A Decision Support System for Paddy Rice Irrigation

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ABSTRACT/ Integrated irrigation management system (IIMS) that is incorporated with a microcomputer-based decision support system (DSS) has been developed and applied to paddy rice irrigation systems management. The system hardwares consist of field data acquisition units, data transmission units, central data processing units, and printing and displaying units. Field data to be collected include incremental rainfall, streamflow and reservoir water levels, and water levels at several irrigation canal sections within an irrigation districts. The softwares are to process field data, real-time forecasting, irrigation control data, and decision variables from data-base and simulation model subsystems. And the user-interface subsystems are incorporated to present the water system operators and managers the results from data and model subsystems. User-friendly menu with animated graphic modules are adopted to help understand irrigation controls for the district.

This paper issues the overal descriptions of DSS as applied to Anjuk irrigation district. The details of major model components for the irrigation controls are presented along with real-time data collection systems. The potentials of DSS have been appraised very practical and promising for better irrigation system operation and management.

1. Introduction

Paddy rice consumes considerable amounts of water during five month growing seasons from May to September in transplanted fields. For periods of approximately 110 days, the consumptive use by the crop sums up to 700 mm for high yield varieties. Except rainy months form July to August, natural rainfall is often insufficient, and supplemental irrigation is a requisite for safe rice cultivation.

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Irrigation reservoirs are typical water resources for paddy fields, covering more than the half of irrigated areas. However, their capacities are often not large enough to overcome drought spans lasting almost a month in early growing stages of the crop. Thus, most of paddy fields are subject to drought damages to some extents. In order to prevent drought damages, additional water resources should be made available. However, water development projects for agricultural uses seem losing their grounds. Few project sites for the purposes are available, and further, sharply increasing water demands from domestic and other industrial sectors need to be met.

In addition to the lack of storage capacities, inefficient water management of irrigation systems is another factor resulting in temporal and spatial drought damages (Chung et al., 1989). Nonuniform distribution of water within a district and low irrigation efficiency on farm levels are two major practices responsible to causing overall system efficiency to be lower than initially planned.

Timely irrigation scheduling is also important to irrigation efficiency. Lee et al. (1990) showed that proper scheduling may improve irrigation efficiencies by nearly ten percent.
Irrigation scheduling directly affects the ponding depths at the field, which control the amount of rain to be used by the crop. Therefore, adequate water allocations, efficient on-farm water management and timely sheduling schemes should be incorporated to an efficient water system operation and management.

Recently, a comprehensive integrated irrigation management system is developed and implemented, which incorporates micro-computer based capabilities for data acquisition and management, analysis, and direct information communications to water system operators and managers for decision support (Chung et al., 1990). A decision support system (DSS) is an integrated computer hardware and software package readily usable by managers and operators as an aid for making implementation and operational decisions, and learning of probable system performance (Johnson, 1986). Examples of DSS's for water management applications are those from Cunningham and Amend (1986), Allen and Bridgeman (1986), Buchleiter and Heermann (1986), Eckhardt (1986), Gooch and Graves (1986), and Koch and others (1986).

This paper provides an overall description of an irrigation management decision support system for paddy rice cultivation. Brief descriptions of the DSS components and the system configurations are presented as applied to a small irrigation district. The paper also includes general reviews on the irrigation control programs used in the system, and highlights the user interface programs which may help operators and managers fully understand the results of probable management alternatives.

2. Integrated Irrigation Management System

Integrated irrigation management systems (IIMS) that are based on a microcomputer-based DSS have been developed exclusively for the operation and management of a small irrigation district. IIMS consists of the system hardwares and softwares. The system hardware includes field data acquisition units, data transmission units, central data processing units, and printing and displaying units. The field data to be collected include rainfall data, streamflow and reservoir water levels, and irrigation canal water levels at points of importance along irrigation districts.

The softwares for IIMS include those programs for database management, models for irrigation controls and operations, and graphic modules for user interface managements. The details of the programs are fully described in Park (1989), Chung et al. (1989, 1990), and will be briefly discussed in later sections. Overall system configurations may be seen as Figure 1.

The functions of IIMS are: 1) to provide operators and managers with up-to-date information about the status and operating conditions of irrigation canals, paddy field blocks, and diversion gates, as well as water level information for reservoirs and streamflows 2) to automatically diagnose the canal operational status as compared to pre-assigned conditions,

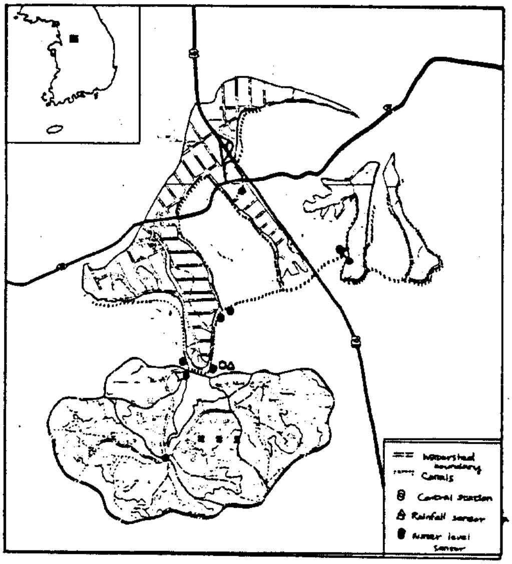

Fig. 1.

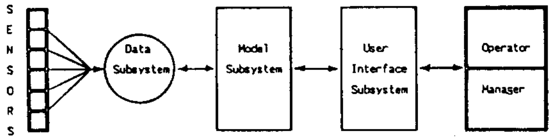

Fig. 2.

and to issue appropriate measures when failed, 3) to provide operators and managers with long-term (seasonal) and short-term (weekly) irrigation plans based on forecasted weather conditions, 4) to allow operators to compare the efficiency of different irrigation schemes and sequences, and to provide with appropriate measures to implement such schemes, 5) to allow operators to generate formatted reports including graphics, and to store and retrieve historical data.

In the followings, an IIMS for the Anjuk irrigation district will be described. It is located near Ansung, Kyunggi-do, about 60 Km from the capital city. It is of typical paddy fields having gentle topography. Total acreage for the district is 395 hectares. Figure 2 shows the location map with sites for hydrologic data collections.

3. Data Acquisition and Management

The data acquisition and transmission system for the Anjuk district is schematized in Figure 2. The gauging stations for the site consist of: (1) one stream flow gauging station at a small creek flowing to the reservoir, (2) one water level gauge at the reservoir, (3) one raingauge station, and (5) eight water level gauges along irrigation canals.

All field data are gathered using sensors and stored in memory at reporting units of microcomputers and periodically transmitted to a central processing unit via modems and telephone cables. Telephone cables were selected because they ensure safe and economical data transmission under varying climatic conditions. The schedules of data transmission are controlled with softwares according to prescibed schedules and operational purposes.

At the control station, four microcomputers are installed, the functions of which include: to process the information from sensors, to display the present status of the operational conditions of the irrigation system and check if they perform all right, and to process information to any queries by operators. All the tasks can be implemented simultaneously and direct dialogue between the system and users is ensured. For the purposes, the Xenix operating systems for microcomputers were selected to perform these multitasking jobs.

Data files are kept and updated in the central processing unit of a microcomputer, which include climatic data, water level data, and irrigation data. Among them, climatic data are to be updated manually based on the reports from a nearby weather station. The irrigation data are to be simulated from water levels at canal reaches using an operational model which will be detailed in the preceding sections. Rating curves calibrated from field data are programmed and used to convert water level data to discharge data at various points.

Other features in database management include data retrieval, editing, file review, automatic updating, formatted printing, and electronic displays. Graphic tools are adopted to realistically depict the data on a monitor. In addition, electronic display unit is set up to show the concurrent flow characteristics at measuring points. The unit is controlled by a microcomputer that handles signals from field sensors. It may be operated while the other three microcomputers are idle.

4. Irrigation Control Programs

The irrigation control programs in the DSS model subsystems that forecast and analyze climatical and hydrological data for irrigation and drainage controls include the followings: (1) long-term and short-term weather forecasting programs, (2) water balance simulation program for the water resources, (3) streamflow recursive simulation program, (4) water demand forecasting program, (5) daily and hourly irrigation system operation simulation program, (6) irrigation systems performace diagnosis program, and (7) operational guidance simulation program.

Overall descriptions of the real-time irrigation control programs are as follows.

Weather Forecasting Program

The weather forecasting program performs forecasting rainy days and the rainfall amounts in long-term and short-term ranges. Long-term forecasting is based on historical rainfall data which are selected from a simple correlation analysis with rainfall records of the particular year and modified to the recorded amounts. Cumulated daily rainfall patterns between the current year and each of 17 years in a data file are compared, and reference year selected from the highest correlationship. The resulting values are adjusted by multiplying a factor to each rainfall data at succeeding days. The adjusting factor is determined from the ratio of observed rainfall amount to that of selected year from the correlation analysis.

Short-term rainfall forecasting is made in two steps: firstly to presume rainy days and secondly to simulate the rainfall amounts for each rainy event. Rainy days may be determined either from weather forecasting data or from a Markov transition matrix method. Weekly weather forecasting from the National Weather Bureau is used to define the rainy days in the first procedure. In the second procedure, the transition matric was derived from seventeen year daily rainfall data at nearby Icheon station, and a Monte Carlo simulation technique is adopted to forcast rainy dates. The transition matrices were constructed for each ten-day period from April to September.

After rainy dates are selected, an incomplete Gamma distribution is used to generate amount of daily rainfall as described in the following equations (Villalobos and Fereres, 1989).

$$f(x) = x^{\alpha-1} \, EXP\,(-x/\beta)/\beta^{\alpha}/t(\alpha) \quad (1)$$

$$\beta = -2.16+1.83\,q \quad (2)$$

$$\alpha = q/\beta \quad (3)$$

where q= mean daily rainfall (= p/d), p= mean monthly rainfall, and d= average rainfall events in a month. The values of p and d in Equation (3) were determined from the data at Ichun station.

Other weather data may be selected either from the year of similar rainfall patterns from the correlation analysis or from normal values. Those are not significantly different from one another for the purposes of irrigation systems operation and management.

The forecasted weather data are to be used to preview the water demand by the crop and the water availability at the reservoir in coming days or weeks. Thus, any precautious measures such as restricted water diversions during the time of water shortage may be explored in advance, so that drought damages can be eased as much.

Water Balance Model

A daily water balance model is formulated to simulate daily fluctuations of water level at the reservoir. The inflow rates are simulated from daily rainfall using a modified tank model of three linear reservoirs in series, which may be conceptually depicted as in Figure 3 (Kim and Park, 1988). Irrigation intake rates are assumed to be equal to the sum of crop water requirements and infiltration rates multiplied by inverse of assumed irrigation efficiency. Water amount over the spillway crest level of the reservoir (113.8 EL.m) is assumed to be released to downstream on that day. The daily reservoir storage is determined from the following equation.

$$S_t = S_{t-1} + I_t + P_t - (R_t + O_t + E_t + L_t) \quad (4)$$

where S = reservoir storage, I = inflow, P = precipitation on water surface, R = water release to canal, O = overflow over the spillway, E = evaporation from water surface, L = minor losses, and subscript t = time in days.

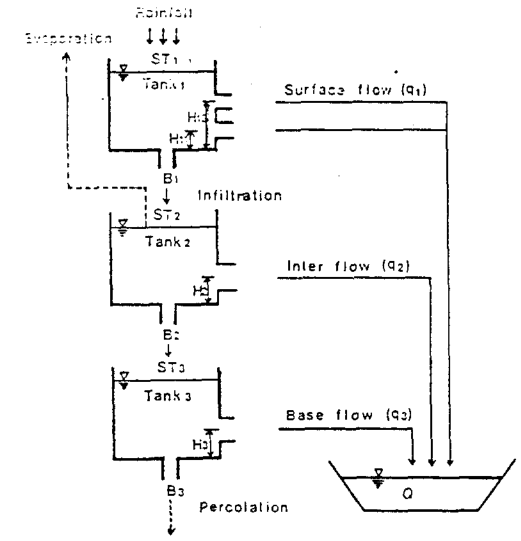

Fig. 3.

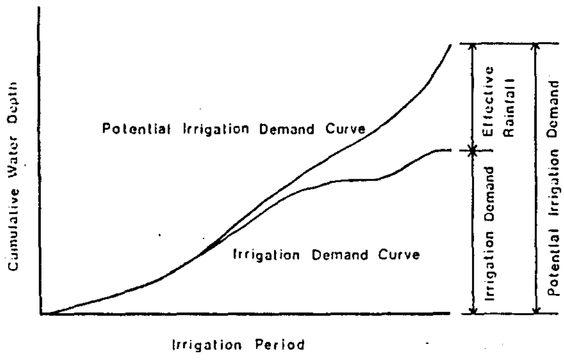

Fig. 4.

The simulation of water levels at the dam may be possible with forecasted rainfall data from the weather forecasting program for long-term or short-term operational studies. When the shortage of water is expected at certain irrigation periods, appropriate measures to reduce irrigation intakes and to allocate lesser amount of water may be explored in advance (Park and Im, 1991). Such measures could save enough water to last until rainy season comes.

Streamflow Recursive Simulation Program

Daily inflow to the dam is instrumental to reservoir operations. For short-term forecasting purposes, a recursive simulation procedure is adopted to automatically calibrate time variant parameters of storage levels at three tanks in the tank model of Figure 3 and to simulate daily inflow rates for the periods using forecasted rainfall input. (Lee et al., 1990) A golden section search procedure is adopted to define optimal values until permissible simulation errors of 0.01 mm is obtained.

Test results showed that initial forecasting for a longer period often results in substantial errors as compared to later measurements (Park, 1989). As time passes, however, the scheme updates the model parameters and correct simulated inflow rates. Thus, it is possible to get more accurate simulated inflow rates in coming days, while higher uncertainty in forecasting of the inflow rates in coming weeks and months remain relatively high.

Water Demand Forecasting Program

A cumulative curve procedure of Figure 4 is used to determine water demands for paddy field irrigation, which depicts accumulated daily values of potential and actual requirements in ten-day periods (Lee et al, 1990). The differences between the potential and actual demands are due to effective rainfall. The program was tested satisfactorily with the data from several reservoirs.

The demand forecasting program is to determine the amount of water intakes for the district. The release rates and durations are determined from the total required intakes. When accumulated irrigation amount is greater than the demand curve due to prior release, intakes may be postponed to later days without causing water shortage in field blocks. This is possible because flooding irrigation allows certain amounts of water stored on each field.

Irrigation Systems Operation Simulation Program

In order to simulate operational characteristics of irrigation systems, the systems are first grouped to several sectors of homogeneous conditions, and then their hydrologic and hydraulic characteristics mathematically modeled. The schematic of an irrigation system as represented in the model is shown in Figure 5 in which geometry of canals, fields, ditches, and streams is depicted with appropriate hydrologic processes controlling flow characteristics and water depths (Lee et al., 1990). However, the dynamic relationships between the upstream and downstream segments exist and thus, should be included to simulate the conditions along canals and eventually all the field blocks. An example of such links is shown in Figure 6, which is used for representing operational characteristics of the irrigation district.

The model may also be used to simulate daily or hourly operational characteristics of the irrigation systems. It was tested vigorously with an irrigation district where more twenty-nine self recording water level gauges were installed at different components of the irrigation systems like reservoir, outlet, canals, ditches, streams, etc. (Chung et al., 1989). Daily simulation results were found to be applicable to the comparision of irrigation efficiencies among different irrigation schemes. And hourly simulation results may be good for evaluating flow patterns and temporal variations of irrigation depths at different field blocks.

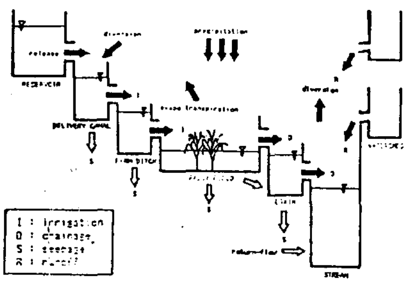

Fig. 5.

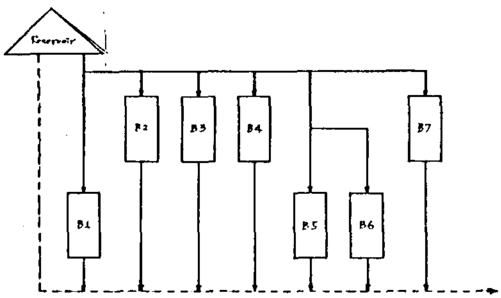

Fig. 6.

The model is set up to estimate daily or hourly water fluctuations in each of seven irrigation units. Diversion rates between gaging stations are determined and the irrigation amount to the units minus estimated drainage amount is used to define water depths in the individual block. The results are kept in a data file and used to control water allocations for the district.

System Performance Diagnosis Program

A diagnostic program is developed to monitor and evaluate the performance of irrigation systems. The program sets its initial conditions according to irrigation schemes, which include the arrival times of water front along irrigation canals and steady flow rates at gaging stations along the irrigation canal. As water release begins, the actual water stages at gaging stations are measured and compared to the simulated results. If measured hydraulic conditions fail to meet the results, a diagnostic routine is called and diversion rates at specific points along the canals computed. The program provides operators and managers with appropriate measures to correct problems, which include the assignments of ditchriders' duties and procedures to control diversion gates. The program is set to run periodically throughout an irrigation sequence, unless it is forced to be silent by users.

Operational Guidance Simulation Program

In order to control irrigation systems in accordance with a selected scheme, a guidance program is developed to adjust the operational conditions to actual processes. To meet certain water demands at a specific day, a set of water release levels can be selected and operated. It is not unusual, however, that the amount of water being released is not enough to suffice actual water demands to beneficiary areas. Diversion amounts may be too small to effectively deliver the amount, or unspecified operational behaviours may cause adequate water delivery to designated areas. This can be checked with the system performance diagnosis program as described earlier. In the case, new sets of operational guidances would be explored and issued to correct such problems.

The program performs to check the required amounts of water at individual irrigation units and to simulate diversion rates to them. If the diversion rates fail to meet the requirements, it simulates the operational alternatives in the following orders: (1) to adjust release amounts, (2) to alter water allocation schemes, and (3) to re-evaluate diversion rates to specific irrigation units. In each module, simple arithematic rules are set to get the results.

5. User-interface Systems

In order to provide the operators and managers with appropriate alternatives for water management, user-interface systems are developed. The systems have the following features: (1) menu-driven command selection with an interactive device like a mouse or digitizer, (2) management alternative query for model systems, (3) graphic displays of data and analysis results from the database and model systems, (4) formatted reports readily obtainable, (5) data query operations for summary tables. The details of each feature are discussed in the followings.

Menu-Driven Commands

Assuming potential users of the DSS to be personnels without extensive training and experiences on computers, menu-driven commands are developed to operate data retrievals and model simulations. A pull-down menu and foot-noted summaries of commands are installed. The menu consists of main and submenus. The main menu have five divisions; data retrievals, irrigation planning, drainage planning, status displays, and help menu.

Special features of each menu are as follows.

Data Retrieval Menu

The data retrieval menu have four selections, file listing and selection, file viewing, file editing, and file printing. At the menu, one can select one of several data files, review the contents of a file, edit it, and print out. Commercially available wordprocessing programs are used in this study.

In addition, graphic programs were developed to display any data from the data bases. The routines are to show visually historical data, which may be helpful to compare present conditions to past data.

Irrigation Planning Menu

Irrigation planning menu have three sub-menu selections, long- and short- term planning, and present irrigation status and planning. Long- and short-term planning submenu consist of three sub-sub menu, pumping plan, water distribution plan, and forecasting. Climatic forecasting, inflow simulation, reservoir water level fluctuations, effective rainfall, and water demands are simulated. The simulation results are graphically displayed or formatted reports can be obtained

Present status and planning selections are directed to five selections; water supply conditions, water release plans, water management status and diagnosis, ditchriders' duties, and water distribution plans. water supply conditions display the present irrigation status based on streamflow and canal flow measurements. Water release plans include estimation of water requirements and release rate and duration. Additional selections for irrigation alternatives are continuous irrigation and scheduled irrigation methods.

Water management status and diagnosis has four selections. The submenu selections consist of water front simulations, flow conditions along canals, water distribution status, and block irrigation depths. Water front simulation depicts the flow advancement along the canals and check if any breakdown takes place along canals where no flow advancement is observed. Flow conditions along canals are simulated from model systems based on water level measurements. Water distribution status depicts the water delivery conditions at canals and blocks, respectively. Block irrigation depths are simulated from model systems based on diversion rates to various blocks and depict irrigation depth variations throughout the district as shown in Figure 6.

Sub-sub menu for ditchriders' duties consists the status of ditchriders for the district, their duties, and emergency duties. When the system breakdowns such as unscheduled diversions at certain points or water leaks along certain reaches of canals take place, nearer ditchrider would be called upon and assigned appropriate actions.

Sub-sub menu for water distribution plans consist of three selections; block irrigation depths, block water demands, and pumping plans. Block irrigation depths are simulated from operational characteristics program and the results are depicted graphically. Block water demands are computed from the water demand model in the model system, and the results are graphically displayed. Pumping plans are to be adjusted based on block water demands and water allocation schemes which the managers and operators determine.

Other Menus

Present status of gauging stations are also provided with graphic displays. And the help selections contain brief descriptions on the integrated irrigation management systems, decision support system, and menu systems, which is to facilitate users to learn the system without detailed manuals.

Animated Graphics

In an effort to realistically representing hydrological processes, the simulation results are depicted using color graphic displays. And animated pictures are generated to depict the changes in water levels, irrigation depths, etc. Thus, users may find the processes of irrigation to field blocks. An example of irrigation animated pictures are shown in Figure 7, which describes the irrigation progress within the district. Such results are found to be important to notify users what is happening under the certain irrigation scheme.

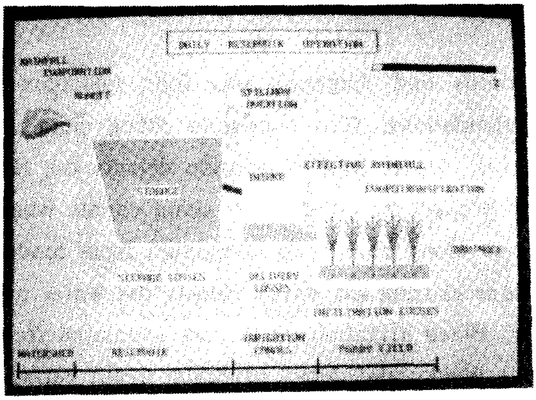

Fig. 7.

6. Operational Features

Currently, the IIMS is operated jointly by the Kiho Farm Land Improvement Association and Department of Agricultural Engineering, Seoul National University. Though comprehensive evaluations on the system performance and feasibility will be available later, initial appraisals by many engineers and managers have been positive. It is inexpensive but is performing all right. The system has been well accepted by personnel involved in the systems operations, who indicate that it is informative and helpful to their operational decision making.

7. Conclusions

An integrated irrigation management system that adopts a microcomputer based DSS was developed and applied to the Anjuk irrigation district having the benificiary area of 395 hectres. The DSS consists of a data acquisition and management system, an irrigation control model system, and a dialogue management system. The system was found to be useful in operating irrigation systems. It receives a warm welcome from field managers and operators. The IIMS of this kind has been requested for other irrigation districts by the district managers. This may reflect that the efficient water management is becoming an important task in the agricultural sectors.

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