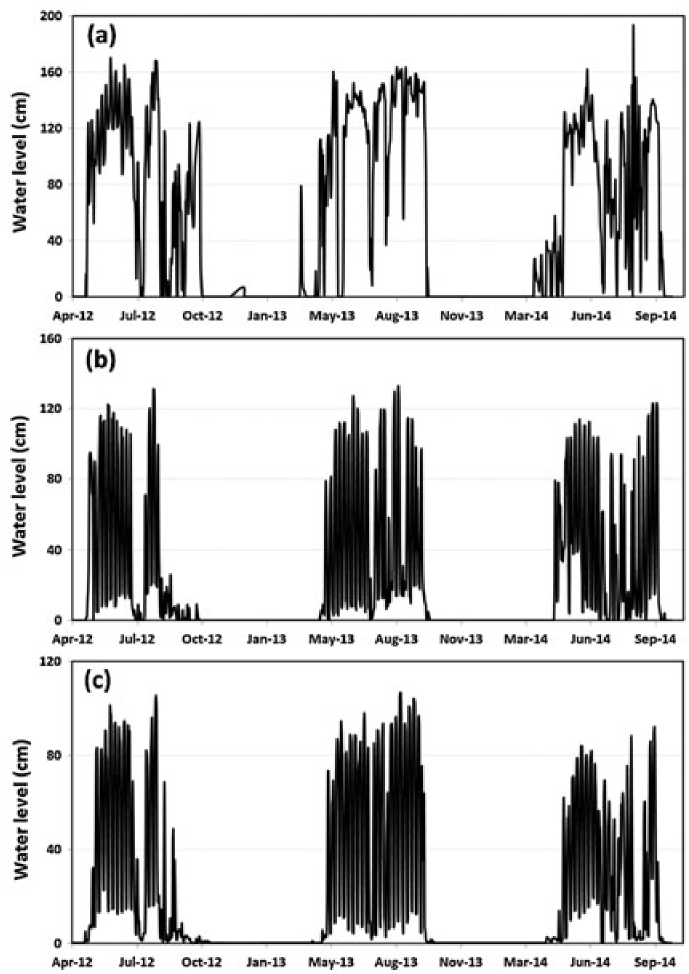

Figure 6. Automatic water level meters (a) Gimjae main canal, (b) Gamgok secondary inlet canal (upper region), and (c) Jooksan secondary inlet canal (lower region)

management with real-time information on water delivery conditions is shown in Figure 5. The DSS for water delivery management can be divided into several primary components including the monitoring of the real-time water-level and meteorological data, an analysis module for water requirements and delivery, an assessment module for irrigation system performance, and an irrigation canal status display module.

The monitoring and data collection system included real-time data collection, such as the water level in each canal and the meteorological data, and static data, such as paddy field management data, crop and soil data, and irrigation scheduling data. The following step was performed by the analysis model. The analysis model system used specific crop growth simulation models in order to estimate the daily crop evapotranspiration and the irrigation water requirement using the water balance analysis in each irrigated area. In the irrigation plan sub-module, the net irrigation requirements throughout the season could be calculated for different cropping patterns with the planting dates. The net irrigation requirements were converted into continuous flow in operating hours, taking the distribution efficiency into account. There was also an irrigation water delivery model for the irrigation water supply of each canal using the real-time water-level data as well as the intermittent irrigation scheduling and irrigation plan. The results of the irrigation water requirement were then compared to the available water delivery capacity. The assessment model system was a crucial phase for the performance of

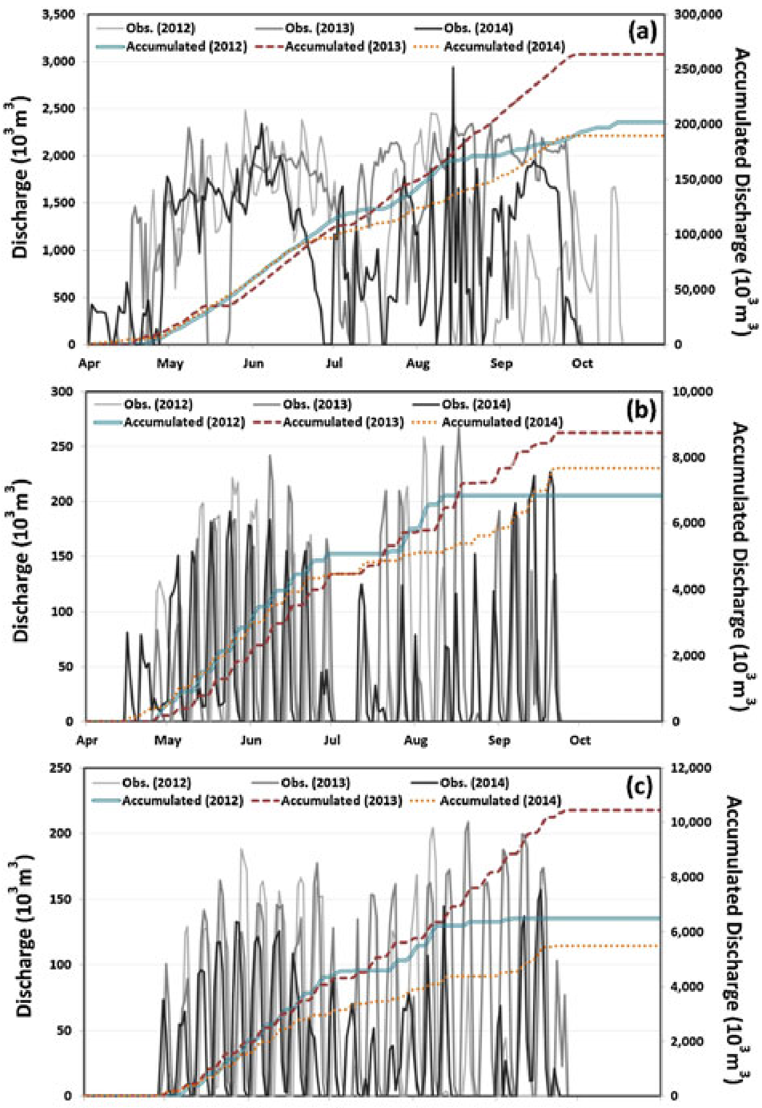

Figure 7. The discharge and accumulated discharge during the irrigation period from 2012 to 2014 (a) Gimjae main canal, (b) Gamgok secondary inlet canal (upper region), and (c) Jooksan secondary inlet canal (lower region)

irrigation system management, because it indicated the progress being made in the learning process towards better irrigation management. The irrigation performance indicator was based on the water application efficiency using the analysis of the water deficit between the irrigation water requirement and the irrigation water delivery of each canal.

The output system was included as integrated information that displayed the results in an easy-to-interpret format using a user interface in a web browser. The user interface used for decision-making depended on several functions: the current water demand and supply of the irrigation districts as it related to the canal levels, and the temporal and spatial patterns of the irrigation water delivery. It also included a variety of result formats, such as a table, graph and query. The feedback system for the optimal irrigation water supply could provide useful information, such as historical records of meteorological data analysis and water supply analysis, the results of the comparison of the water demand (irrigation plan) and the water supply (irrigation water delivery), and the irrigation efficiency. This system was developed to be an expert system that can aid in the selection of appropriate response measures by comparing existing conditions to a variety of historical data in a database. This analysis can provide elements to adapt and improve plans in a continuously updated feedback process.

APPLICATION AND DISCUSSION

Analysis of the irrigation water supply pattern using monitoring data

In this study, the daily water level in each canal was monitored and calibrated in order to estimate the amount of irrigation water supplied. Figure 6 shows the water levels at the starting point of the Gimjae main canal, at the inlet of the Gamgok in the upper region, and at the inlet of the Juksan in the lower region since 2012. Using the rating curves and the water-level data for each of the canals, the amount of daily irrigation water and the water delivery patterns were calculated. Figure 7 shows the water supply distribution of the Gimjae main canal, and Gamgok and Juksan since 2012. At the starting point of the Gimjae main canal, on average 242 400 × 10^3 m^3 of irrigation water was supplied during the irrigation period. The amount of irrigation water per unit area ranged from 15.8 (2012) to 20.8 (2013) × 10^3 m^3 ha^{-1}. At the upper region of the Gimjae main canal, 1056 (Shinpyong) to 10 285 (Daepyong) × 10^3 m^3 of irrigation water on average moved from the main canal to each secondary canal. The amount of irrigation water per unit area was 10.1 × 10^3 m^3 ha^{-1} (4.4 (Shinpyong, 2012) to 20.1 (Shinyong, 2013) × 10^3 m^3 ha^{-1}). At the lower region of the Gimjae main canal, 2036 (Bukjuk) to 15 127 (Neungjae) × 10^3 m^3 of irrigation water on average

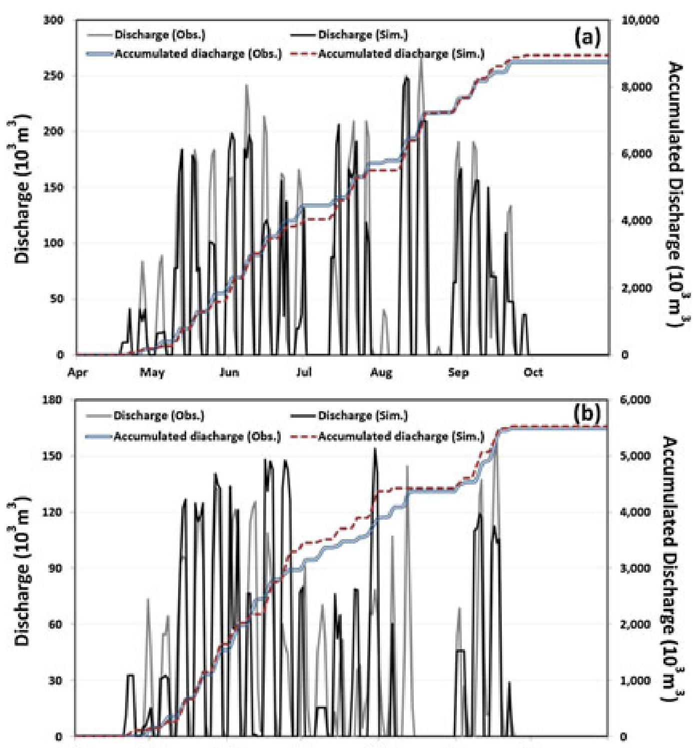

Figure 8. Comparison of the observed water delivery and the simulated water requirement: (a) Gamgok secondary inlet canal in 2013 (upper region), and (b) Jooksan secondary inlet canal in 2014 (lower region)

was moved from the main canal to each secondary canal. The amount of irrigation water per unit area was 21.1 × 10^3 m^3 ha^{-1} (1.6 (Bukjuk, 2014) to 75.3 (Neungjae, 2013) × 10^3 m^3 ha^{-1}).

Application of the intermittent irrigation model and suggestion for the optimal water delivery curve in each canal

Using the monitoring data, the intermittent irrigation model was calibrated using a constant conveyance loss rate. The first few runs of the model showed a discrepancy between the observed and simulated results. It was found that the conveyance losses varied from canal to canal. Therefore, after calibrating the irrigation scheduling, we calculated the conveyance losses in each canal and applied tehm in order to estimate the minimum and maximum water supply discharge in each of the canals. Figure 8 shows the comparison between the observed water delivery and the simulated water requirement using the intermittent irrigation model.

The average conveyance loss in the upper region of the Gimjae main canal was approximately 20% and that in the lower region of the Gimjae main canal was approximately 30%. Using the rainfall minimum and maximum scenario, the rainfall in dry and wet years, the average conveyance losses, and the optimal and boundary water supply curves were suggested as shown in Figure 9. In this intermittent irrigation model, the user could easily modify the conveyance losses or other parameters, and they could calculate the optimal water supply curve. In addition, the current water supply patterns could be compared to the historical pattern of the water supply by presenting the water supply curve in particular previous years and with certain conveyance loss rates. Utilizing this model, users can check the current water management and supply progress, and water management efficiency can be analysed. In addition, the water supply curve could be provided annually by projecting the previous irrigation water supply efficiency onto future water management. During the irrigation period, the daily water supply curve could also be updated, and the daily optimal supply curve and water management pattern could be suggested.

Development of the DSS for water delivery management

The development of the DSS for water delivery management proposed in this study, called the 'Smart Water Management System', was designed to support the preliminary steps of the irrigation water decision-making process aimed at evaluating the water delivery performance of irrigation canals. The KRC Corporation launched a prototype web-based DSS for irrigation water delivery management in

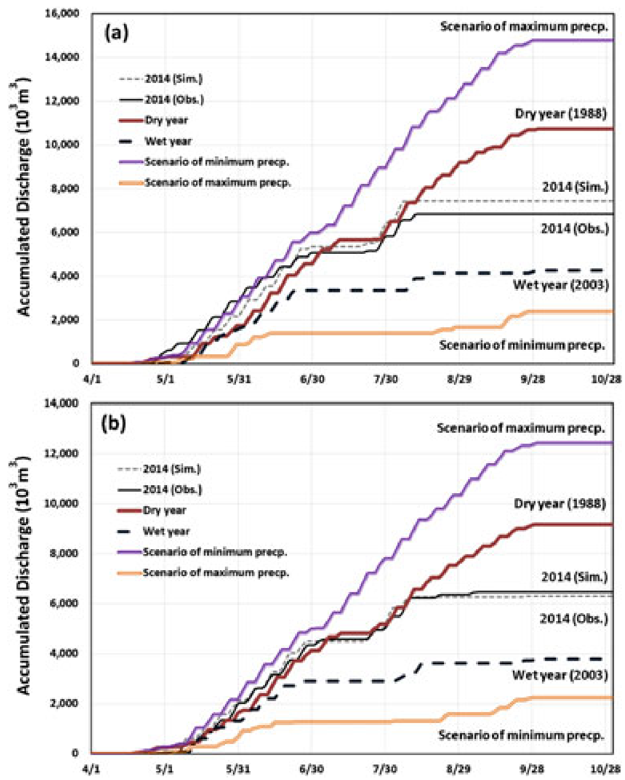

Figure 9. The optimal and boundary values of the optimal water supply curve based on the precipitation scenario: (a) Gamgok secondary inlet canal in 2013 (20%) (upper region), and (b) Jooksan secondary inlet canal in 2014 (30%) (lower region)

order to present the real-time water-level data of the canals. The DSS can be accessed through the website http://dongjin.uirri.kr.

The web working environment of the web-based GIS, as a captured screen snapshot, can be seen in Figure 10(a) main page, in which the Donjin Basin study area is also displayed. All of the needed information was arranged in terms of maps that the user may overlay in various combinations in order to make navigation easier throughout the regional territory. The user interface was supplied with functions, which were grouped according to four thematic categories, namely: real-time irrigation water supply status of each canal, historical data including meteorological and water-level data, and emergency and optimal irrigation water analysis for decision-making. Figure 10(b) shows the real-time water delivery status of the irrigation canals that were used for graphical display. The irrigation manager could make spatial and temporal comparisons in order to identify the water efficiency of each canal where the management was relatively high or low.

A web-based DSS targeted at novice and expert users should provide additional functionalities in order to help users understand the results in several different formats (Nam *et al.*, 2012a). The DSS allowed interactive

(a) Main page (location map of irrigation canals)
(b) Real-time water delivery status of irrigation canals
(c) Comparison of daily water delivery and meteorological data
(d) Comparison of historical water delivery (tableau based)
(e) Comparison of historical simulated water delivery (graph based)
(f) Comparison of water delivery status of irrigation canals

Figure 10. Decision support system for irrigation water delivery management

communication between web services and end-users based on various tools, and it also provided end-user access to a variety of tools that facilitate both the visualization and analysis of the spatial distribution of the water delivery and the simulated irrigation water requirements at different temporal scales. Figures 10(c) and (d) show a graph and a table of the water level and the trend analysis of the meteorological data. Such functionality made the results more helpful and it helped the users to analyse and understand the results. The function of the optimal irrigation water analysis for decision-making was included for the comparison of the historical simulated water supply between dry, normal and wet years, and the comparison of the time-series water delivery of each canal where particular attention was paid to the planner or decision-maker for irrigation system performance analysis, as shown in Figures 10(e) and (f). The function could also provide a basis for making adjustments and improving water supply countermeasures for future water shortage events. The development of a procedure capable of evaluating irrigation system performance was critical for improving irrigation water supply efficiency and for providing decision makers with information for irrigation water supply policy and management.

CONCLUSIONS

In this study, automatic water gauges were installed and an intermittent irrigation model was developed in the Dongjin River Basin, South Korea, in order to make a real-time DSS for irrigation water management. The amount of irrigation water per unit area in the upper region was 10.1×10^3 m^3 ha^{-1} (4.4 (Shinpyong, 2012) to 20.1 (Shinyong, 2013) $\times 10^3$ m^3 ha^{-1}) and the amount of irrigation water per unit area in the lower region was 21.1×10^3 m^3 ha^{-1} (1.6 (Bukjuk, 2014) to 75.3 (Neungjae, 2013) $\times 10^3$ m^3 ha^{-1}). The actual amounts of irrigation water supply were compared with the estimated irrigation demand using the intermittent irrigation model. Using the minimum and maximum rainfall scenario, the rainfall in the dry and wet years, the average conveyance losses, which were 20% in the upper region and 30% in the lower region, and the optimal and boundary values of the irrigation water supply curves were suggested. In this model, users could modify the conveyance losses or other parameters, and they could calculate the optimal water supply curve. Using the irrigation water supply curve of particular previous years and certain conveyance loss rates, the current water supply patterns could be compared to the historical pattern of the water supply.

Using these monitoring data and the model, the DSS for water delivery management was proposed and it was designed to support the preliminary step of the irrigation water decision-making process aiming at evaluating the water delivery performance of irrigation canals. The DSS for water delivery management had several primary components, including monitoring of the real-time water level, an irrigation canal status display module, and an analysis module for the water supply. The DSS system could provide insight into the possible improvement methods to develop canal water management policies that enable irrigation planners to optimally manage scarce water resources.

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