3rd World Irrigation Forum

1-7 September 2019, Bali, Indonesia

International Workshop on

Modernizing Irrigation Services for Water, Food, and Nutrition Security (M&R)

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CONTENTS

International Workshop on Modernizing Irrigation Services for Water, Food, and Nutrition Security (M&R)

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International Commission on Irrigation and Drainage (ICID)

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Hosted by:

Indonesian National Committee of ICID (INACID)

Ministry of Public Works and Housing

Directorate General of Water Resources

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Supported by:

Ministry of Public Works and Housing; Ministry of Agriculture; Ministry of National Development Planning; Ministry of Foreign Affairs; Ministry of Tourism; and Provincial Government of Bali, Republic of Indonesia

Working Group on Modernization and Revitalisation of Irrigation Schemes (WG-M&R)

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August 2019

USING SMART WATER OPERATION CENTER (SWOC) FOR BETTER WATER MANAGEMENT IN THAILAND

Chaiwat Prechawit[1], Thanet Somboon[2], and Lerboon Udomsap[3]

ABSTRACT

The Royal Irrigation Department of Thailand (RID) has been given the mandate to manage the water in the reservoirs and rivers, by irrigation infrastructures, for agricultural purpose and other purposes e.g. urban and domestic water supply, industrial, environment, etc.

However, due to growing competition from water use in other sectors, increase in dry season cultivations, frequent flooding resulting from erratic climate, growing urbanization, and changing in way of life in rural areas, all these factors, has led to a need for accurate managing of the basin water to be able to make fair allocation of water to all sectors, to minimize damage from droughts, and to mitigate the damages that may be caused by flooding.

The area responsible by RID is quite large and varied; from the large and complicated Chao Phraya river basin with its 4 large tributaries and its large delta of 1.2 million hectares irrigated area which is the major rice bowl of Thailand to the large Northeast plateau with its 2 major river basins, the Chi basin and the Mun basin, draining into the Mekong river. The total cultivated area of Thailand is 5.2 million hectares.

To monitor and evaluate the water situation, RID has set up the center for water management during time of crisis for both floods and droughts. A working group composed of representatives from water related departments was set up to closely monitor the situation and prepare recommendations for RID and the Government's decisions makers. However, as floods and droughts occurred more frequent recently, the public is eager for information for early preparation; therefore, there seem to be a need for improving the effectiveness of the existing arrangement.

After the disastrous flood of 2011, RID planned to set up a new Smart Water Operation Center (SWOC) and a large new building was constructed just for this purpose. It was linked to the servers in the computer center of RID to facilitate collecting, storing and computing. Many programs, apps and mathematical models for forecasting of floods and droughts are set up. There are large teleconference rooms for meeting of the new subcommittee for water monitoring and evaluation with members from 10 departments involving in water chaired by the deputy director general of RID. The meeting can be done online together with the 17 Regional Irrigation Offices of RID, other Departments, the Ministry of Agriculture and Agricultural Cooperatives and the Government's Office of Water Resources Management. The operating staff of SWOC are working full time to provide analysis, reports, warnings, short communications, etc. to RID management and to the public through the SWOC website.

SWOC has been in operation from its first stage completion in 2015 and the resulting in handling of many water crises are quite successful. The online teleconference meeting every week united all water management staff of RID to be able to report and discuss problems and at the same time receive instructions to be implemented spontaneously. The government and the public are satisfied with the result of SWOC.

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There are some programs to further increase SWOC's capacity in forecasting water crises but as of now the work process and the operation of SWOC can be a good example for setting up a good water management system elsewhere.

Keywords; *Smart Water Operation Center, water management, teleconference, floods, draughts*.

1. INTRODUCTION

Thailand is a country situated in the Indo-Chinese peninsular with total area of 51.4 million hectares. The area suitable for agriculture is 23.8 million hectares. for which about 5.247 million hectares has been developed for irrigation. The area is divided into 77 provinces with Bangkok, the capital, situated in the lower Chao Phraya delta. Total population is about 64.8 million.

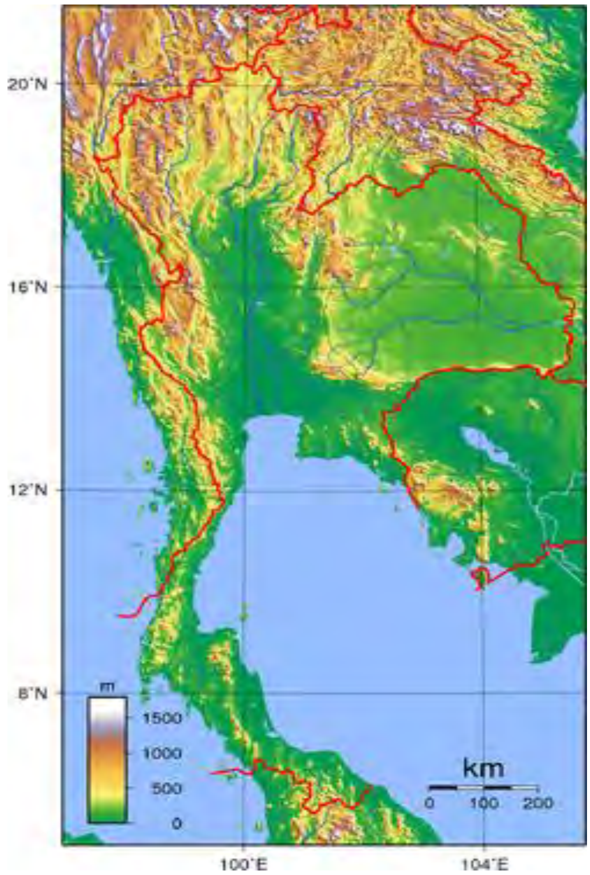


Figure 1 Topography map of Thailand

Thailand can be divided into 6 geographical regions (according to The National Research Council); the North Region, the Northeast Region, The Central Region, The East Region, The West Region and the South Region. Features of Thailand's terrain are high mountains, a central plain, and an upland plateau (**Figure** 1). The central plain is a lowland area drained by the Chao Phraya River and its tributaries, the country's principal river system, which feeds into the delta at the head of the Gulf of Thailand. The Chao Phraya system drains about one-third of the nation's territory. In the northeastern part of the country the Khorat Plateau, a region of gently rolling low hills and shallow lakes, drains into the Mekong through the Mun River. The Mekong system empties into the South China Sea and includes a series of canals and dams.

The climate of Thailand is under the influence of monsoon winds of seasonal character. The southwest monsoon, which starts from May until October is characterized by movement of warm, moist air from the Indian Ocean to Thailand causing abundant rain over most of the country. The northeast monsoon, starting from October until February brings cold and dry air from China over most of Thailand. In southern Thailand, the Northeast monsoon, bring mild weather and abundant rainfall on the eastern coast of that region. Most of Thailand has a “tropical wet and dry or savanna climate. The majority of the South as well as the eastern tip of the east have a tropical monsoon climate. Parts of the south also have a tropical rainforest climate.

2. POLICY OF ROYAL IRRIGATION DEPARTMENT (RID) ON WATER RESOURCE DEVELOPMENT.

Modern development of irrigation in Thailand started in the Reign of King Chulalongkorn (Rama V) when the King requested the service of a Dutch hydraulic engineer to study and lay out a plan for irrigation in the central plain. J. Homan van der Heide arrived in Thailand on 13 June 1902. After a year of study, he submitted a report called “General Report on Irrigation and Drainage in the Lower Menam Valley”. Although the report was well received but due to the country’s limited budget the project was postponed, however a department called “Krom Klong” was established with van der Heide as the Director General in 1903 to manage and improve the use of canals (klongs) for agriculture. Only after world war II in 1953 that construction of the Chao Phraya, the key to water management in the Chao Phraya delta, begun and completed in 1957. From then on, the irrigation development in Thailand gain momentum until today where Thailand rank eight in the world in term of total irrigated area developed. Existing Water Resources Development in Thailand is shown in **Figure** 2.

Existing Water Resources Development

Irrigation Project Classification	Number project	Capacity (MCM)	Irrigable Area (ha)
Large Scale	68	10,595.64	2,689,191.68
- Pumping	18	2,084.99	201,421.92
-Operated by EGAT	10	61,203.48	-
Sum	96	73,884.11	2,890,613.60
Medium Scale	729	5,394.63	1,069,227.20
- Pumping	28	2.75	32,299.04
Sum	757	5,397.38	1,101,526.24
Small Scale	16,762	2,685.59	552,589.76
- Pumping	2,518	36.43	702,559.04
Sum	19,280	2,722.02	1,255,148.80
Sum	20,133	82,003.51	5,247,288.64

Source: RID, 2017

Figure 2. Existing Water Resources Development in Thailand

Water requirement from agriculture sector increase steadily, when farmers increase the area of dry season cropping of rice and also try to plant a second crop of dry season rice or to plant all year round. This has resulted in very high demand for release from the reservoirs especially in Chao Phraya Basin. Rivers and Dams in the Chao Phraya Basin is Shown in **Figure** 3. At the same time water use in other sectors also increase, while Thailand is frequently hit by erratic weather condition of series of draughts and floods, it is extremely difficult to plan and to manage water resources to cope with these situations.

RID's 5 Strategies in the 20-year-Plan (2017-2036)

(a) Water resource development to increase irrigated area according to basin characteristic and potential. (Basin-based approach)

(b) Increase efficiency in integrated water management according to purpose of water use.

(c) Prevention and mitigation of water related disasters.

(d) Local networking and participation in irrigation water management.

(e) Turnaround RID into intelligent organization.

As part of the RID No.1 plan, RID also stresses on increase efficiency in water management by extending the scope of SWOC to include forecasting and warning and also increase using of technology either by software, digital platform and using of Big Data for water management data base system.

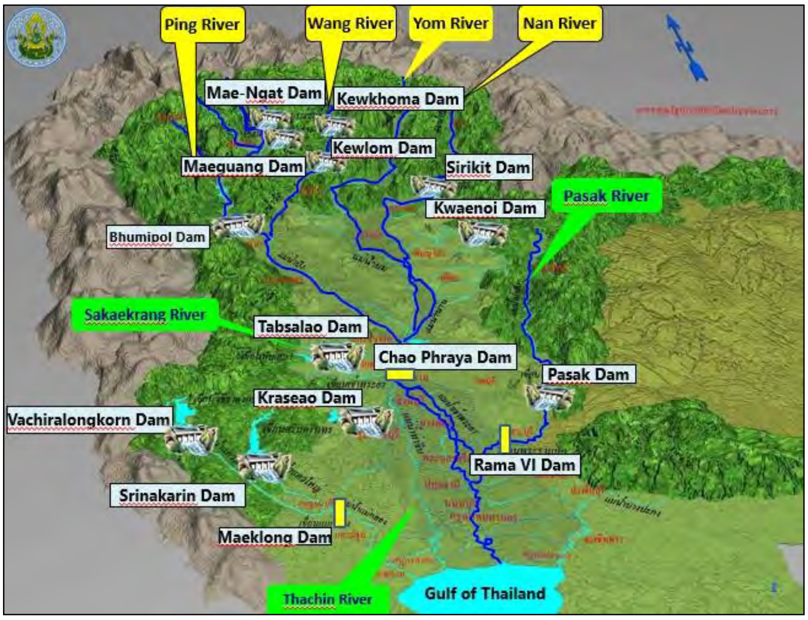


Figure 3. Rivers and Dams in the Chao Phraya Basin.

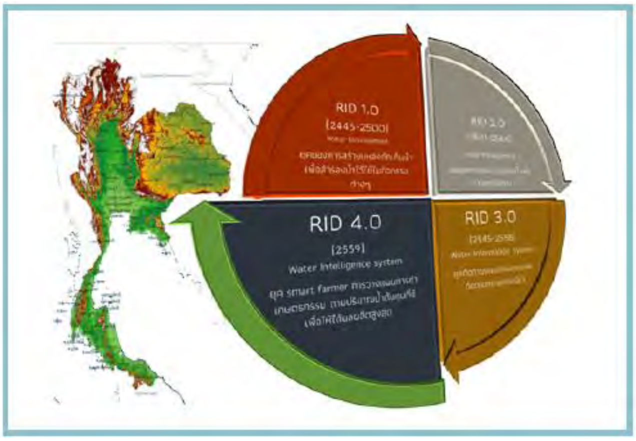
3. RID'S APPROACH TO BETTER WATER MANAGEMENT

RID is in the process of RID No.1 campaign. This is the strategy in the plan for strengthening the RID organization to be one of the leading agencies in Thailand. As part of the RID No.1 plan, RID stresses on increasing efficiency in water management by extending the scope of SWOC to include forecasting and warning and also increasing the use of technology either by software, digital platform and using of Big Data for water management data base system.

Panuwat Pinthong explains the changing of RID from RID 1.0 to RID 4.0 in his paper (**Figure** 4) "Water Sustainable Management for Agriculture Revolution in Thailand (waterSMART)", a research project for Agricultural Research Development Agency (public organization) as follows;

- RID 1.0: Water resources development during 1902-1957. This is the period of early establishing of responsible departments for water resource developments (Krom Klong, Krom Tod Nam, etc.)

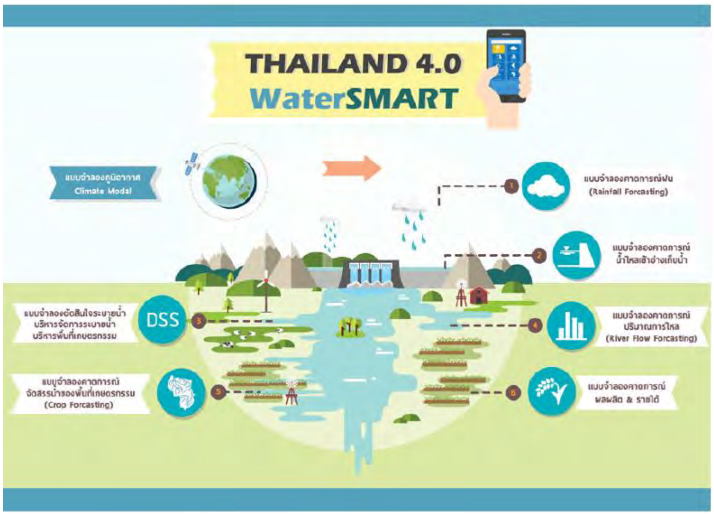
- RID 2.0: Water Management, 1957-2001. A period of water management of reservoirs, diversion dams, irrigation canals for rice cultivation in wet and dry season.
- RID 3.0: Water Information system 2002-2015. A period of telemetering systems for monitoring of stream flows, levels, for online decisions in response to floods and draughts.
- RID 4.0: Water Intelligence, from 2016. Managing limited water supply to get maximum benefit stressing smart farmer's access to data, water availability, land suitability, etc., to make proper decision to get maximum yield and benefit.



Source: Panuwat Pinthong, 2018

Figure 4. The changing of RID from RID 1.0 to RID 4.0

The obstacles to reach RID 4.0 are fluctuation in water availability, increase in water demand from agriculture and other sectors, risks from floods and draughts, low agricultural products yields and prices. The answer to these questions is the need for better water management. Thailand 4.0 WaterSMART is shown in **Figure** 5.



Source : Panuwat Pinthong, 2018

Figure 5. Thailand 4.0 WaterSMART

Evolution of SWOC

In the past around 1960 when large storage reservoirs upstream of the Chao Phraya river were not constructed the management of RID concentrated more on disasters especially floods. During the time prior to and between floods approaching and inundated Bangkok war rooms were set up at RID main office, the Director General and his ad hoc teams usually stayed at the office 24 hours every day, monitoring and making decisions on where and how to protect the weak spots. Construction teams were usually busy with new large pumping stations or temporary closing of canals branching out of the Chao Phraya River to prevent flooding to orchards and communities.

The organization was improved step by step bringing in representative from various departments concerning weather and water monitoring and forecast.

Stages 1: Preventing and resolving flood and drought problems of the Royal Irrigation Department from past to 2007.

- In 2004 Establishment of a special center for flood and drought prevention and response with working groups to monitor and analyze water management plans.

Stages 2: Establishment of sub-committee for monitoring and analyzing water situation trends

- In 2007 The Office of the Royal Development Projects Board in response to the Royal Initiative established the water management board for managing the water in Bangkok and its vicinity. The Prime minister was the chairman of this committee.
- The center was renamed to Water Watch and Monitoring System and Warning Center.
- In 2008 Establishment of sub-committee for monitoring and analyzing water situation trends. The Deputy Director General for Operation and Maintenance of the RID is the chairman. Ten agencies concerned with the water resources in Thailand are member of the subcommittee.

Stages 3: Establishment of Smart Water Operation Center

- RID finally decided that it needs a special center that has all facilities to handle all data collecting, transferring, analyzing, also with many meeting rooms for all levels of management briefings including teleconferences with the government's water operation center, other departments and, most important, to the 17 RID regional offices. This make instant reporting from the regions and also from the spot of the incidents possible. The SWOC center is also a suitable place for detail report to the press.
- RID constructed a new large building dedicated only for SWOC. It was designed during 2011-2013, constructed in 2014-2016, installing the system 2016-2017, and completed commence operation on June 13, 2017.

4. SWOC PROJECT INFORMATION

RID uses the slogan "FAST" to be the goal of SWOC. (**Figure** 6) The SWOC building is a 4 story building equipped with 1 large conference room suitable for meeting and teleconferencing (**Figure** 7). It also has 2 other smaller meeting rooms and a special room for press conference. There is also work space for staff and another meeting room for internal use. It is equipped with computers, large video wall screen, multimedia projectors, motorized screen, VDO conference and streaming system, Digital signage and SMATV. The price of the building of the SWOC building and the tool is approximately 15,900,000 US dollars.

Figure 6. Slogan of SWOG

For software used:

(a) Water situation monitoring: SWOL WL, Application "WMSC"

(b) Water Management: ANNs, Simulation tool, NARK, MIKE11, ROM

(c) Communication: Software control monitor, Software control conference (SCOPIA)

SWOC's staff is 26 at present and planned to be increased later especially the number of irrigation engineers, electric and communication and computer technicians.

Figure 7. The building of SWOC

Decision Support System for Water Management: NARK 4.0

RID's plan for the Chao Phraya River Basin compose of 6 decision support systems.

(a) Rainfall forecasting.
(b) Inflow forecasting.
(c) Reservoir operation and planning.
(d) River flow forecast model.
(e) Crop forecasting.
(f) Forecast of crop yield and adjustment to match available water supply.

Panuwat Pinthong[4] has developed a system for decision support in water management in the Chao Phraya river basin called NARK 4.0. The first step is forecasting rainfall in the Chao Phraya basin using a statistic downscaling of the weather model by International Research for Climate and Society (IRI). Then the monthly rainfall will be used in the rainfall-runoff model to compute the inflow into the reservoirs of the 4 major storage dams. Another model for reservoir management will suggest optimum release to match downstream water demand. Then the hydrodynamic model (Mike11) will be used to simulate flows in rivers downstream. Hydrographs of key measuring stations in the 4 tributaries, Ping, Wang, Yom and Nan and the Chao Phraya itself will be forecasted in order to prepare for cases of river bank spills or in case of keeping minimum low flow to maintain proper river environment.

Panuwat Pinthong also link forecasted flow in main rivers to water allocation for the 26 irrigation projects in the Chao Phraya delta. He claims it can provide planning of crop area in case of limited water supply by link to the Agri-Map of Ministry of Agriculture and Cooperatives.

The program NARK 4.0 and its mobile application WaterSMART was installed at the SWOC center for improvement of existing water management program.

5. IMPLEMENTATION OF SWOC

SWOC was in operation since 2016 with 5 major roles: Monitor, Evaluate, Analysis, Forecasting and Making decisions (**Figure** 8).

Figure 8 Roles of SWOC

Figure 9 The sub-committee for monitoring and analyze trend in water situation

The sub-committee for monitoring and analyze trend in water situation meet every week to hear latest situation and trend of rainfall and stream flows together with report on disasters, then propose adjustment in reservoir releases, sending pumping trucks to where flooding is expected, prepare for high sea water level from storm surges, anticipate floods flows from the North, or in case of draughts decides on additional releases, sending pumping trucks to supply water, request for Royal Rain Making Units to make artificial rain for filling up reservoirs and to help orchards or crop land (**Figure** 9). When disaster situation occurred the Minister of Agriculture was briefed about latest situations (**Figure** 10). Realtime teleconference with agencies and all RID Regional Irrigation Offices with direct report onsite help close consulting and fast decision making is shown in **Figure** 11. Latest data provide by various agencies help in close monitoring of disasters is shown in **Figure** 12.

Figure 10 When disaster situation occurred the Minister of Agriculture was briefed about latest situations.

Figure 11 Realtime teleconference with agencies and all RID Regional Irrigation Offices with direct report onsite help close consulting and fast decision making.

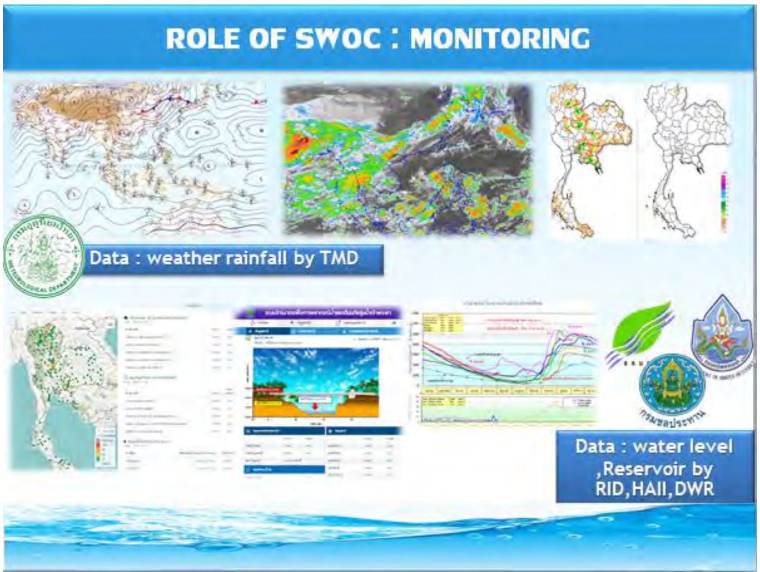


Figure 12 Latest data provide by various agencies help in close monitoring of disasters.

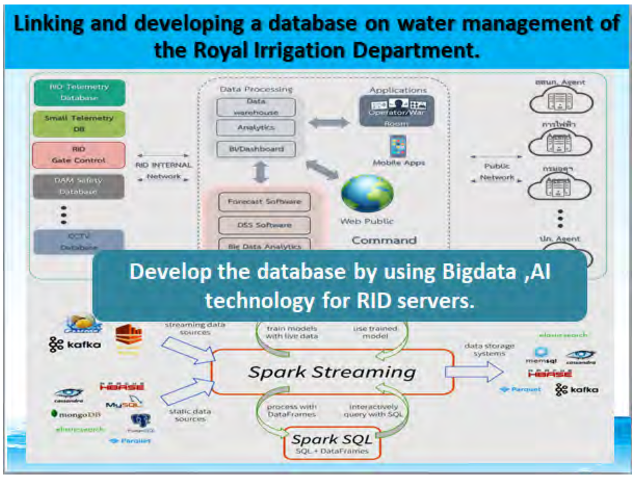
6. LESSON LEARNT AND BENEFIT

SWOC has made water management much more effective. It has raised the level of participation of everybody into the process of decision making. From reporting on weather condition and forecast by Meteorological department and Hydro and Agro Informatics Institute to reports of water levels and trends of EGAT hydroelectric dams, report on level of rivers by Department of Water Resources, situation of water in Bangkok by Drainage department, BMA, to a detail report on water available in RID dams and water level and flows from key stations in major rivers by RID. With this briefing and more information like sea level forecast by Hydrographic department, RTN, and the online reporting from RID Regional Offices, this will lead to proper execution of water management decisions. Not only that, when the regional offices have been briefed and understand the real situation together with central office, when instruction was given to implement some action, it will be done without delay. Besides, it is real time 2 ways communication so misunderstanding and mistakes were prevented.

The software for water management such as NARK 4.0 can help in making seasonal plan for reservoir releasing and plan for crop area in advance. Therefore, for normal weather condition advance planning can be made with reasonable accuracy.

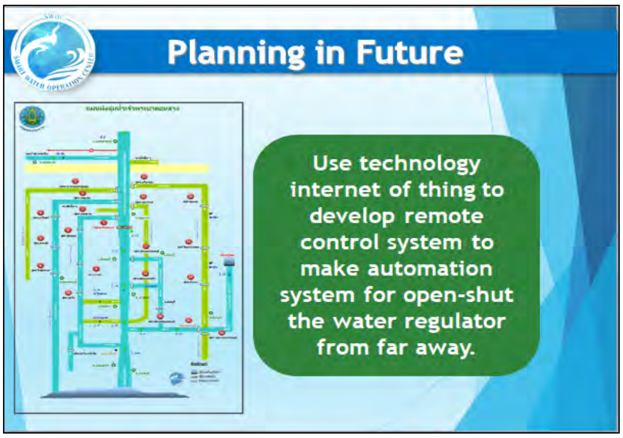
SWOC also post some water data on the SWOC website therefore smart farmers can monitor and plan accordingly.

RID top management can benefit from mobile applications such as WaterSMART that will keep them informed of the water situation at all time.



Source: SWOC, 2018

Figure 13 Linking and developing database on water management



Source: SWOC, 2018

Figure 14 Using IOT to develop remote control system for operating structures.

7. WAY FORWARD OF SWOC

SWOC has proved its value in a few years that it has been implemented. Already there are plans to extend its usefulness such as to bring in Big Data to support more investigations and analysis (**Figure** 13). Using of internet of things for remote operation of structures. Adding more nodes in order to bring in more SWOC sites, e.g. from Province Irrigation Offices and Operation and Maintenance Irrigation Offices. Although this may sound like progress but we must be careful to weight between taking too much resources and time just to reach everybody or simply to reinforce existing set up so it can work smoothly without interruption anytime. Using IOT to develop remote control system for operating structures is shown in **Figure** 14.

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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).

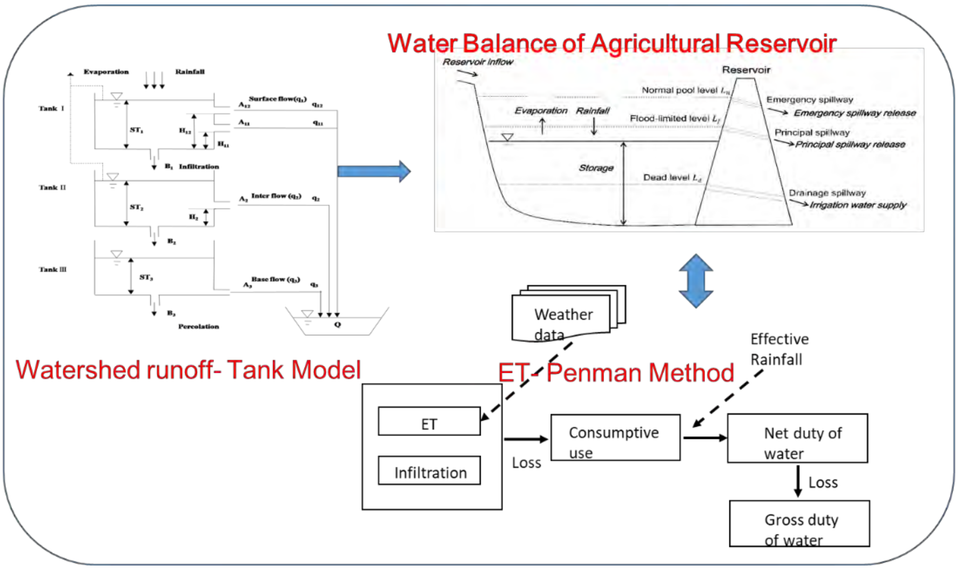

Figure 2. Components of hydrologic operation model for water resources system (HOMWARS).

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.

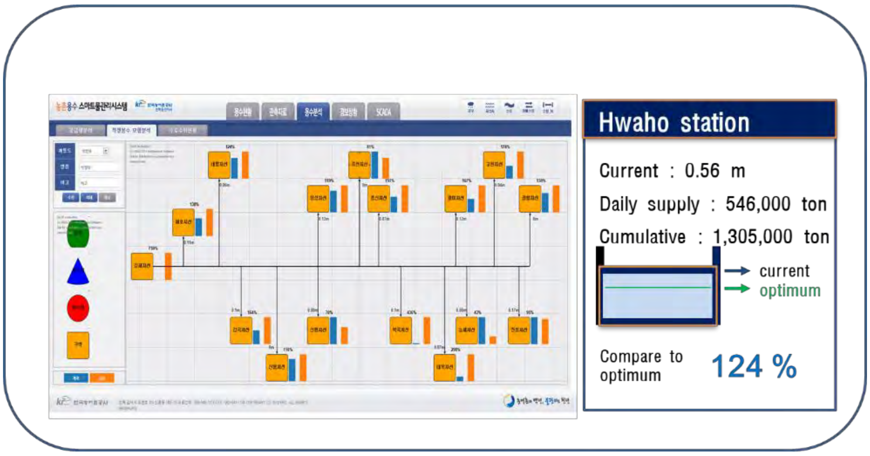

Figure 3. Irrigation canal water delivery monitoring system.

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).

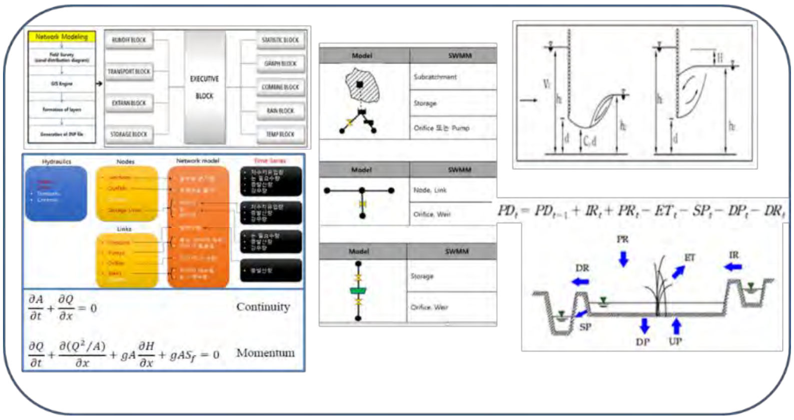

Figure 4. Components of a hydraulic model for irrigation water distribution system.

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.

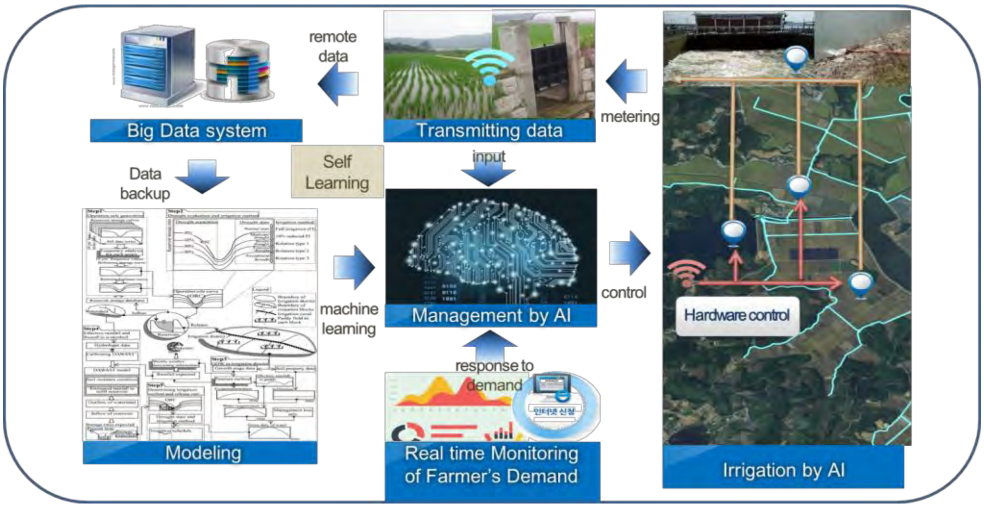

Figure 5. Intelligent irrigation system with machine learning technology analyzing farmer's irrigation practice.

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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PRACTICAL EVALUATION OF ICT SMART AUTOMATED SLUICE GATE FOR PADDY FIELDS FROM THE ASPECT OF AN ADDITIONAL FUNCTION OF PONDING WATER TEMPERATURE CONTROL

Masaomi Kimura[1], Wenpeng Xie[1], Katsunori Shimomura[2], Takeshi Tsuji[3,4] and Kiichiro Katsumata[5]

ABSTRACT

Enhancing the productivity of paddy rice per labor cost of farmers is crucial for a future that is expected to encounter several problems, such as the aging of farmers and decreasing number of successors. As some statistical analyses have indicated, labor associated with daily water management, such as opening/shutting inlet/outlet gates of paddy fields for irrigation and drainage, accounts for the major proportion of the total labor time for cultivating paddy rice.

In recent years, technical innovation in the discipline of water management in paddy fields has shown steady progress, thereby enabling the reduction of labor associated with daily water management. ICT smart automated sluice gates for paddy fields is one of the solutions that enable remote control of inlet and/or outlet gates of paddy fields as well as automatic scheduling of irrigation and drainage. While it may be easy to understand the usefulness and effectiveness of such automated gates for reducing labor costs, these gates may bring in an additional advantage by enabling the control of ponding water temperature in paddy fields. The damage to rice grains due to high temperatures is one of the major concerns in Japan. Thus, being able to control the water temperature in paddy fields would be beneficial to several paddy rice farmers who want to avoid excessive increase in the water temperature, especially during extremely hot summers.

We performed field experiments in two paddy plots in different regions in Japan, where ICT automated gates were installed at each inlet. In one of the experimental plots, an ICT automated gate was also installed at an outlet of the paddy fields. We will present the experimental findings, focusing on the spatio-temporal variation of the ponding water temperature and the effect of scheduled water management by utilizing ICT automated gates on decreasing the water temperature.

Keywords: Paddy ponding water, Adaption strategy, Climate change, Paditch Gate, Labor saving for paddy water management, Japan

1. INTRODUCTION

Recently, high temperature damage to the ripening rice grains has been a big concern in Japan. It reduces yield, produces inadequately felled grains, and causes cracking of rice grains and milky white kernel. In addition to reduced rice yield, the quality of rice is also degraded. These adverse effects were conspicuous in the extremely hot summer of 2010 when the first-class rice rate came down to 62%, which is ordinarily about 80% (Nakagawa, 2013). High temperature damage is thought to be mainly caused by high temperature on days after rice heading (Morita, 2008). The quality of cultivated rice

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grain is reduced due to high water temperature which may also lead to the value decrease of rice production. When the daily average temperature exceeds 28 degrees, the risk of high temperature damage increases extremely. From the analysis of variance and multiple regression analysis, 1 degree increase in daily minimum temperature during 10 to 30 days after heading reduced the ratio of first-class rice by 3.57%. Nowadays, some effective measures are proposed to prevent the damage, such as cultivar improvement, fertilizer management, delay of rice planting, paddy water management, and so on. Among them, the paddy water management is indeed one of the simplest ways for famers.

On the other hand, the future projections of Japanese rice farmers estimated by several institutes using various statistical data show that the Japanese rice farming faces complex and serious problems such as the aging of farmers and decreasing number of successors. Therefore, enhancing the productivity of paddy rice per labor cost of farmers is crucial for a future that is expected to encounter such kind of problems. As some statistical analyses have indicated, labor associated with daily water management, such as opening/shutting inlet/outlet gates of paddy fields for irrigation and drainage, accounts for the major proportion of the total labor time for cultivating paddy rice. In recent years, technical innovation in the discipline of water management in paddy fields has shown steady progress, thereby enabling the reduction of labor associated with daily water management. ICT smart automated sluice gates for paddy fields is one of the solutions that enable remote control of inlet and/or outlet gates of paddy fields as well as automatic scheduling of irrigation and drainage. While it may be easy to understand the usefulness and effectiveness of such automated gates for reducing labor costs, these gates may bring in an additional advantage by enabling the control of ponding water temperature in paddy fields. Considering the fact mentioned above that the damage to rice grains due to high temperatures is one of the major concerns in Japan, being able to control the water temperature in paddy fields would be beneficial to several paddy rice farmers who want to avoid excessive increase in the water temperature, especially during extremely hot summers.

In this study, field experiments were performed in two paddy plots in different regions in Japan, where ICT automated gates were installed at each inlet. In one of the experimental plots, an ICT automated gate was also installed at an outlet of the paddy fields. We will present the experimental findings, focusing on the spatio-temporal variation of the ponding water temperature and the effect of scheduled water management by utilizing ICT automated gates on decreasing the water temperature. In this paper, we will also focus on the description of the numerical models that can represent the mechanisms of water temperature variation in paddy ponding water by combining a heat balance model among air-rice plants-water-soil with 2-dimensional flow analysis models.

2. METHODS

2.1 Field experiments

Two observation paddy plots were selected from Toyama prefecture and Mie prefecture in Japan. Plot A is located at 36°39'16" N, 137°17'51" E in Toyama prefecture, and plot B is located at 34°46'20" N, 136°29'28.95" E in Mie prefecture. In plot A, an ICT automated gate (Paditch Gate, Enowa Co.,Ltd.) is installed at its inlet (**Figure 1**) so that the paddy farmer can control the gate and manage the irrigation to the paddy plot remotely at arbitrary timing. Plot A can access relatively cool and large amount of

Figure 1. Paditch Gate (ICT smart automated sluice gate) installed at plot A.

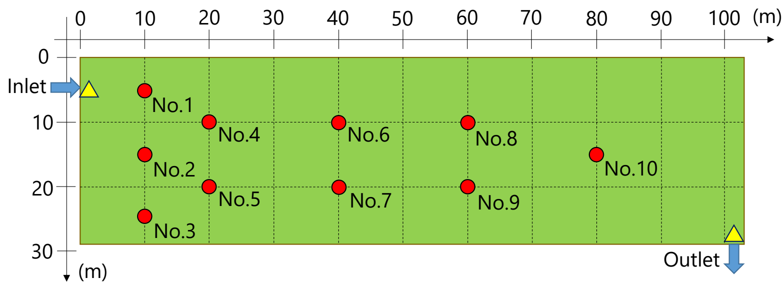

Figure 2. Observation points of water temperature and depth of ponding water in plot A.

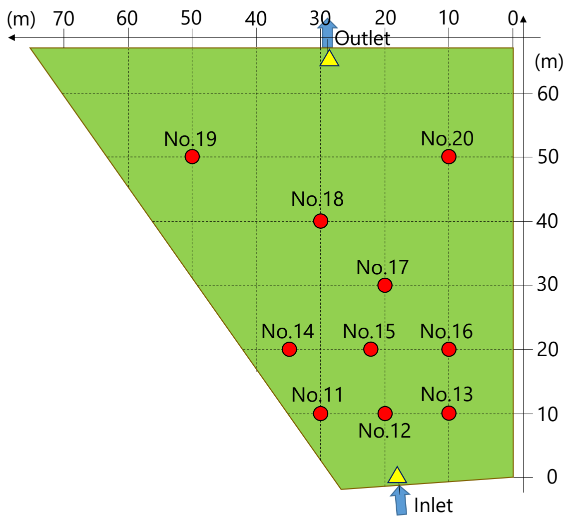

Figure 3. Observation points of water temperature and depth of ponding water in plot B.

irrigation water from its mountainous basin. Plot B has an ICT automated gate installed at its outlet as well its inlet so that both of irrigation and drainage management can be controlled remotely. In addition, the Paditch Gate also has the scheduled operation function which can be set thorough a web site. Since plot B is located downstream of branch irrigation channel and it is hard to access relatively cooler and larger amount of irrigation water, the daily operation schedule of ICT automated gates installed at plot B was set as follows; the Paditch Gate at inlet opens at 10:00 and closes at 18:00 and the gate at outlet opens at 15:00 and closes at 5:00. The above schedule was considered to be effective to suppress the water temperature increase since it is figured out by previous studies that the shallower the ponding water depth is at nighttime, lower the peak of water temperature becomes because of the lowered heat capacity of the ponding water.

In order to grasp the spatio-temporal variation of ponding water temperature in each plot, ten temperature loggers (HOBO MX2201, Onset) were deployed, respectively, the place where they were set is illustrated in **Figure 2** and **3**. An auto-capturing camera (TLC 200, Brinno) was also installed at inlets scoping the ICT automated gate to capture the situation around the gate every 30 min. as well as the temperature and depth loggers (HOBO U20, Onset) were installed at inlet and outlet as illustrated in **Figure 2** and **3**. Meteorological data (air temperature, relative humidity, atmospheric pressure, wind speed, solar radiation) during the observation term was also obtained by the weather station (ATMOS 41, Meter) installed adjacent to each plot.

2.2 Numerical models

In this section, the numerical algorithms will be described which were developed by the authors in order to simulate temperature distributions of paddy ponding water and evaluate the efficiency of decreasing ponding water temperature by utilizing the automated sluice gates. **Figure 4** shows the schematic diagram of the numerical models (layer model) which consist of three parts (rice leaves, water body, and underground soil) described below. This layer model referred to several previous related studies (e.g. Yoshida et al., 2013).

The basic equation for the heat balance of leaf surface is given as;

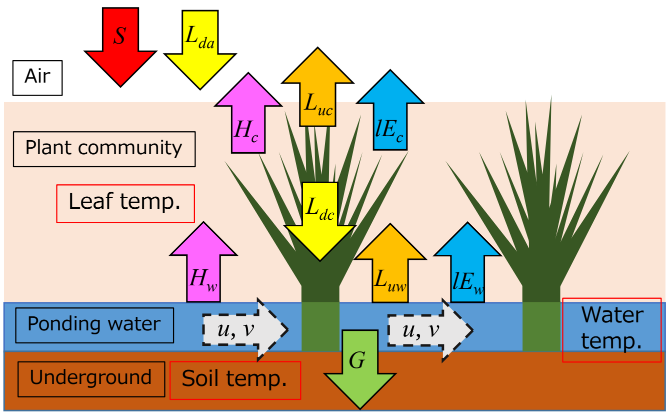

Figure 4. Schematic diagram of the numerical models for thermal energy exchange considering the flow velocity of ponding water in a paddy plot.

$$\frac{\partial T_c}{\partial t} = \frac{R_{nc} - H_c - lE_c}{c_c \rho_c l_c LAI} \tag{1}$$

where, T_c is plants community temperature, R_{nc} is net radiation to the vegetation layer, H and lE are sensible heat flux and latent heat flux, respectively. c_c is specific heat of leaves, ρ_c is leaf density, l_c is leaf thickness and LAI is leaf area index.

The net radiation R_{nc} can be expressed by following equation;

$$R_{nc} = (1-f_v)\{(1-\alpha_c)S + L_{da} + L_{uw} - L_{uc} - L_{dc}\} \tag{2}$$

where S is solar radiation, α_c is albedo of vegetation, L_{dc} and L_{da} are downward long wave radiation of plants and atmosphere, respectively. L_{uc} and L_{uw} are upward long wave radiation of plants and water, respectively. f_v is radiation transmittance of vegetation which is expressed by the following equation;

$$f_v = \exp(-k \cdot LAI) \tag{3}$$

where k corresponds to the degree of extinction. Subscription a, w, c means atmosphere, paddy water and vegetation, respectively.

The basic equation for the heat balance of water body is given as;

$$\frac{\partial T_w}{\partial t} + u\frac{\partial T_w}{\partial x} + v\frac{\partial T_w}{\partial y} = D_w\left(\frac{\partial^2 T_w}{\partial x^2} + \frac{\partial^2 T_w}{\partial y^2}\right) + \frac{R_{nw} - H_w - lE_w - G}{\rho_w c_w h} \tag{4}$$

where u and v are the components of x and y axis of flow velocity of ponding water, respectively, which are given by solving the shallow water equations considering the resistance of rice bunches represented by drag coefficients (Kimura et al., 2015). D_w is diffusion coefficient of water temperature, G is heat flux to the ground and h is water depth. The net radiation R_{nw} can be expressed by following equation;

$$R_{nw} = f_v\{(1-\alpha_w)(1-\alpha_c)S + L_{da}\} + (1-f_v)L_{dc} - L_{uw} \tag{5}$$

In order to calculate the soil heat flux G, the vertical soil temperature distribution is estimated by following equation.

$$\frac{\partial T_g}{\partial t} = D_g \frac{\partial^2 T_g}{\partial z^2} \tag{6}$$

where T_g is soil temperature, D_g is thermal conductivity of paddy soil and z is depth from the soil surface. In this study the upper boundary condition was set as water temperature and the lower boundary condition was set as the annual average air temperature of the observation field.

Form the soil temperature distribution, G was calculated by following equation.

$$G = c_g \rho_g \int_0^D \frac{\partial T_g}{\partial t} dz \tag{7}$$

3. RESULTS AND DISCUSSION

The discharge of water taken through the Paditch Gate at inlet of each plot was calculated by utilizing the equation of overflow discharge of weirs and the observed water level at upstream of the gate. The time series of calculated discharge and the observed water depth near the inlet and outlet at each plot are shown in **Figure 5** and **6**. The functions of the ICT automated gates in terms of the remote scheduled paddy water management were easily confirmed by the results. However, while the value of discharge was relatively high always when the gate was opening at plot A, the discharge of plot B showed almost none at several timings even when the inlet gate was opening. These phenomena were considered to be caused by the lack of irrigation water in the connected channel. Hence, it should be noted that the efficiency of deployment of the ICT automated gates strongly depends on the availability of irrigation water at the installed point, such as water pressure in pipelines or water level in open channels.

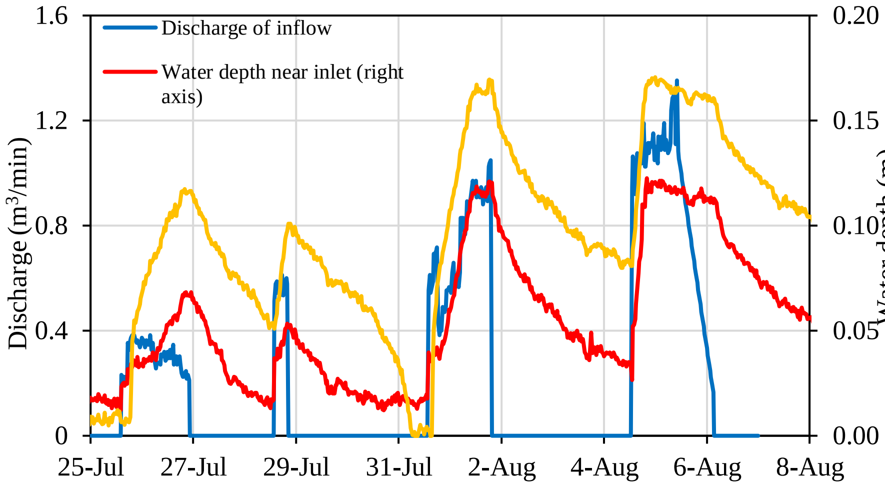

Figure 5. Discharge of inflow from the ICT automated gate and water depth near the inlet and outlet at plot A

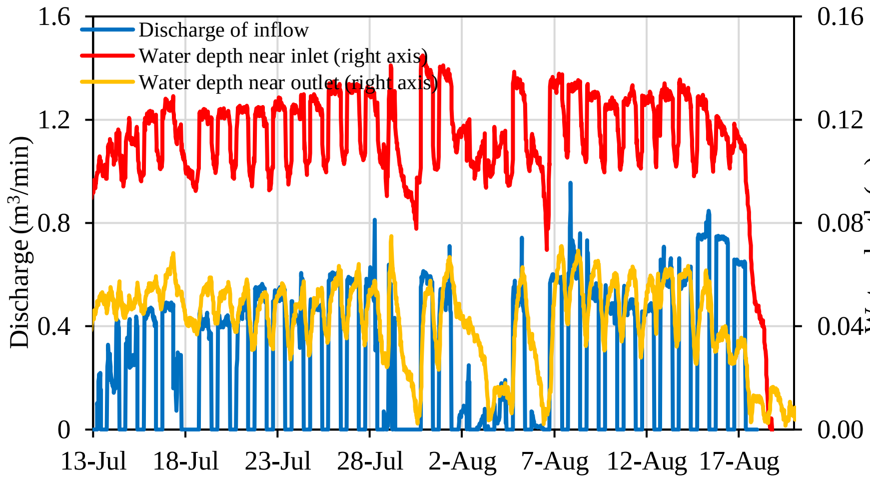

Figure 6. Discharge of inflow from the ICT automated gate and water depth near the inlet and outlet at plot B

The time series of water temperature obtained at ten points inside the paddy plot are illustrated in **Figure 7** and **8**. The water temperature variation showed a tendency that the closer it is to the inlet point of paddy fields, the cooler the ponding water was. Therefore, it is revealed that the water temperature near the inlet was easily lowered during the gate opening period compared to the other position. The magnitude of efficiency to suppress the water temperature rising seemed relatively higher in plot A compared to that in plot B, as the temperature of the available irrigation water to plot A was lower than plot B.

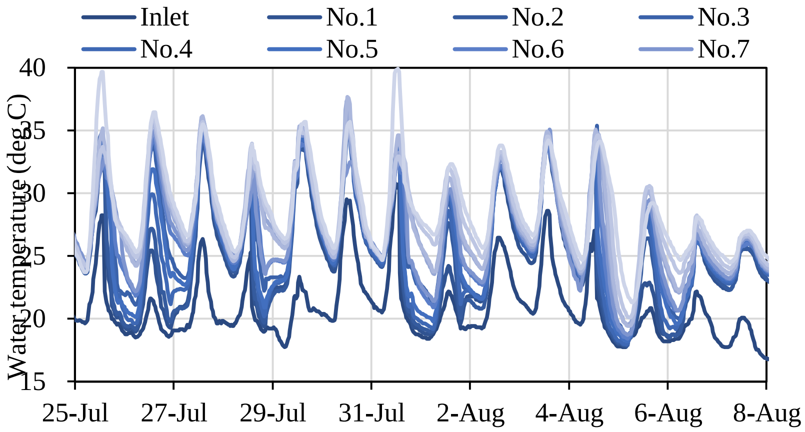

Figure 7. Time series of ponding water temperature distribution in paddy plot A

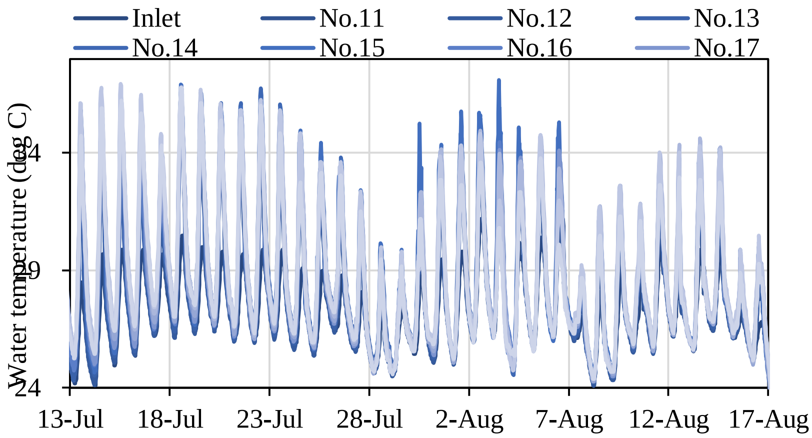

Figure 8. Time series of ponding water temperature distribution in paddy plot B

4. CONCLUSIONS

In this study, field experiments were performed in two paddy plots in different regions in Japan, where ICT automated gates were installed at each inlet in order to clarify the additional function of the gates in terms of ponding water temperature control. The observed results showed the firm reliability of remote scheduled ICT automated gate management. However, the efficiency of deployment of the ICT automated gates strongly depends on the availability of irrigation water at the installed point, such as water pressure in pipelines or water level in open channels. The observed variation of ponding water temperature suggested a possibility of temperature management in thermal environment in paddy plots which may contribute to deciding the adaption strategy against high temperature damage to rice grains by paddy water management controlled by the ICT automated sluice gates in future. Further quantitative analysis regarding the effect of scheduled paddy water management on decrease of the ponding water temperature rise is undergoing and the results and findings will be performed.

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INNOVATIVE INITIATIVES IN WATER STRESSED AREA BY EFFECTIVE MONITORING OF CANAL OPERATIONS

Riaz Muhammad[1], and Kamran Muhammad[2]

ABSTRACT

The Indus Basin Irrigation System (IBIS) of Pakistan ''by design'' delivers scarce water quantities at all hierarchies. Historical evidence shows that the widespread irrigation system was never designed on the irrigation principle of adequacy and reliability and was part of the British colonial irrigation era policy. Agriculture is the biggest consumer of water in the world, and therefore, in order to mitigate the consequently water scarcity, it is important to reduce irrigation water losses and to improve the poor collection of hydraulic status data. Irrigated agriculture is the major determinant of economic growth potential of the Punjab Province as it accounts for 26 percent of the GDP and caters for over 40 percent of the province's work force.

In order to improve equity and transparency in the system, a Programme Monitoring and Implementation Unit (PMIU) was established as a reform unit to implement efficient and optimal canal operations. The Unit has developed Irrigation Management Information System (IMIS) and Decision Support System (DSS) in order to improve the equity and transparency in the system. The Unit has also developed Irrigation web portal (*http://irrigation.punjab.gov.pk*) and various data collection & monitoring modules for timely communication /sharing of information among the stakeholders.

In this purview, PMIU has shifted conventional decision making to a new paradigm of closely knitted latest technology with engineering models and techniques. Water Resources Information Systems (WRMIS) has been developed for efficient water managments for the irrigation canal systems in the Punjab. WRMIS uses mobile and web technologies, integrated with spatial database, hydrological and hydraulic models for efficient system operation and maintenance. This forms the basis of a comprehensive Decision Support System (DSS) to present the systems key performance indicators (KPIs) both in the form of spatial maps and conventional tabular reports.

This paper describes the monitoing procedures/modules developed to improve the efficiency of canal operations. Performance Evaluation System (PES) has been framed by linking the IMIS and DSS to closely monitor the channel operation activities to improve equity, reliability and transparency in available canal supplies. WRMIS handles diversified system of data units, which is shared between multiple modules in a unified way. For instance, data entry of 'Daily Operation' is an input of Seasonal Planning module for necessary conversion into 10-day basis and thereby utilized for entitlements and deliveries. WRMIS not only handles real time operational model of irrigation system operations, but it also caters day to day business needs of the department such as tendering, schedules & inspection, closure operations etc. Introduction of Real Time Flow Monitoring Systems (RTFMS) also lead to better and real-time decision-making for improved and efficient management of water resources, and detect intentional or unintentional variations in water supplies.

After implementation of WRMIS, 24/7 online data has been availble for decision makers and this leads to fewer complaints as compared to earlier. The use of decision support systems linked with RTFMS presents a very effective method for irrigation water distribution, which may ultimately result into conservation of precious water. It is

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recommended that the DSS could be utilized in any irrigation system worldwide that practices surface irrigation techniques.

Keywords: Irrigated Agriculture, Irrigation Management Information System (IMIS), Decision Support System (DSS), WRMIS

1. INTRODUCTION

Pakistan being located in South Asia is an arid to semi-arid country and extends over an area of 796,000 km^2 with a great diversity in temperature and precipitation. The eastern areas of the southern half mainly receive precipitation through the southwest summer monsoon (from June to September), while the northern and western areas of the southern half of the country get rains mainly through western weather disturbances in winter (from December to March). The summer monsoon accounts for around 60% of the total annual precipitation. The climate varies from arid to semiarid where three-fourths of the country receive rainfall of less than 250 millimeters (mm) annually, except in the southern slopes of Himalaya and the submountain region in the northern segment of the country, where annual rainfall ranges from 760 mm to 2,000 mm (Qamar Uz Zaman, 2017).The northern region includes some of the world highest mountain peaks, such as K-2 (8,611 meters [m] high), and the largest glaciers including Siachen (70 kilometers [km] long) and Biafo (63 km) that feed the Indus River and some of its tributaries. During winter, the temperatures in this region drop to as low as –50°C and stays around 15°C in the warmest months of May to September (Wrold Commisiom on Dams, 2000).

Indus Basin Irrigation System (IBIS) is facing many water management challenges like poor irrigation infrastructure, low system efficiency and storage capacity, rapidly depleting aquafer, reducing water reservoirs capacity due to sedimentation, climate change vulnerability and transboundary issues etc (Bastiaanssen et al. 2002; Saeed et al. 2015; Yousaf et al. 2018). In Pakistan, approximately 22 million hectares are cultivated for agriculture out of total area of 80 million hectare. Pakistan is an agricultural country and depends on irrigation. With a prodigious Indus basin irrigation system, no one can overlook its usual and strategic importance. Over 90% of country's agriculture, which is a major chunk of GDP, is dependent on irrigation system. Unluckily, irrigation system of Pakistan is in hot waters. In developing countries, such as Pakistan, agriculture sector is growing (FAO 2003). The Indus Basin Irrigation System provides surface water for irrigation of croplands. Groundwater also plays an important role in meeting about 50% irrigation requirements of irrigated land (Qureshi et al. 2010).

Agriculture is the backbone of Pakistan's economy and major contributor to food security. It contributes about 20.9% (agricultural GDP) to Pakistan's national GDP and accounts for about 60% of foreign exchange earnings (Chandio et al. 2016). Over 18 million ha of land in Pakistan are irrigated from the Indus River and its tributaries. Therefore barrages in the Indus Basin are vital parts of Pakistan irrigation network for national GDP. The main purpose of the barrages is to divert water from the rivers into canals serving vast areas of irrigated land. Some of the newer barrages also divert water into link canals that join the main rivers of the Indus Basin, namely, the Indus, Jhelum, Chenab, Ravi and Sutlej. Many of the of the older barrages built 50 to 100 years ago in Punjab are in need of rehabilitation to take care of aging, design and construction defects, changes in hydrological conditions, and deferred maintenance. Some of them require urgent remedial measures to avoid severe economic and social impacts on the lives of millions of poor farm families through interruption of irrigation on millions of acres of irrigated land (World Bank 2004).

Punjab province is highly dependent on irrigation for agriculture. It is one hundred years since the irrigation system was established and the canals and watercourses for the irrigations systems have been decaying, which impedes the efficiency of allocation of water. To strengthen and improve the management and maintenance of the irrigation system: The project was started in March 2009 to enhance water use efficiency and on-farm productivity. The project applied the results of former JICA support and Japan's 60 years experience for the water user associations named "Land Improvement District" (LID) through the collaboration with JICA's Yen Loan Project "Punjab Irrigation System Improvement Project" (PISIP). The project aims to establish the model of appropriate irrigation management system through verification activities in the pilot areas which in turn contribute to the improvement of the management and maintenance of the irrigation system and increase water use efficiency and on-farm productivity (JICA 2008).

In Pakistan, Distribution of surface water between the distributaries and between the outlets is substantially inequitable which contributes to declining agricultural productivity (Bandaragoda et al. 1995). The estimated overall average irrigation efficiency ranges from 38.7 to 42.6%, which is quite low and is largely due to poor operation and maintenance of the irrigation infrastructure (Aslam 2016).

As a consequence of excessive load on current irrigation system, the sustainable irrigated agriculture is at threat. The main reason for such an increase in crop water requirement is the agricultural sector growth and its trend towards commercialization, due to which there is increase in cropping intensity, crop diversification and cultivation of high yielding crop varieties that ultimately demands more water (PIPIP, 2011)

2. POLICY

Challenges of food security

In Pakistan, lack of purchasing power and access rights to an adequate food supply by many of its poor people is the key reason for the country's low level of food security. Pakistan is a low-income developing country and agriculture is its most important sector due to its primary commitment of providing healthy food to her fast-growing population. A country unable to produce the needed food and has no resources or afford to buy food from the international market to meet demand-supply gap, is not food sovereign state [Pinstrup Andersen (2009)]. Food security is thus fundamental to national security, which is generally ignored [Fullbrook (2010)]. The extra-ordinary rise in food prices in later part of the first decade of 21st century raised an alarm bell on food security. The food security issue is coupled with the water availability and scarcity challenges. Rapid growth in population has placed the pressure on nature resources.

Challenges of water security

According to the UN report, Pakistan is going to be a water scarce country. Average canal-water supplies to the Indus Basin canal commands are around 104 MAF. Out of this, around 38 MAF are available during the Rabi-season. The shortage of water during the current Rabi- season (2018-19) would be over 32%, this shortage of water not only affected the Rabi-season crops but would also affect the plantation of other crop, especially in the Southern punjab. In addition to water scarcity, there are other major problems facing the subsector: inefficient management of the surface water system (that is, low delivery efficiency and inequitable distribution, and supply based delivery of water); waterlogging and salinity; over exploitation of groundwater in fresh areas; inadequate operation and maintenance (O&M); and insufficient cost recovery (Pakistan Irrigation and Drainage: Issues and Options 1994). Similary Kahlow and Majeed 2002 described the key issues related to water availability as following.

(a) Reduction in capacity of storage reservoirs due to sedimentation
(b) Increase in domestic and industrial demands and consequent reduction in supplies for irrigation
(c) Poor delivery-efficiency in irrigation and municipal water supply systems, and Deterioration of water-quality due to disposal of untreated urban sewage and/or agricultural drainage effluent

(d) Depleting groundwater tables, due to over exploitation

The reduction of water availability for agriculture sector due to high demand of water in other competitive uses could be managed by increasing water use efficiency in crop production (Razzaq et al. 2018)

How irrigation water allocation system are being effected

Vast stretches of land are lost due to salinity and waterlogging in Punjab, making it one of the greatest impediments to increased crop production and achieving food security. Flooding is the most common irrigation method practiced by the farmers and its efficiency is not more than 50 percent. Such low irrigation efficiencies at farm level are major constraints in attaining potential production from otherwise highly productive agricultural lands. In addition, more than 40 percent of canal water is lost between mogha / outlet and farmers' fields due to poor condition of tertiary conveyance system (watercourses). The crop water requirements are not met timely because of supply based irrigation water delivery, which negatively affects the overall agricultural production. The absence of proper drainage system chokes the Indus Basin's massive irrigation structure through waterlogging and salinity. Similarly the main cause of the problems in irrigation system is that it manages water based on available supply not demand based supply. Irrigation system was designed on 67% cropping intensity but currently it has risen up to 150- 200% which means more water demand for agriculture sector. Punjab Irrigation Department has also shifted to equitable supply rather crop based supply. Since Girdawari is stopped in 2003 by Irrigation Department, changes in cropping pattern are not considered while demanding the cropp water requirements. The field staff doesn't uses scientific approach for indent calculation, rather places their indent from tail-end to head works by using conventional approach i.e. by considering major crops demand, weather conditions, canal condition and design discharge.

What strategies are being adopted

At present, matching year approach is used for forecasting at rim stations. In this method historical flow data is used and sometime Punjab Irrigation Department faces issues to find the matching year in order to find the probabilities (e.g. in case of Mangla Kharif, 2018 forecast). In this method climate factor is not considered and this method may lead to less precision of forecasting in snow and glacier dominated watershed. Canal losses and river reach losses are considered conventionaly/ empirically. Similarly conventional procedures adopted in the field to calculate irrigation demand and monitoring of irrigation supplies which consume massive resources and workforce. To overcome the the issues, PMIU has developed Snow runoff model for forecasting Crop Water Requirement Model for cropwater deficit at main canal command area and Hydraulic Model to findout losses in main canal and branch canal and network operational model for river reach losses and RTFMS for 24/7 monitoring.

How increasing more crop per drop challenges is being proposed to be met

Groundwater quality, crop phenology, rainfall forecast also need to be considered while calculating the water requirements, because area deprived of irrigable groundwater and lesser rainfall is more dependent on irrigation water than other areas. Inadequate operation & maintenance of irrigation infrastructure also becomes hurdle in many cases to place required indent. Similarly, L-sections need to be updated and conveyance losses need to be calculated accurately. Lack of understanding of modern tools and technologies in field staff requires capacity building as well. To summarize, under such a situation there is a need to characterize the complete Punjab irrigation system through model simulations using latest technology. The reservoirs, barrages/headworks, link canals and main canals needs to be incorporated by considering all the constraints and complexities of the system.

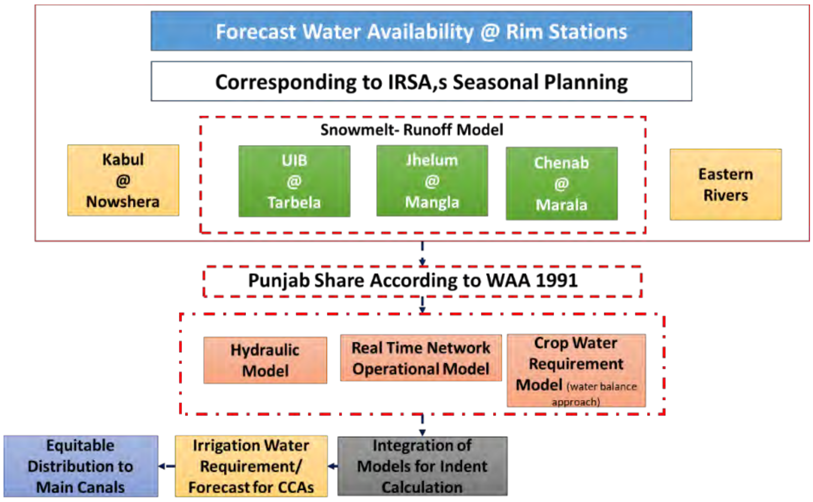

Figure 1: Schematic Diagram of Models Integration

There is a requirement of integration of real time forecast crop water deficit model, SRM hydrological model and river basin modelling, as shown in the figure 1, which is capable enough for operational management of surface water for equitable distribution to main canal. The conveyance losses and gains in the system and crop water requirements needs to be estimated which contribute towards the overall water balance of the system.

3. APPROACH TO MODERNIZATION

3.1 Project Description

The complete project consists of four major components. Component A is designed to specifically address the problems of Jinnah Barrage (Rehablitation of Jinnah Barrage), while component B is aimed at building capacity and modernizing the water resources and irrigation management in Punjab and prepare future investment project in the province. Component C is for proper monitoring of project implementation, supervision of the Evaluation and Monitoring Consultants and implementation and project impact. Component-D is related to supporting project implementation technical assistance and training.

Decision Support System (DSS) integration of two major componants. 1) Real time Flow Monitoring System (RTFMS). 2) Water Resource Information System (WRMIS). PMIU was assigned to excute a part of World Bank Funded Project tittled "**Improvement and Modernization of the Irrigation and Water Management System**".

PMIU is the primary entity for the implementation of the B1.1 component of the project. PMO Barrages provided support to PMIU in carrying out the procurement and financial management and M/S NESPAK provided the consultancy for WRMIS project while M/S MM Pakistan (Pvt.) Ltd and ISTec C-Digital (JV) play the consultancy and contractor role for RTFMS component . The detail of the project components is given as following.

Component B: Improvement and modernization of the irrigation and water management system (US$15 Million).

This component comprises: B1 Improvements in irrigation and water management systems, and B2 Preparation of future irrigation and water distribution improvement projects. B1 is further divided into B1.1 Management of information system, monitoring and decision support system and B 1.2 Modernization of water management equipment and facilities.

Component B1: Improvements in Irrigation and Water Management (US$9 Million).

Component B1 project awarded to M/S NESPAK through World Bank funding. The purpose of this component is to advance the improvements in irrigation and water management initiated by the Program Monitoring and Implementation Unit (PMIU) and to provide equipment and facilities to modernize further irrigation and water management planning. It includes further upgrading and modernization of the PMIU systems. This includes the development and use of modern databases; GIS Systems; models; decision support systems; and management information systems for improving planning and operation of the complex irrigation system of Punjab. This is also include forecasting; planning; and operational tools for seasonal and 10-day (as needed) planning forecasts; and demand management systems with client interfaces. These tools aid irrigation planning and link with the reservoir operation decisions of the Indus System River Authority (IRSA). A system (RTFMS) under the project componetnt B1-2 of water measurements, accounting and transmission have been introduced at key locations in the river and link canal system and the main and branch canals. A data communication network is installed to gather information to be sent to central locations and the IPD headquarters. The database and management information system has been upgraded to collect, store and disseminate flow data and other relevant information to help system wide water management. Modem controll management rooms for operation and management of the provincial canal system also be established. The cost of the project is given in the following table.

Table 1: Project cost by component and expenditure category

Project cost by componant and expenditure category (US $ Million)							
Component	Description	Works	Goods	Consultancy Services	Increment operating	Training	Total
B.	Improvemetn and moderenzation of the Irrigation and water Management System						
B1	B1.1 Management Information, Monitoring and Decesion Support System	0.0	1.5	3.0	0.4	0.1	5.0
	B1.2 Modernization of water managent , equipment and facilities	0.0	3.5	1.1	0.3	0.1	5.0
B2	Preparation of future water and irrigation projects	0.0	-	3.5	1.0	0.5	5.0
Sub Total -B		0.0	5.0	7.6	1.7	0.7	15.0

Table 2: Project Cost by Component and Year

Project Cost by Component and Year (US$ million)						
Component	Year-1	Year-2	Year-3	Year-4	Year-5	Total
Improvement and moderenzation of the Irrigation and water management system	-	2.816	3.506	6.574	2.104	15

Project Information

Punjab Irrigation System is being succesfully operated by all the experience profesionals through their experience and good understanding of the system. All the issues to the system were known to the operators either through their personal experience or reported by the various canal divisions. Operation of the system involves planning of the available water resources and transfering the cheap and good quality water resources to the irrigation fields in view of cropwater requirements corresponding to various stages of crop growths. The task of the operators are not much simple as can described in simple word. Challenges are high as the system demands are much higher than the available share of surface supplies. Due to lesser storage in the reservior (about 10% of total system inflows -14 MAF against 140 MAF) to transfer river flows from one season to another is another challenge to the irrigation water management. .Furthure more due to inflow in the river which leads to the shortage in water is also big challenge for the irrigation management which are erratic in nature and difficult to predict in the absense of scientific tool for reliable forecast and monitoring of canal system which was not available with the Irrigation Department.

Therefore, Punjab Irrigation Department has been assigned to execute a part of World Bank Funded Project of cost Rs. 930 Million tittled **" Improvement and Modernization of the Irrigation and Water Management System" under the components B-1.** This project provides for the development of three integrated systems viz. Water Resource Management Information System (WRIMS), Decision Support System (DSS) and Real Time Flow Monitoring System (RTFMS). The former two systems would have been develop and allow Irrigation Department to develop hydrological model for forecasting water availability during a cropping season, calculating crop water requirement, mapping fluctuation of Ground Water table and hydraulic modeling of all Main and Branch Canals. Further in B-2 component, the Real Time Flow Monitoring System (RTFMS) is being installed on pilot basis (ESC and all barrages) at various location will allow real time measurement of flows in the canals at critical points to take timely decisions and digitalization of water management system to ensure equity and transparency in canal water allocation and distribution, Figure 2 . Further, the DSS has been linked to Management Information System (MIS) developed for handling large data set, and provide facility to DSS for storage and retrieval of canal and river data, required for models.

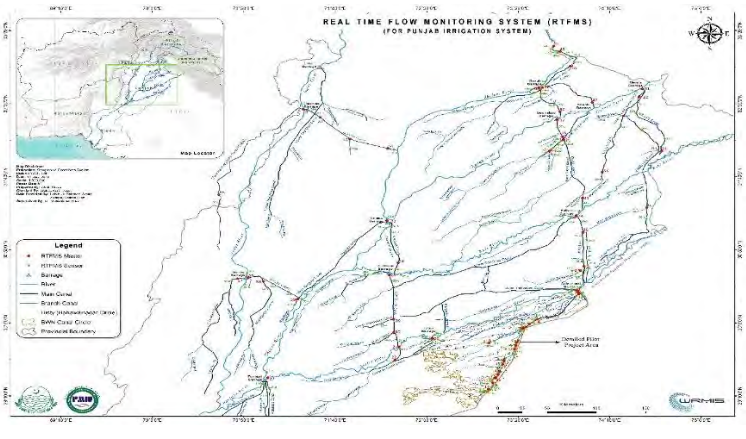

Figure 2. Real Time Flow Monitoring System (RTFMS) Installed at Project Area (Eastern Sadiqia Canal)

The complete application would be Water Resources Management Information System (WRMIS) which are facilitating the decesion makers in making informed decesion regarding water availability and system responce against various management scenarion.

Figure 3: High-Level Concept Diagram of WRMIS-DSS

Figure-3 represents the high level concept of WRMS-DSS project. The overall objective of this is to develop, interactive, graphical; web based Water Resource Management Information System (WRMIS) along with Decesion Support System. The system includes the development and use of modern database; Geographic Information System (GIS); hydraulic models of main canals; Decision Support System (DSS); and Management Information System (MIS) for improving planning and operation of the complex irrigation system of Punjab. This also includes forecasting; planning; and operationaltools for seasonal and 10-day (as needed) planning forecasts and demand management systems.The hydraulic models of the main canals will be linked up with the Real Time Flow Monitoring System (RTFMS). These tools are very helpful in irrigation planning and link with the reservoir operation decisions of the Indus River System Authority (IRSA).

The system comprised of the following sub-components,

(a) Modern Database (Task-A)

(b) GIS System (Task-A & D)

(c) Decision Support System (Tasks B, C and E)

(d) Management Information System (Task-A)

The Project scope was divided further into two broad divisions and five tasks. The divisions are as follows:

(a) Hydrological and Hydraulic Modelling which form the basis of Decision Support System (DSS) and,

(b) Software Development which translate/integrate the modelling tools in the form of application and the interface of application to support input/output of the DSS in graphical and tabular forms. The application further be required to provide linkage with other departments for fetching of data/dessiminating the results. Scope of services included the following tasks,

Task-A: Review / upgrading of Water Resources Management Information System (WRMIS) and integration with Decision Support System (DSS).

Task-B: Hydrological Modelling for Forecast of Water Availability and Determination of Punjab's Share.

Task-C: Development of a Real-Time Operations Model.

Task-D: Determination and Mapping of Water Table Fluctuations.

Task-E : Development of Hydraulic Models of all Main and Branch Canals of Punjab Irrigation System.

Implementation of modernization proposal

Task-A of the WRMIS application development process starts with the 'Data Collection' and 'Review of Existing System'. Initial acquisition of existing IMIS application, database and its comprehensive review highlighted the requirements for the developed WRMIS system which GIS, as being one of the presentation layers of the project, requires design and components of the WRMIS as a pre-requisite. Therefore, all GIS sections have been placed after MIS application development.

Geo-spatial Database Development; highlights the GIS data collection and development activities that has been carried out during the project. It primarily covers development of irrigation network layer with upstream/downstream tracing feature. **Near Real Time Crop Water Requirements (CWR);** this section illustrates the use of Remote Sensing (RS) technology to figure out crop type and water deficiency. **Web GIS Application;** highlights the process of development of browser-based GIS application. Various spatial analysis tools that present the system's Key Performance Indicators (KPIs) have been explained in detail with special significance to the water management practices of the Punjab Irrigation Department. Based on these performance indicators, the Performance Evaluation of Canal Operators have been prepared through PES module on fortnightly basis. This is being helpful in creating the competition environment among the canal operators resulting improvement in performance of field staff. On the basis this PES, Administrative Department are issuing appreciation letters to the top 5-ranked canal operators and similarly, displeasures are also issued to the bottom 5-ranked canal operators.

Indus River System Authority (IRSA), as the regulator of Pakistan water resources, is responsible for distribution of surface water share to provincial irrigation departments at canal head according to surface water shares defined in the Water Apportionment Accord (WAA) of 1991. For this purpose, IRSA plans the surface water distribution in advance of seasons and distribute in real time as per plan water allocations by adjusting the shares as per actual water availability in the reservoirs. All the informations have beem incorporated related to IRSA's planning procedures in the WRMIS application. IRSA has been maintaining various excel worksheets to carry out their primary seasonal planning function. Review of various historical worksheets revealed that the all procedures are although performed on worksheets but all the inputs and outputs are manually prepared. This requires a lot of effort by the user as well as a good acquaintance to the Indus Basin River System which is required before using these sheets to perform the seasonal planning. Automating the manual or semi manual existing systems was rather a complex task as this required an automated system which should incorporate all possible scenarios involved in reservoir operation, system losses, canal releases and system outflows.

Futhuremore, Real Time Operational Model (Task C) has been developed and the primary purpose is to develop an operation model for water distribution along main canals of the Punjab Irrigation System (PIS) keeping in view the objectives of i) maintaining an equitable distribution as per canal entitlements and, ii) maximizing water utility by meeting agricultural water demands and system indents.

Development of groundwater fluctuation maps have been included in Task-D of the subject project. The purpose of this task is to developed GIS based interpolated surfaces of Depth to Water Table (DWT) maps as well as GW quality maps.

In the hydraulic models for complete Eastern Sadiqia Canal System and main & branch canals of rest of the Punjab have been developed in this WRMIS project under Task E.

Considering specified objectives of the modeling activity, i.e., fair distribution of water and suggestions for canal operations under different water supply maintenance scenarios, it has been ascertained that all required objectives can be addressed through development of 1-D unsteady hydraulic models so that any violation in defined operating instructions can be identified through use of canal models. Besides development of hydraulic models, also others tools and procedures have been developed in water distributions along irrigation canals that computes and highlights various performance indicators including; Relative Delivery Performance Ratio (DPR) and GINI Coefficients.

Real Time Flow Monitoring System (RTFMS) comprises 60 RTFMS stations which include 139 data collection points on irrigation network comprises 89 Ultrasonic Sensors and 50 Radar Sensors. The system was installed on pilot basis. The scope of RTFMS is to collect data automatically without any human interventions which are providing real time measurement of flows in canals at critical points, converting to canal discharges and its real time communication to the central database deployed at Irrigation Secretariat. This state of the art system enables the department to ensure equity and transparency in canal water distribution. It also facilities the process of making rational decisions with the help of informed data on regulation, vis-à-vis entitlement and deliveries resulting control on water theft resulting from violation of rotational program. This is the step forward in digitalization and automation of irrigation network flow data which is paramount for effective utilization of water. The following quantifiable targets has been made through RTFMS.

(a) To ensure transparency and equity in canal operation.

(b) Control on water theft via monitoring of rotational program.

(c) Monitoring of canal operations for 24/7.

(d) Automation of real time flow data.

(e) Resolution of conflicts between Service providers (PID Staff) and consumers (Farmers)

(f) Measurement of flows in real time and hydrological statistical analysis of the data for future forecasting and losses estimation.

Figure 4: RTFM Sensors installed at Eastern Sadiqia & Fordwah Head at Suleimanki Barrage and at Jalwala Head

Moreover, 10 Nos. Conductivity, Temperature and Depth (CTD) Groundwater (GW) sensors were installed at pilot area (ESC) of the project which enables the department to collect three parameters of the GW including conductivity, Temp. and depth to water table on real time basis with preset interval. The data from these sensors is directly received via GPRS technology in database servers without any human interventions. [Figure-5&6]

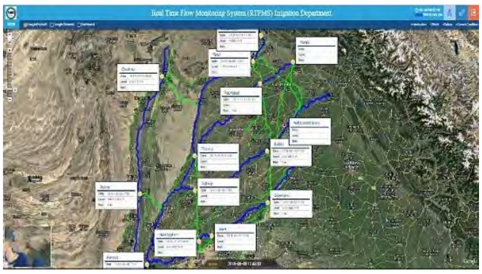

Figure-5: RTFMS website screenshot

Figure-6: CTD sensor installed at Jalwala head (ESC Tail)

Lessons learnt including benefits from modernization

In this project, Water Resource Information Management System (WRIMS), Decision Support System (DSS) and Real Time Flow Monitoring System (RTFMS) have been developed. In WRMIS, Smart Monitoring modules has been developed for the efficient & optimal canal operations oriented towards equity and transparency for enhancing and upgrading the existing data transmission system by using Android Smart Phones with GPRS technology. Initialy the field operators refused to takeover and use this module as they hesitate to provide location based data reporting. To overcome this dificulties, the same module has been provided to the PMIU field staff in order review the benefits of this module for transparent collection of flow data. On the basis of these results, a comprehensive demostration /training was planned to provides training / demonstration to the field staff for their capacity buildings. Now some divisions used Android Smart Phones for canal operations which gives fruitful result in view of transparent canal operation data. This is also being helpful for finalizing the enquires against the canal operators who indulge in water theft. Similarly, Hydrological model (SRM+G), Hydraulic model real time cropwater requirement model were also develped under WRMIS component. In Hydrological model it was difficult to find the groundstation data (rainfall , temperature, snow cover, glacier) in the up stream of the catchment of each rim station. To overcome this issue, different remote sensing satellite data products have been used and statistical checks have been performed with available ground station by reducing significant bias and random error. The outcomes of this module is using for forecast at rim station since 2017 gives better forecast results as compared to statistical matching year approach. In hydraulics model, it was also difficult to conduct survey for actual cross section for the modelling purpose. To overcome this difficulties, L-section is used for modeling purpose which is based on design bed level. In this way to replicate the actual field scenarios, the modeler should know the canal regime using rating discharge table and incorporate this in the modeling. The output of this model for better canl operation and estimate actual losses and useful for evaulation of rotational plan. Real Time Crop Water Requirement model was also develped for estimation of cropwater need. Initially, this module was develped to find the deficit for the crops of canal command area. Now this module is expanded by the GIS team for water budget (consumption, need and supply).

Out of these three systems, Real Time Flow Monitoring System (RTFMS) is being installed on pilot basis at 139 different locations which will allow real time communication of flow data at head and at critical points to take timely decisions. In this regard, the contract for RTFMsystem procurement, installation and implementation was awarded to ISTec C-Digital (JV). Following are the short-comings/ lesson learnt for the above mentioned Project.

(a) Initially, it was decided to install RTFM system at all main canals, off-taking points of distributaries/ minors. The estimated number for all these points was 1548 but to test the working of system, it was decided to install RTFM system at Eastern Sadiqia Canal as Pilot Project with 14 Barrages (Upstream & Down stream) main canals, link canals offtaking from barrages, tailrace of Mangla Power house, UJC, Bong Escape and LCC Feeder off taking from QB Link Canal.

(b) Field survey was carried out to check feasibility of installation of RTFM system at 139 points all over Punjab. The most important requirement for RTFM system installation included telecommunication coverage to all sites. There was no single telecom operator in Pakistan that covered all selected sites in Punjab. Hence, two different networks were selected but still there were a few points that had mild/no coverage. Therefore, signal boosters were installed to ensure data communication to server installed at Head Office, Irrigation Secretariat Lahore.

(c) RTFM system is built on very sophisticated technology. The technology used by sensors and data logger was not available in Pakistan. Hence, the technology was imported from ISTEC, who design and manufacturer in-house in South Korea. But the drawback of this out-sourced designed & manufactured item is that the department may not be able replace the sensors or cards of data loggers from local market 10 or 20 years down the lane when system needs upgradation or replacement at expiration. It makes one company sole-proprietor of the installed technology which is not very safe lane to choose.

(d) The software of data logger that stores data and transmits it to central server is intellectual property of ISTec which is not shared with department due to copy rights issues. It is also a biggest draw back because once a system is purchased, it must be handed over both front-end and back-end engineering so that R&D department may take the source codes and do research on it to make system better and more customizable for its users.

(e) Finally, this technology may work for 10 or 15 years but without any daily basis trouble shooting team and R&D team for debugging the codes and simultaneously removing bugs, it may not be able to work smoothly for even next 05 years.

(f) The output of the WRMIS-DSS development is to upgrade the existing IMIS and Public Website of Irrigation Department to develop Water Resources Management Information System (WRMIS) by utilizing.

(g) Modern Database: Re-designing of existing and proposed data models for efficient storage and retrieval of data for various functional requirements.

(h) Modern Web-Application: Redesigning of existing IMIS system by incorporating additional functionalities to automate the business process

(i) Android Application to record the data and observations at field level

(j) Reports through SQL Server Reporting Services: A comprehensive way of extracting information from the database.

(k) Revamped Public Website: Re-designed Public Website having integration with WRMIS application.

The outcomes of the RTFMS are the water levels and discharges of main canals (Head) and Link Canals (Head & Tail) and also for one complete Eastern Sadiqia Canal System, Branch Canal, Distributaries/Minors water levels and discharges is monitored on 24/7 at 10-15 minutes time step which is very useful for the water manager for timely decisions in irrigation management. Additionally, water levels of barrages at Up Stream (U/S) and Down Stream (D/S) is monitored on 24/7. Moreover, the benefits of RTFM System is without human interruption so any change inflow of water in distributaries/ canals is immediately automatically reported to Head office. Accordingly, water theft at main canal level can be minimized through monitoring of violation of Rotational Program on 24/7.

Summary and Conclusions

DSS is developed to help water resource management decision makers address water resources management problems. DSS-WRMIS has been developed as a user authenticated application consisting of Web and Android applications and modelling. This emphasizes the impacts of human activities on water resource management, which includes crop water requirements, hydraulic structure and multi-level water authorities. Accordingly, the DSS is effective for water allocation in agricultural regions.

In addition to that the revamped of existing application is the good step by analysing the whole application in detail and using the modernized techniques of storing data in database, used workflow for assignment, automatic notifications and modern reporting.

The modules which are in the scope of WRMIS-DSS are:

(a) Projects / Works

(b) Accounts

(c) Assets Management

(d) Mobile Application

(e) Smart Monitoring

The list of existing modules for which functionalities were improved:

(a) Daily Operational Data (Web & Android)

(b) Water Theft (Web & Android)

(c) Schedule & Inspections (Web & Android)

(d) Tenders Monitoring (Web & Android)

(e) Water Losses

(f) Flood Operations (Web & Android)

(g) Closure Operations (Web & Android)

(h) Performance Evaluation

(i) Canal Operations Reports

(j) Rotational Programs

(k) Entitlements & Deliveries

(l) Content Management of Public Website.

Some modules are added to support the administration and configuration of the application.

(a) Irrigation Network

(b) User Administration

New modules which are added as follows:

(a) Auctions

(b) Effluent & Canal Water Charges

(c) Small Dams

(d) Flood Bund Gauges Data

(e) Flood Early Warning System (FEWS)

(f) Seasonal Planning & Snow Run-off Modeling

Major features/functionalities that are aimed in WRMIS-DSS application are:

(a) Modules are fully integrated.

(b) flow information has been automated and a workflow has been captured.

(c) Standardization of data throughout the application

(d) Administration of Users, defining access rights for every user.

(e) Implementation of notifications.

(f) Input information and proper search functionalities for retrieval.

(g) Android Application Interface where applicable.

All the above modules have been develped under the WRMIS-DSS component. The development of Decision Support System (DSS) incorporating the intelligence of existing canal operators supported by scientific tools including flow forecasting tools, simulation models for rivers and canals; facilitating the operator in equitable management of precious irrigation flows throughout the system. The development of hydrological and hydraulic models to develop water ability at rim stations using remote sensing settlite data for Decision Support System (DSS) . Further, the DSS has been linked to management information system for handling large data sets, and provide facility to DSS for storage and retrieval of canal and river data, required by the models. The Water Resources Management Information System (WRMIS), developed under the present project has various modelling components to facilitate the decision makers in making informed timely decisions regarding water availability and system response against various management scenarios.

This RTFMS component has provided technical assistance to the canal operators; vize-e-viz training and equipment including hardware and software; latest discharge measurement equipment; echo-sounders with geo-positioning system for taking cross-sections of the rivers and canals; and modem equipment for measuring flow velocities etc. Moreover, after the successful completion of this project, this department intends to install RTFM sensors at all other locations of Punjab Irrigation Networks having more than 1500 sites provided that the funds are available. In this regard, the department is preparing a strategy to include the cost sensors both for surface and GW in the furture coming projects in order to sustain the monitoring mechanisim through this state-of-art technology.

In the future, all the modules will be integrated and will be used for Water-use efficiency and the Sustainable Development Goals approach using remote sensing technique. For this purpose, it is recommended to encourage stakeholder in irrigation system to use water stress indicators. The spatial variability of soil moisture contents and crop water stress determined from point measurements leads to uncertainty in the calculation of the crop water requirements and irrigation scheduling. In this regard, forecast rainfall and irrigation supply play an important role. Remote sensing techniques are useful in detecting soil moisture and crop water stress over larger areas and thus are accurate in calculating the evapo-transpiration and crop water requirements at a regional scale. Further research and application should be encouraged in this direction.

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RE-VISITING THE RAP EVALUATION FOR IRRIGATION MODERNIZATION: CONCEPT AND APPLICATION FOR SMALL-SCALE IRRIGATION

Maher Salman[1], and Eva Pek[2]

ABSTRACT

Implication of irrigation development needs systematic assessment to close the gap between the conceptual frameworks and the pragmatic approaches in order to make investments fully functional. Re-visiting the Rapid Appraisal Procedure RAP) for assessing irrigation performance has been conducted, breaking through the asymmetries of small-scale irrigation schemes (SSI), while developing a methodology to assist stakeholders engaged in all aspects of modernizing irrigation systems. The new RAP evaluation was conducted in five pilot schemes in Central-Asia and Africa. The irrigation schemes are analyzed through multi-layer management, each layer provides water service to the lower level. Through RAP, cause-effect relationships were set amongst the aspects of irrigation management, and conclusions on irrigation performance were drawn from the results. Amongst the main findings, the RAP exercise underpinned the importance of water-related data acquisition and the need of strong institutions grounded in data-driven improvement. Instead of traditional analysis, social (PIM) and institutional management together must be considered. The case studies prove that farmers' contribution is at the core of irrigation management, and the relatively good performance of a scheme at headworks can be completely undermined at farmer-operated levels. The common phenomenon occurred in every scheme that O&M works still share a negligible amount of the budget and some schemes almost reached the complete deterioration due to weak institutions. Although the Central-Asian schemes introduce instruments to adjust water supply to water demand, the theory has not been fully put into practice yet. Irrigation scheduling is limited to fixed rotations in every case. The little-explored possibilities in more flexible water services is translated into within-system inequity and farmers who are affected by inefficiencies at conveyance level are continuously exposed to the upstream events.

Keywords: Small-Scale Irrigation, RAP, MASSCOTE, Irrigation Performance Assessment, Water Use Efficiency, Irrigation Modernization, Developing Countries

1. INTRODUCTION

The age-old preposition that agriculture is the engine of growth in the overall economic well-being and non-agricultural sectors still holds in an increasingly globalized world (Pingali, 2006). Most countries aspire to increasing economic growth through agriculture, thus making it the most important driver in freshwater exploitation (Nechifor & Winning, 2018). Despite their role in agricultural growth and the received huge investment, several irrigation projects and schemes are underperforming in delivering reliable irrigation services (Elshaikh, et al., 2018). Technical and management design to reduce the inefficiencies in irrigation systems – as it relates to the flexibility, reliability and equity of the services – needs careful review (Burton & Malano, 2001). Elaborating the appropriate design and management is particularly difficult at small-scale irrigation

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(SSI), which generally present high degree of heterogeneity and disparity among the farmers and are less resourced to increase efficiency (Kamara, et al., 2001). Implication of the irrigation development – almost certainly essential to combat food insecurity and poverty – needs systematic assessment to close the gap between the conceptual frameworks for implementing the projects and the pragmatic approaches to make investments fully operational in predominantly SSI schemes (Hussain & Hanjra, 2004; Siddiqi, et al., 2018). Rapid Appraisal Procedure (RAP) as the first step of the Mapping System and Services for Canal Operation Techniques (MASSCOTE), developed by the Food and Agriculture Organization of the United Nations (FAO), consists in a comprehensive set of determined indicators to establish a diagnosis and performance assessment of the irrigation system (FAO, 2007). Re-visiting the Rapid Appraisal Procedure RAP) for assessing irrigation performance has been conducted, breaking through the asymmetries of SSI, while developing a methodology to assist stakeholders engaged in all aspects of modernizing irrigation systems. This paper explores some implications based on five case studies in Central Asia and Africa, namely in Tajikistan, Uzbekistan, Burkina Faso and Uganda.

2. POLICY

Agriculture uses 80 percent of the total water consumption in Central Asia, meanwhile the region almost exploits its irrigation potential at average 73 percent with significant disparity across the countries (FAO, 2013). Food security trends here are influenced by many factors related closely to irrigated agriculture, such as transition period after the collapse of former Soviet Union, transboundary resource management, climate change and diminishing water availability (FAO, 2017; Lioubimtseva, 2018). The agricultural reforms and introduced policies predominantly focused on increasing the efficiency and transforming the Soviet collective farms to small-scale family farming by privatizing the production assets. During the economic transition in Central Asia, the new system was adopted to vanish the collective system, while a gap occurred due to the incomplete replacement of the old institutions. This process put burdening pressure on I&D structures as previously the central agencies were responsible for their O&M. Nevertheless, irrigation became strategic sector in the national pro-poor policies as irrigated land contributes three times more to per capita expenditure than the rainfed lands (Bucknall, et al., 2003; Spoor, 2004).

Despite its ample water resources, the situation of irrigation in Africa is worse off than in other continents due to the extremely low ratio of irrigated land over the potential (6 percent) and its high degree of concentration (You, et al., 2010). The large ratio of rural population drives the governmental programs to increase the output of the agriculture, thus, establish many public schemes assigned to smallholders. However, schemes suffer from deficiencies. They are often divided into simply too small plots to provide economic threshold for the minimum subsistence (Moyo, et al., 2017). Furthermore, these schemes are often established as part of the national food security measures and farmers are suggested to select staple-crops which are less profitable than other cash-crops. The lack of profitability is then transmitted into shortfalls of operation and maintenance works (O&M), under-resourced reinvestment and other management failures.

3. THE APPROACH TO MODERNIZATION PLANNING

Following pilot approach, RAP evaluation was conducted in five SSI schemes in Central Asia and Africa, namely in Tajikistan, Uzbekistan, Burkina Faso and Uganda. With different action plans and overall impacts, the common objective of the on-going development programs of these schemes is to enhance water use efficiency in a more systematic manner that builds on previous management experiences. As rule of this adaptive water management approach, the assessment considers that there is no “one-size-fits all' model which can be applied to all (McNabb, 2017). The RAP evaluation gives sufficient flexibility for wide implementation in different conditions. The irrigation schemes are analyzed through multi-layer management, each layer provides water service to the lower level, from the overall water supply in the scheme to farm-level deliveries. This sequential approach enables the RAP application at different scales of the irrigation schemes – involving a wider range of stakeholders from managers to final users. While establishing a cause-effect relationship of the current undesired conditions, the RAP evaluation represents a stocktaking exercise of what essential functions are missing to reach an efficient irrigation scheme. The selection of the pilot schemes was based on multiple criteria analysis to ensure the applicability of the RAP such as scheme boundaries – administrative or hydrological, operational WUA, hydrological feature and other criteria making the schemes representative in the country's context.

Where there is equal access in water distribution, the impact of improved irrigation management on productivity is more likely poverty reducing (Lipton, et al., 2002). Unlike in large-scale systems, the design of small-scale systems is often adjusted by the farmers. As a result, the asymmetries in system design can lead to less reliable water service, thus, making farmers less willing to contribute to O&M activities (Reid Bell, et al., 2016). The non-probability sampling aimed at measuring the uniformity of water services among the farmers in different parts of the schemes. The sampling focused both on downstream farmers and on those who are adversely affected by any constraints on water access. The principal criteria is the design based sampling which requires an in-depth knowledge on the engineering, topographical, flow regime and other possible constraints and their effect on the water users.

4. REVIEW OF THE PILOT SCHEMES

The five pilot schemes differ greatly from each other despite the applied selection criteria. However, the common objective of their development strategies remains the same: improving farmers' livelihood through enhanced water use efficiency.

The two selected schemes in Africa are established as governmental program in 1960s to increase national food security. Mubuku irrigation scheme in western Uganda and Ben Nafa Kacha scheme in western Burkina Faso are – almost identical – small-scale, gravity-fed and open-canal irrigation schemes. The schemes have tropical dry climate in Ben Nafa Kacha and tropical wet in Mubuku distinguishing two agricultural seasons. In order to diversify the production, the farmers apply double- and multi-cropping systems limited mostly to staple crops such as rice, maize, onion or tomato. The low profitability of these crops often undermines the feasibility of the investment in irrigation. As farmers cannot invest to maintain or rehabilitate their hydraulic structures, the water loss at tertiary canal level is considerable in both schemes. On the other hand, the multi-cropping in small plots create a high spatial- and temporal variability of crop water requirement. The scheme managements have often difficulties to match the fixed irrigation turns to the actual water demand in this "patchwork" of cropping pattern without effective hydraulic structures for water control. This shortfall and the inflexibility of the irrigation management are the two bottlenecks of improving water use efficiency. As a result, the water withdrawal exceeds by far the average requirement and a large amount of water ends up in the drains. Therefore, the estimated water use efficiency remains low (below 50 percent).

The three schemes of Tajikistan and Uzbekistan are currently under transition from the large-scale, Soviet irrigation systems to smallholder farming (Dehkan) through privatization and re-distribution of land and production resources, institutional transition and modernization. Regardless of the same roots, the development pathways of the two countries differ from each other. After the civil war, the two small-scale schemes of

Tajikistan, Eshon and Hochi Hochakul open-canal schemes in Panjakent district, have not undergone rehabilitation works. The residuals of the previous irrigation institutions are vanished, and replacement has partially taken place yet. This process led to the deterioration of the irrigation schemes to such extent that the estimated conveyance efficiency declined to 45 and 35 percent respectively. The primary objective of the current governmental investment in irrigation scheme is poverty and food insecurity reduction in the rural Tajikistan. In contrary, Uzbekistan aims at converting the irrigation schemes into commercial farming, changing the traditional cotton cultivations to exportable cash-crops, and lowering the import-dependency through increased domestic production. The two landlock countries have dry continental and semi-arid climate allowing only one agricultural season with limited possibility of double cropping, translating into high water losses due to high evapotranspiration. Moreover, the emerging water scarcity sets burden on the further development of irrigated agriculture in the two countries.

5. RAP APPLICATION AND LESSONS LEARNT

This sections draws on the systematic analysis and main findings of the implemented RAP in the five irrigation schemes, and it presents the results through four main categories: (1) analyzing irrigation efficiency and other external indicators through Water Balance approach, (2) institutional analysis emphasizing the O&M works and role of WUAs, (3) managerial deficiencies through rapid appraisal of the conveyance structures, and (4) assessment of water service.

The external indicators are computed through Water Balance approach, whereas water supply and water demand are matched throughout the irrigation seasons. After surveying the cropping pattern during the water year, the calculation of field water requirement was conducted based on monthly-step reference evapotranspiration (ETo) and the adjusted crop coefficients by FAO 56. To do so, the climatic data were collected from local stations, ETo values were calculated by CROPWAT, and effective precipitation was calculated by FAO 25 approach. The overall crop water requirement per crops was computed in monthly step, and the sum-up of the crop requirements results the field irrigation requirement – the overall water demand in the command area. On supply side, the water supply was estimated through different metering and benchmarking methodologies depending on the scheme's facilities. The piloting showed that although acquisition of discharge data is an evidence for proper management, only Gaznon and Mubuku schemes have sufficient measurement activities limited to main canal level. By matching the water supply and requirement, Command Area Irrigation Efficiency (CAIE%) is computed for all schemes except Hochi Hochakul, where demand exceeds the supply. One important finding is that most of the scheme has enormous water over-supply associated with irrigation schedule in fix rotation. This inflexible scheduling forces the management to withdraw the maximum possible water amount. In case of Mubuku and Eshon schemes, the supply is more than four times higher than the demand thus resulting around 13.2 and 11.4 percent CAIE. By correcting the overall water supply with the conveyance efficiency, Field Irrigation Efficiency (FIE%) is computed. Since the schemes embrace several types of conveyance deficiencies, such as seepage and runoff, the water loss can decrease the water supply to such extent that schemes fail to meet irrigation demand such in the case of Ben Nafa Kacha. As shown in Figure 1, all schemes – except Mubuku – are hit by temporal water shortage despite of the sufficient cumulative delivered amount when supply is analyzed on monthly-basis. For example, the cumulative delivered supply meets the overall demand in Gaznon scheme, but the temporal water deficit per land unit can reach 1800 m^3/ha in vegetation period thus indicating severe water scarcity. Nevertheless, the high ET as main cause of water scarcity has not been addressed yet neither at scheme nor at farm level.

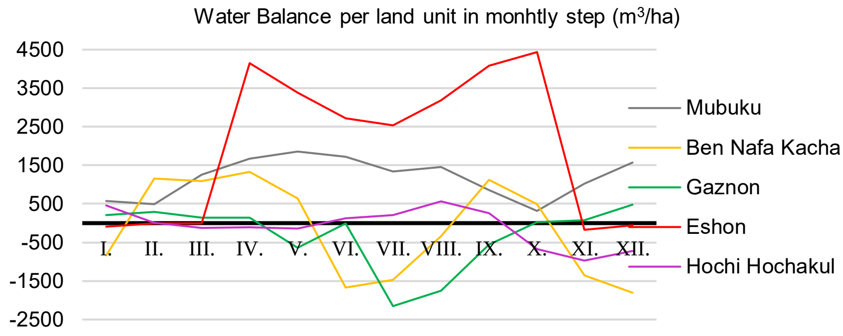

Figure 1: Monthly-step water balance in the schemes (Water Year: 2017)

While comparing the crop water requirement of upland rice in Mubuku and paddy rice in Ben Nafa Kacha, the appraisal shows that rice consumes 504 mm water in Mubuku, and 1100 mm in Ben Nafa Kacha. Farmers in Ben Nafa Kacha pay high water fees for energy thus questioning the economic feasibility of this staple crop. Once again, the example well explains the pro-poor effect of irrigation techniques and the complexity of decisions on irrigation planning.

The most evident difference between the African and Central-Asian managements is the role of the governmental bodies. While the WUAs are fully responsible for the operation and management, without receiving external funding in Africa, the Central-Asian schemes are co-managed, and the maintenance works are often financed by governmental bodies. However, regular maintenance works by governmental bodies are almost always based on priorities and not on farmers' contribution. In almost every case, the WUAs' only revenue is the water charges paid by the farmers. But farmers are often not willing to pay; furthermore, only the Tajik schemes practice enforcement mechanism. Gaznon scheme has the lowest fee collection efficiency at 20-30 percent due to the water scarcity-driven dissatisfaction. Ben Nafa Kacha has also considerable shortcomings because the WUA collects only 65 percent of the fees, meanwhile the energy costs are significant. The analysis of the budgets clearly shows that WUA's financial strengths are sufficient for operation, but not for maintenance and re- or further investments (Figure 2). As conclusion, those schemes which are hit by water scarcity and have no enforcement mechanism, are more exposed to the farmers' non-compliance and financial instability. The RAP findings indicate the need to strengthen the institutions in order to make investment on infrastructure sustainable.

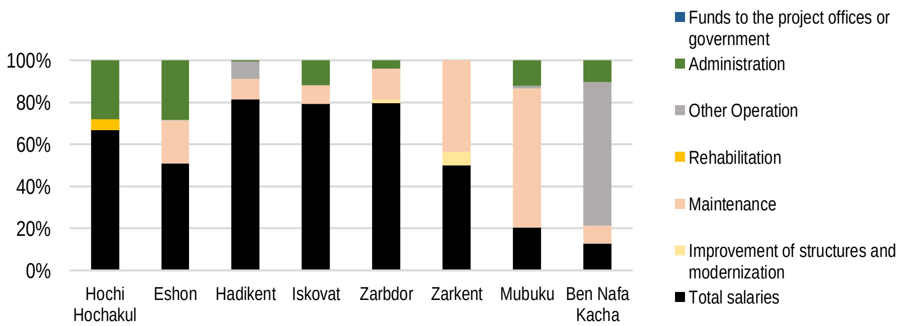

Figure 2: Budget composition of the schemes (2017)

Interestingly, all the five schemes have institutional and social layers in their management. The Participatory Irrigation Management (PIM) has numerous merits not only to exploit the potentials but to reduce the WUAs' financial burdens and provide more equity amongst farmers. Four schemes from the five, except Gaznon, created the informal institution of farmer-led irrigation, where the communities of secondary or tertiary canals appoint a leader to manage irrigation. As PIM is growing into key operational strategy for governments and agency to delivery services, evaluating farmers' contribution is at the core of performance assessments. The RAP evaluation allows the appraisal of interfering management dimensions, thus, measuring the effect of informal initiatives of scheme management on water use efficiency.

The RAP approach requires the estimation of conveyance and application efficiency which is derived from managerial and hardware conditions. The RAP combines these two aspects at each water delivery level from main canal to final deliveries involving both expert-based benchmarking and self-assessment. The assessment of levels always involves the organizations or groups who are responsible for the operation to obtain cause-effect relationship between the management and conditions. From managerial point of view, the constraints of water management, such as the identified temporal water shortage, gives much importance to irrigation scheduling services. Although, there is a vast number of scheduling methods to set-up water balance at scheme and farm level, the analyzed schemes fail to put it into practice due to the lack of sufficient infrastructure. The Central-Asian schemes took over the defined crop water requirement from the previous systems ("irrigation norm"), but applied water is only roughly estimated due to the lack of effective measurement at tertiary level. Moreover, the African schemes have not been familiar with the crop water requirement concept yet. The analysis underpinned the need of introducing methods and techniques on better irrigation scheduling based on real-time demand and creates a more flexible mechanism of distribution. The conditions of the irrigation hardware, however, vary on a wide range. The Tajik schemes are heavily deteriorated, both the original design and the current conditions do not allow a smooth transition from large-scale to small-scale farming unless the scheme is rehabilitated to the level of original condition and new development strategies are based on the restored conditions. Both the African schemes have the same feature of well-maintained main and secondary canals, fully functional offtakes and discharge measurement. Nevertheless, the rigid irrigation schedule shared by many farmers results in less frequent, but long irrigation turns, thus, releasing high discharge into the tertiary canals, and consequently runoff into the drains. So, the main water loss occurs below the tertiary levels, and farmers are not resourced to carry-out the maintenance. Yet the responsibility of O&M is not shared between farmers and WUAs below tertiary canal level, so the system performance below tertiary level depends on the farm profitability. As backbone of the assessment, the RAP carefully appraises each delivery levels and their interaction to establish cause-effect relationship related to water use efficiency issues – which are often not very obvious.

The performance indicators of flexibility (Flex), reliability (Re), flow (Vol) and equity (Eq) referred in the paper to describe the quality of water service. These indicators provide a detailed overview of the current operating conditions and the water delivery service at each level of the irrigation system. The weighted indicators are grouped into three primary indicators (presented in Figure 3). Each indicator is scored by all the service delivery levels from main canal to the final delivery. With re-visiting the RAP, the concept of most downstream farmers is replaced with the "farmers most exposed to poor water services". Through surveying, the analysis selected the farmers with inferior water service and compared their scoring to the management's scoring and weights were given to the selected farmers' scores. For example, the topography sets limit on the equal water access due to extremely altering elevation profile of the schemes in Tajikistan; meanwhile, downstream farmers in Gaznon scheme receive supplementary water supply from groundwater sources in Uzbekistan, therefore the farmers relying only on surface water in the middle of canal system are more exposed to water shortage.

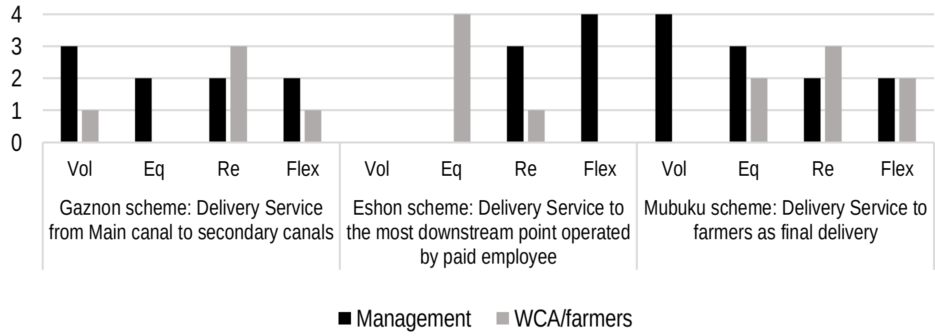

Figure 3: Scoring of internal indicators of the RAP in different schemes

Figure 3 presents an example of each computed indicators from the case studies to represent the clear differences between management and farmers' perspectives. Despite of the enormous amount of water oversupply of Eshon and Mubuku schemes, still, the farmers do not score the flexibility and reliability high. Moreover, the oversupply does not necessary create equity among farmers as Mubuku scheme shows, but the lack of equity and flexibility necessary occurs in each scheme hit by water scarcity. Experiences, however, show that the assessment of Africa is particularly difficult due to the varying degree of diversity.

The RAP approach's comparative advantage is clearly demonstrated with the combined qualitative and quantitative indicators drawing unbiased examination of the water service. It also brings together the stakeholders' perspectives from water users to decision makers thus recommends collaborative solutions for the development.

6. WAY FORWARD

This current series of RAP evaluation has its high value proving a clear guide on how to conduct coherent assessment of irrigation performance under different irrigation managements. The re-visited RAP approach comprises a number of options to establish cause-effect relationships between different aspects of irrigation management thus making it appropriate tool to examine deficiencies and define modernization pathways. Such diverse results of the piloting underpin the importance of the next steps to do to ensure compatibility and coherent development strategies at country level. The main lessons, however, learned are that:

(a) Agreeable irrigation management strategies arise from proper data acquisition that involves both water supply and water demand sides, and contains information on economic, social and environmental aspects of water resources;

(b) To the extent that water related institutions are grounded in data-driven improvement. Yet scheme managements rarely apply information acquisition tools and methodologies;

(c) Instead of traditional analysis, social (PIM) and institutional management together must be considered: the case studies proved that farmers' contribution – both in monetary and in-kind terms – is at the core of irrigation management, and the relatively good performance of a scheme at headworks can be completely undermined at farmer-operated levels;

(d) Farmers are also responsible to financially contribute to the system operation: the case studies show that O&M works still share a negligible amount of the

WUAs' budget and some schemes almost reached the complete deterioration due to the lack of strong institutions.

(e) Rehabilitation is more tangible though, soft components of irrigation management are as effective means as infrastructural development: although some of the scheme managements introduce instruments to adjust water supply to the water demand, the theory has not been fully put into practice yet and irrigation scheduling is still limited to fixed rotations in every case; and

(f) Little-explored possibilities in more flexible water services is translated into within-system inequity: farmers who are affected by inefficiencies in the conveyance systems, are continuously exposed to the upstream events. From slight water shortage to complete production failure, inequity has multiple adverse effect. For example, in Africa, where farmers are supposed to make profit from limited resources.

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AUTOMATIC SUBSURFACE IRRIGATION AND DRAINAGE USING SHEET-PIPE TYPED MOLE DRAIN

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ABSTRACT

Sheet-pipe is a sort of perforated mole-drain used mainly to draw the excess of water from a water-logged paddy field. During installation, sheet-pipe is inserted horizontally into the soil at a certain depth using heavy machine called mole-drainer. After a heavy rainfall, the groundwater can decrease faster and be maintained at expected levels. As the soil aeration is getting better and soil salinity decrease due to leaching, better growth and higher productivity can be achieved. This paper reports plan and progress of sheet-pipe installation in Indonesia. A conceptual design of automatic irrigation and drainage using the sheet-pipe is described with the objective to minimize irrigation and drainage rates to maintain the groundwater at expected levels. Water flow model is developed to figure out profiles of the groundwater level and patterns of the drained water. And, combined with a controller model to determine the appropriate rate of returned flow from to drainage to the irrigation canals. Compared the field without sheet-pipe, the paddy field installed with sheet-pipe drained faster and could manage groundwater level ±5 cm right after a heavy rainfall ceased. Pattern of infiltration rate formed parabolic curve with the maximum value of 0.94 cm/h. Drainage rate also formed parabolic curve with the maximum and average values 0.899 m^2/h and 0.758 m^2/h, respectively. The profile of groundwater level was horizontally flat but then curved as closer toward the sheet-pipe. Soil salinity reduced to 0.42 mS/cm while productivity increased 6%. Further plans are to develop remote control system and install it in laboratory and field experiments.

Keywords: Paddy field, sheet-pipe, irrigation, drainage, water level, water-use efficiency, water productivity.

1. INTRODUCTION

Indonesia has a vast swampland accounted for 43.7 million hectares, and out of it, about 9.8 million hectares have been identified potential to develop as paddy fields [1]. Currently, more than 1 million hectares of the swampland has been converted into paddy fields [2] and cultivated at least one time every year. In general, the paddy fields inundated with water due to a frequent and high intensity of the rainfall with a periodic sea tide [3]. This paddy field also faces saline or acidic soils with low percolation due to the high content of heavy clays [4]. Land preparation usually starts after passing the peak of the rainy season. With low agricultural inputs as traditionally practiced by the local farmers, the averaged land productivity is about 3 t/ha of the wet paddy but with intensive treatments and better water management can attain more than 5 t/ha [5]. Low productivities of the paddy fields in swamplands have been reported elsewhere [6] [7] [8].

An effective drainage system is imperative to maintain the groundwater level preferable for the optimum growth of the plants. A combination of surface and subsurface drainage can intensify land utilization and increase yield increase, which, in turn, gain additional farmers' income [9]. Design criteria and practices and viable alternatives are available for the improvement of subsurface agricultural drainage systems to meet the demands

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of modern agriculture [10]. A shallow subsurface drainage system with a drain depth of 0.3 m and drain spacing of 8 m can increase yield and facilitate safe harvest while avoiding pre-monsoonal rainfall damage [11]. A subsurface drainage system can reduce salinity by about 80% in the topsoil (20 cm depth) [12].

In Japan, land consolidation and drainage improvement for farm mechanization in paddy fields began during the 1960s. It was not easy to use big machines in the muddy conditions caused by the clayey soil and heavy rainfall during the harvesting period. Several investigations were carried out by many researchers, and factors relating to drainage were clarified. Not only surface drainage but also under drainage was planned. However, drainage was not always enough, because the clayey surface soil was impermeable to ponding water. It became clear that under drainage for a clayey paddy field for the harvest is quite different from under drainage for an ordinary field. Field and soil characteristics, as well as water conditions, should be scrutinized before planning drainage improvement for farm mechanization [17].

On irrigated lands, drainpipe performance is often below standard due to clogging, siltation and root growth inside the pipe., an innovative pipe–envelope concept was tested on a 50-ha pilot area in Harran, Turkey, in 2015 and 2016. The new concept, HYDROLUIS, consists of a corrugated inner pipe with three rows of perforations at the top and an unperforated outer pipe that covers about 2/3 of the inner pipe leaving only the unperforated bottom part of the inner pipe in contact with the soil. The main advantages of the new concept are that it works for a wide range of soil textures, and there is better protection against root growth inside the pipe. The new concept was compared with a geotextile envelope, a gravel envelope, and a control with no envelope. The HYDROLUIS and gravel envelopes had a significantly lower entrance resistance compared to the geotextile, the best drain performance, and no signs of sedimentation nor of root growth inside the pipe. The production costs of the HYDROLUIS envelope are comparable to those of pre-wrapped synthetic envelopes and considerably lower than gravel envelopes. It can be concluded that the HYDROLUIS envelope is a promising alternative for sand/gravel or synthetic envelopes in irrigated lands [13].

Many studies have been conducted on the role and importance of subsurface drainage in groundwater table control to discover new techniques and more economical solutions, particularly relating to different pipes, envelope materials, and their installation. This research was conducted to investigate the applicability of rice husk in drainage as a drain envelope material s compared with a standard sand and gravel envelopes. Some of the physical and hydraulic properties of rice husk such as bulk density, void ratio, gradation curve, and hydraulic conductivity were measured. A physical model that simulated a part of the drain trench enabling groundwater table control was used to simulate land drainage in the laboratory and to test filtration and water conductivity of a rice husk envelope. The experiments were carried out in two soils that required envelope material based on standard methods. The results of this study showed that hydraulic conductivity of the rice husk even under large loads was high enough to guarantee its hydraulic function as an envelope. Furthermore, the rice husk envelopes had proper function compared to mineral envelopes [14].

Since 1993, the Red River of the North Valley in North Dakota (ND) and Minnesota (MN), in the USA has experienced increased annual rainfall which has caused localized seasonal Soil waterlogging and inhibited crop yield potential in the unique, high water table clay soils of the region. Subsurface (tile) drainage has been increasingly considered by farmers to help reduce excess water in the crop root zone. Producers desire to manage the water table for optimizing yield and trafficability of the field. The objective of this research was to evaluate differences in soil penetration resistance and water table depth between subsurface (drained) and non-subsurface drained treatments (undrained), using water control structures, in fallow, and cropped soybean (*Glycine max* L. Merr.) and wheat (*Triticum aestivum* L. emend. Thell.) cultivars on a

Fargo-Ryan silty clay soil near Fargo, ND, USA in 2009 and 2010. The experimental design was a randomized complete block in a split-plot arrangement with four replicates.

The whole plot treatments were drained and undrained (control structures opened and closed, respectively). Soil penetrometer readings and water table depth were measured weekly. Yields of each crop were not different comparing drained and undrained treatments in 2009 and 2010. The depth-averaged drained penetration resistance was 1,211 kPa compared with 1,097 kPa for undrained treatment, averaged across 2009 and 2010. The depth-averaged drained penetration resistance values for fallow, soybean, and wheat were 1,077, 1,137, and 1,420 kPa, respectively. The undrained values for fallow, soybean, and wheat were 1,001, 1,021, and 1,267 kPa, respectively, all significantly lower than the drained treatments, indicating that the drained soil is capable of a higher load carrying capacity compared to the undrained soil. The average depth to the water table was greater on drained soil compared to the undrained soil both early and late in the growing season. Forty-two percent of the variation in the penetration resistance can be explained by the level of the water table below the surface. Water control structures can be used to manage the water table level and soil penetrations resistance. The ability for land managers to enter drained fields with farm equipment earlier lengthens the growing season and potentially increase crop yields in this region [15].

The study revealed the performance of subsurface drainage systems for the long-term sustainability of irrigated agriculture. The performance of subsurface drainage systems was evaluated based on drain spacing equations for disposal of effluent and hydraulic characteristics. Three important synthetic envelopes, HG 22, SAPP 240 and CAN 2 were tested in the laboratory using sand tank model and permeability apparatus to compare their performances in terms of entrance resistance and hydraulic conductivity of soil envelope system. The hydraulic conductivity for SAPP 240 filter was found the highest and entrance resistance the lowest. Performance of four unsteady state drain spacing equations viz. Glover-Dumm, Van Schilfgaarde, Integrated Hooghoudt, and Modified Glover equations were also tested to evaluate disposal efficiency of excess water. The percentage deviation between predicted drain spacing and actual spacing was -33.31% to -31.55%, 9.40% to 17.07%, 11.84% to 20.83% and 6.10% to 14.62% for Glover-Dumm, Van Schilfgaarde, Integrated Hooghoudt, and Modified Glover equations, respectively. Modified Glover equation showed minimum deviation from actual drain spacing due to its versatile applicability. Therefore, the Modified Glover equation with SAPP 240 filter was recommended for the subsurface drainage system in sandy soil texture areas [16].

Modern technology of subsurface drainage known as the sheet-pipe system has been developed in Japan for 20 years ago. Merits of this system among others are fast installation process and easy to operate and the paddy field installed with this system is readily arable with many other crops beside paddy. This system has been introduced in Indonesia since 2018 under cooperation among JICA, Ministry of Agriculture, Kyouwa Kensetsu Kogyo Co., Ltd, Yamaguchi University and Bogor Agricultural University. This paper reports development plan and progress of the implementation with special attention given to a field experiment conducted in 2018/2019 located in the Rice Research and Development Centre belongs to the Ministry of Agriculture of the Republic Indonesia.

2. DEVELOPMENT PLAN AND PROGRESS

2.1. Sheet-pipe

As shown in **Figure 1,** Sheet Pipe (SP) is a sort of perforated sheet made of High-Density Polyethylene (HDP) that can be formed into a pipe using a sheet-pipe roller that inserts pin E into the socket B. There are 22 holes per 3 cm along its length (see, E+F). The diameter of one hole is 2 mm, and that of the pipe is 5 cm with its thickness 1 mm. The sheet pipe is manufactured by Polymer Japan and produced in two types, SP50-1 t (1 mm thickness) and SP50-0.7t (0.7 mm thickness). The sheet pipe is packed in the form of a sheet roll having 100 m length per roll.

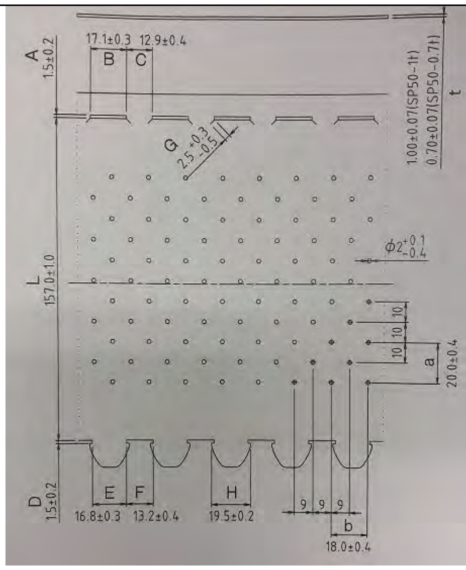


Figure 1. Sheet-pipe Specification

2.2. Conceptual Design

Sheet-pipe used formerly to draw the excess water from the water-logged farmlands. It is inserted horizontally into the soil at a specific deep (±50 cm) using a heavy machine called mole drainer. The installation is very fast around 3 days per hectare on a field having a length of 100 m with a spacing of 4 m. **Figure 2** shows a conceptual design of automatic control of subsurface irrigation and drainage with the sheep-pipe system.

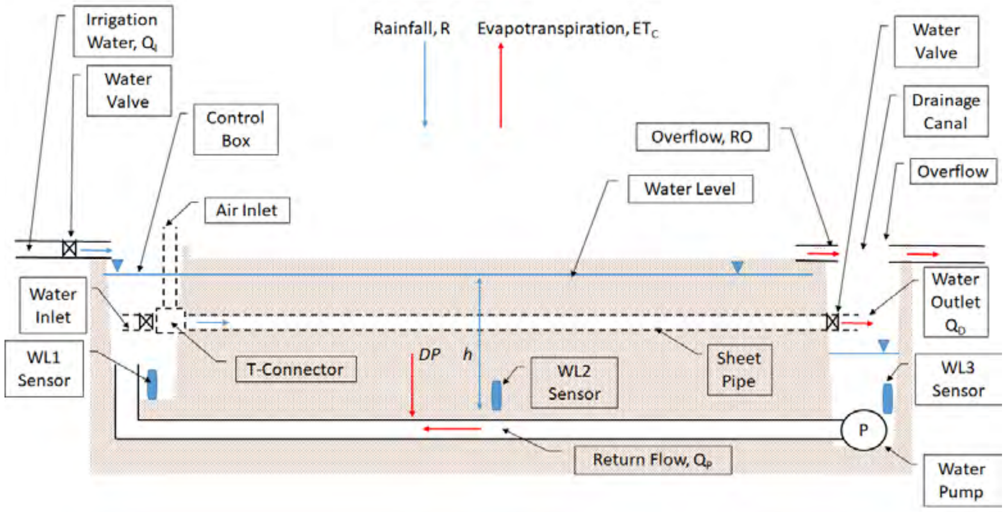


Figure 2. Conceptual Design

Referred to **Figure 2,** the following is a short explanation of the operating mechanism:

(a) The main target is to maintain the water level in the farmland (WL2) at a specific range.

(b) The farmland receives the water from occasional Rainfall and the Control Box.

(c) The Control Box receives the water from the Irrigation Canal and the Drainage Canal.

(d) The water from the Irrigation Canal is regulated with a floating-type Water Valve (WV1).

(e) The water from the Drainage Canal is pumped operated by an electrical switch referred to the water level in the Control Box (WL1) and in the Drainage Canal (WL3).

(f) In general, the control mechanism is as follows:

 (i) When WL2 is higher than the highest limit, WV1 closes, and WV2 opens.
 (ii) When WL2 is lower than the lowest limit, WV1 opens, and WV2 closes.
 (iii) When WL1 is higher than the highest limit, the Pump is off.
 (iv) When WL1 is lower than the lowest limit, the Pump is on.
 (v) When WL3 is lower than the lowest limit, the Pump is off.

(g) Rainfall and evapotranspiration are measured intensively and used for water balance analysis.

2.3. Performance Indicators

Performance indicators to be sought, among others, are groundwater level, hydrograph, infiltration and drainage patterns, leaching effectiveness, irrigation efficiency, and water productivity.

2.4. Implementation Plan and Progress

1) First Stage in 2018/2019:

   a. Box experiment in the laboratory to characterize the decrease of water level profiles and drainage flow;
   b. A field experiment in a paddy field to characterize groundwater level (GWL), hydrograph, infiltration, and drainage patterns and leaching effectiveness.

2) Second Stage in 2019/2020

   a. Field monitoring and measurements of irrigation efficiency and water productivity
   b. Box experiment in the laboratory to test the performance of the control system.
   c. Engineering design of the automatic control system in field scale.

3) Third Stage in 2010/2021

   a. Installation and monitoring of the control system in the field.
   b. Field monitoring and measurements of irrigation efficiency and water productivity

3. FIELD EXPERIMENT IN THE FIRST STAGE

3.1. Location

The investigated site is located inside the Indonesia Centre for Rice Research belongs to the Ministry of Agriculture, the Republic of Indonesia in Sukamandi District, Subang Regency, West Java, Indonesia (**Figure 3**) with the elevation is about 13 m from the sea level.

There are 2 investigated plots. The first plot (P1) located at 6°20'48.19"S and 107°39'2.00"E is the common paddy field without SP having an area of 1.12 ha with its perimeter 426 m; and the second plot (P2) located at 6°20'46.33"S and 107°39'4.01"E was the paddy field which has been installed with SP having an area of 1.1 ha with its perimeter 434 ma. A small ridge surrounds each plot. From these plots, the draining water flows to the drainage canal (P3). The base of the drainage canal is the reference level or datum from which the elevations of P1 is 105 cm, and P2 is 104 cm. With this, a small difference (1 cm) both plots can be considered at the same level.

In P2, there are 8 rows of sheet-pipe with a 4 m-lateral distance in each other with the length of each row was about 100 m perpendicular to the irrigation and drainage canals. Sheet pipe was installed using a mole drainer Komatsu SP30 having a high level of accuracy in placing SP horizontally about 40 cm below the soil surface. Each SP has a water valve installed at its lower end that can be used to regulate the draining water manually.

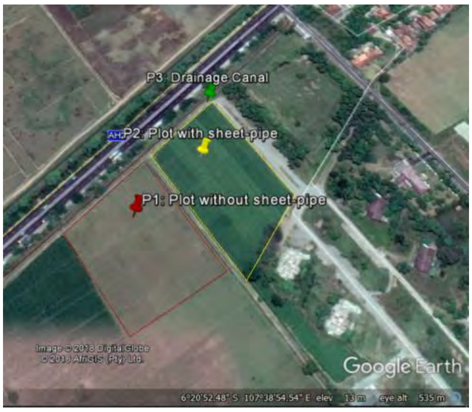


Figure 3. Investigated Paddy Fields

3.2. Field Investigation

Water level (WL) in the 3 points (P1, P2, and P3) were measured intensively using the CTD type WL sensors produced by Meter Group, Inc, WA. The USA. In P1 and P2, the sensor was placed at 70 cm depth from the soil surface or 30 cm below the sheet-pipe; and in P3, the sensor was placed at the bottom of the drainage canal. The sensor can also measure water electrical conductivity (EC) and temperature (Tw) simultaneously. Soil moisture at a depth of 5 cm in P1 and P2 was measured using 5TE produced by the same group that can also measure soil temperature (Ts) and electrical conductivity. Furthermore, the weather data: Rainfall (R) was measured using ECRN-100 Precipitation, Solar Radiation (Rs) using PYR Solar Radiation, and air temperature (Ta) and relative humidity (RH) were measured using EHT RH/Temp.

Acquisitions of weather, water, and soil data use EM50 data logger produced by the same group with a measurement interval of 30 minutes. A field investigation started from May 4th to August 7th, 2018 in which P1 and P2 cultivated with paddy for the second planting season from wet to dry period.

To get a hydrograph unit of a rainfall event, the water flow from the irrigation canal was stopped before the rainfall occurrence to eliminate its influence on the water level. By this, it could be distinguished effects of sheet-pipe on the water level at each rainfall event.

3.3. Data Analysis

As the relation of rainfall and water level was the primary concern of this investigation, data analysis focused on each rainfall event that resulted in a significant rising of water level in both plots. A unit hydrograph consisted of rainfall and water level was depicted to figure out how the water level gave responses to the rainfall. Elapsed times to attain the peaks in the two plots were analyzed and compared to see the differences. Percolation and soil permeability were calculated from the declining section of the hydrograph.

Furthermore, the continuity equation of water flow in a saturated porous medium was applied to figure out the profiles of water level and their changes with time in the plot installed with sheet-pipe. The equation is as follows:

$$\frac{\partial h}{\partial t} = K_s\left(h\frac{\partial^2 h}{\partial x^2} + \frac{\partial h}{\partial x}\frac{\partial h}{\partial x}\right) + p \qquad (1)$$

Where h is water level (cm), K_s is saturated hydraulic conductivity (cm/h), p is percolation rate (cm/h), x is the distance (cm), and t is time (h) subjected to the following boundary conditions:

$$q(0,t) = p(0,t)\frac{\Delta x}{H-h(0,t)} \quad (2)$$

And,

$$h(L,t) = f(L,t) \quad (3)$$

Where q is horizontal water flux (cm/h), Δx is spatial interval (cm), H is the depth of sheet-pipe from the soil surface (=40 cm), L is length of water flow domain (=200 cm) from the sheet-pipe which is set at x=0 cm, and f is an interpolation function of the measured water level at x=L. Subjected to the initially measured water levels, the equations above were then solved numerically using the explicit scheme of Finite Difference Method.

4. RESULTS AND DISCUSSIONS

4.1. Weathers

During field investigations, there were 6 rainfall events (see **Table 1**) in which the most significant rainfall occurred from May 23rd, 2018 at midnight and lasted about 6 hours and produced 34 mm of the rainwater with the averaged rate 5.67 mm/h. This rainfall resulted in measurable water inflows into P1, P2, and P3 and will be taken into attention for further analysis in this paper.

Table 1 Rainfall Events within the Period of Investigation

No	Started	Length (h)	Amount (mm)	Rate (mm/h)
1	20-May-18 04:30	2.0	0.8	0.40
2	21-May-18 02:30	1.5	1.2	0.80
3	22-May-18 00:00	5.5	3.4	0.62
4	23-May-18 00:00	6.0	34.0	5.67
5	23-May-18 20:00	6.0	25.6	4.27
6	25-May-18 06:00	3.5	3.6	1.03

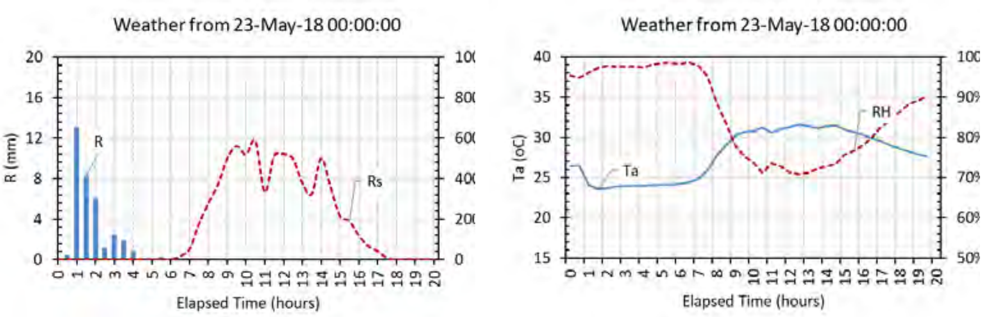


Figure 4. Rainfall (R), Solar Radiation (Rs), Air Temperature (Ta), and Relative Humidity (RH)

As shown in **Figure 4**, the rainfall attained its peak after one hour then gradually decreased with time and stopped after 6 hours. During the rainfall which was still dawn, Rs was very low, and Ta was about 24° C while RH was high closer to 100%. After the rainfall, which was during daylight, Rs increased steeply to reach a maximum value of 600 W/m^2, and Ta increased above 30 °C while RH decreased to 70%. About 17:30, Rs reduced to zero at the nighttime.

4.2. Water Level and Soil Moisture

Figure 5 water level and soil moisture fluctuations in P1 and P2. The water level was referred to the bottom of the drainage canal (P3) where is WL fluctuated from 10 cm and reached maximum 40 cm after lasted 8 hours then gradually decreased below 30 cm after lasted 20 hours. The water level in P1 was always higher than that in P2. Even WL in P1 was always above the soil surface while WL in P2 was mostly below the soil surface, which was stable at about 5 cm depth after lasted 10 hours. As also shown in Figure 5, soil moisture in P1 was slightly higher than that in P2, but then similar lasted 8 hours and reached saturation at about 46% of VWC.

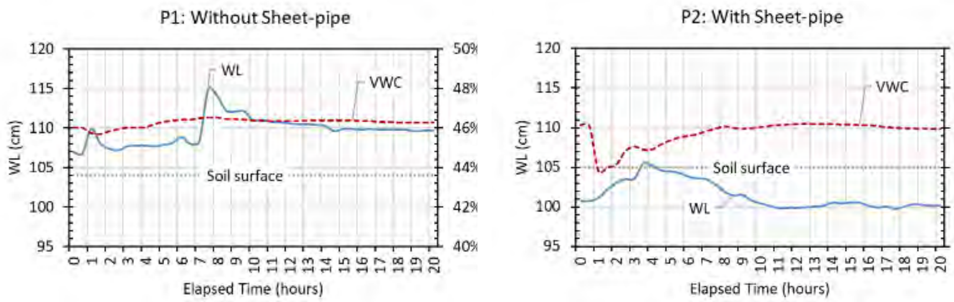
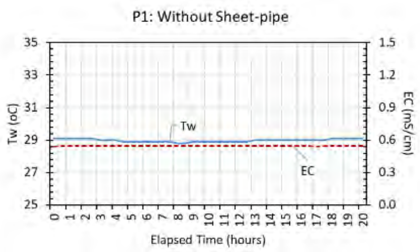


Figure 5. Water Level (WL) and Volumetric Water Content (VWC) in the Plots without Sheet-pipe (P1) and with Sheet-pipe (P2)

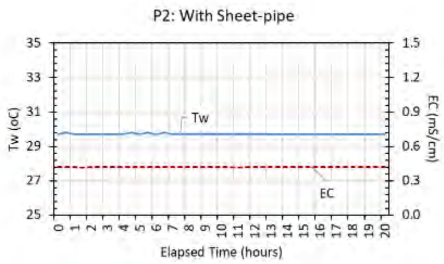
4.3. Temperature and Electrical Conductivity

Figure 6 shows temperature and electrical conductivity in P1 and P2. Water temperature (Tw) were relatively stable in average at 29.0 °C in P1 and 29.7 °C in P2 compared to soil temperature (Ts) which was oscillated with time because it was close to the atmosphere and influenced by the air temperature (Ta). The minimum and maximum Ts in P1 were 26.6 °C and 31.8 °C, respectively; and those in P2 were 27.4 °C and 32.3 °C, respectively.

Soil EC was relatively stable in average at 1.05 mS/cm in P1 and 1.11 mS/cm in P2 which were not significantly different in each other. These values are more significant than those reported by [9] in the range of 0.6–1 mS/cm in paddy fields under anaerobic condition. While in most uplands under aerobic condition EC is commonly around 0.33 mS/cm [10].



In the water at 30 cm depth



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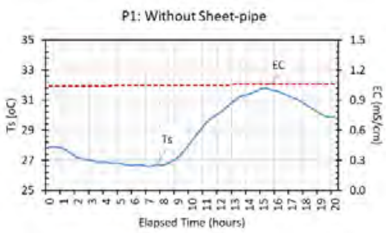
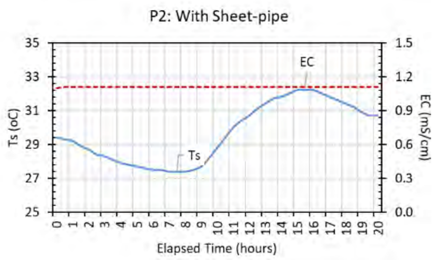


In the soil at 5 cm depth



In the soil at 5 cm depth

Figure 6. Water Temperature (Ts) and Electrical Conductivity (EC) in the Plots without Sheet-pipe (P1) and with Sheet-pipe (P2)

Water EC was 2 times lower than the soil EC. Water EC was relatively stable but that in P1 was slightly higher on average at 0.55 mS/cm than that in P2 at 0.42 mS/cm which might be influenced by the leaching effect while water EC in P3 was 0.25 mS/cm the lowest as the consequence of the accumulation of rainwater and drained water.

4.4. Hydrograph Patterns

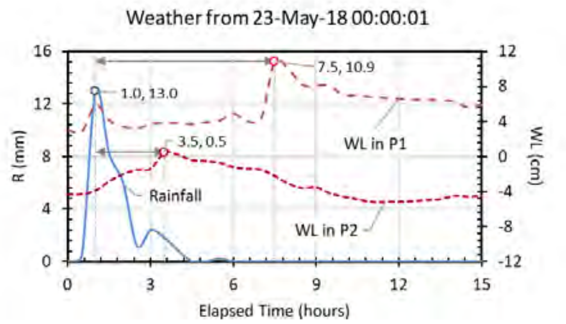


Figure 7. Hydrographs of Rainfall and Water Level

Figure 7 shows two hydrographs comparing responses of WL in P1 and P2 to a single rainfall event. The differences are apparent. In P1, the rainwater accumulated mainly on the soil surface and reached the maximum WL at 10.9 cm after lasted 7.5 hours then gradually decrease with time to reach 5.9 cm after lasted 15 hours. While in P2, the maximum WL was only 0.5 cm reached after lasted 3.5 hours then gradually decreased below the soil surface and reached -4.5 cm after 15 hours. This decrease indicates that the large part of the rainwater percolated to deeper layers and discharged through the Sheet-pipe.

4.5. Infiltration Patterns

Figure 8 shows the cumulative infiltration (CI) defined here as the accumulation of rainwater entering the soil surface, starting from the maximum WL then percolates to the deeper layers. In P1, the data of CI formed a parabolical curve as commonly occurs in normal plots while in P2, the data formed a slight S-curve in which the total infiltrated water was 4.5 cm. Herewith, both curves are represented by the 4th Polynomial Equation, which gained determination coefficients close to 1 subjected to the time length from 0 to 6 hours. The infiltration rate (IR) which is the first derivative of the polynomial equation formed a typical decreasing pattern in P1 and attained steady rate at 0.121 cm/h while IR in P2 formed a parabolical curve having a maximum value of 0.94 cm/h at elapsed time 3.5 hours.

4.6. Water Level Profiles

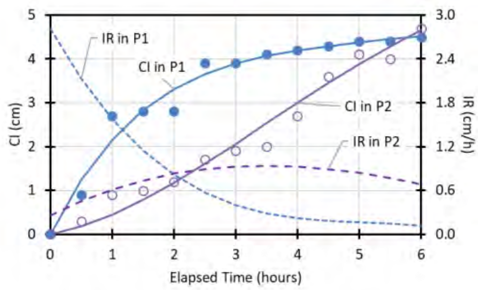


Figure 8. Cumulative Infiltration (CI) and Infiltration Rate (PR)

Figure 9 shows the calculated water level profiles in P2 for several elapsed hours. In general, the WL curves flatted horizontally excepting at the points closer to the sheet-pipe (x=0) are lower, indicating there were outward gradients of water head. Figure 9 also shows the drained water per unit length of sheet pipe, which again formed a hyperbolic curve having a maximum value of 0.899 m^2/h with an average of 0.758 m^2/h.

The results of the analyses show that seepage velocity along the ponded surface water decreases with distance from the ditch, and accordingly, leaching of salts is non-uniform [11].

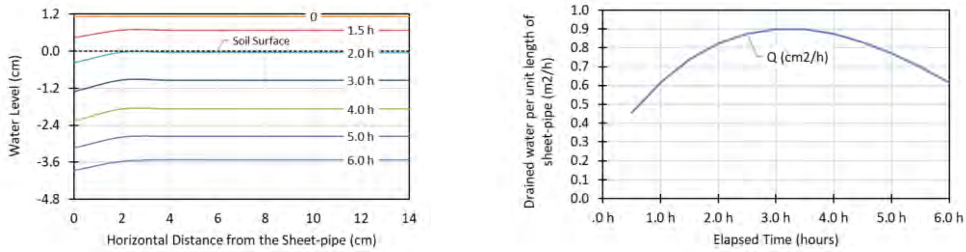


Figure 9. Profiles of the Water Level in the Paddy Field with Sheet-pipe

5. CONCLUSIONS

The paddy field installed with sheet-pipe can drain faster, and in consequence, its water level can be managed easier, which is an important key to be able to regulate anaerobic and aerobic conditions. Right after a productive rainfall event, the rainwater immediately infiltrates downward, resulting in a parabolic curve of infiltration rate, which differs with a standard infiltration curve. Water level profile is horizontally flat except at the points closer to the sheet-pipe, which is showing the presence of outward gradients of the water head. Soil electrical conductivity was lower due to the leaching effect, which is potential to move unexpected substances commonly found in the wetland.

ACKNOWLEDGMENTS

This paper is a part of the results of a joint research between Bogor Agricultural University, Indonesia and Yamaguchi University, Japan entitled "*Laboratory Test to Confirm the Mechanism of Sheet-pipe System for the Feasibility Survey for Improvement of Agricultural productivity by Adapting Sheet-pipe System in the Republic of Indonesia*" funded by Kyouwa Kensetsu Kogyo Co., Ltd, Japan in 2017/2018.

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A CASE STUDY ON CONVERSION OF CANAL BASED IRRIGATION NETWORK SYSTEM TO PRESSURIZED PIPE BASED NETWORK SYSTEM INTEGRATED WITH SOLAR PLANT IN THE STATE OF UTTAR PRADESH, INDIA

Sabarna Roy [1], Rajat Chowdhury [2]

ABSTRACT

Badaun irrigation project was designed many years back by the Government of Uttar Pradesh on Canal Based Irrigation Network. The project could not be completed in so many years except for the majority part of the Main Canal that too at substantially escalated project cost and after long delays due to land acquisition and many other associated problems, but none of the branch canals including the distributaries could be completed.

The Champatpur Branch Canal with its distributaries as such was taken up on Pressurized Piped Irrigation Network basis, considering the advantages as mentioned in the Central Water Commission PIN Manual of Government of India of July 2017. The project has been designed as per the instructions of the UP government, adopting modern irrigation system is proposed to be sprinkler irrigation under the pressure irrigation integrated with Solar Plants of the Champatpur branch system, by which irrigation can be done in more areas with less water.

The paper discusses design aspects, all costs and comparative costs in detail, which will help engineers at the threshold of converting Canal Based Irrigation Network to Pressurized Pipe Based Irrigation Network.

1. INTRODUCTION

Badaun irrigation project (currently known as, Aonla Sprinkler Irrigation System in district Bareilly in UP, India) was designed many years back by the Government of Uttar Pradesh on Canal Based Irrigation Network. The project could not be completed in so many years except for the majority part of the Main Canal that too at substantially escalated project cost and after long delays due to land acquisition and many other associated problems, but none of the branch canals including the distributaries could be completed.

The Champatpur Branch Canal with its distributaries as such was taken up on Pressurized Piped Irrigation Network basis, considering the advantages as mentioned in the Central Water Commission PIN Manual of Government of India of July 2017, which are as follows:-

i. As most of a piped distribution system underground, right of way problems are significantly reduced, allowing more direct and rational layouts to be chosen. Because outlet location is not limited by topography, pipe systems are better able to accommodate existing patterns of land ownership with the minimum of disruption compared with new irrigation development using CDN.

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ii. Cross Drainage and Cross Masonry (Communication) structures can be omitted or minimized.

iii. Irrigation works become obstacles in the way of free drainage of water during rainy season and thus results in submerging standing crops and even villages.

iv. No damage due to heavy rainfall or flood during monsoon.

v. More Suitable option for flood-prone area.

vi. No hindrance in movement to the farmers and farm equipments.

vii. Increase in CCA as compared to canals, as the water losses are negligible and acquired land for canal network can also be used for cultivation as Piped Irrigation Network is under ground.

viii. Better option for undulating fields.

ix. Because of shorter transit times for water from source to field, lower conveyance losses and the smaller volumes of water in the conveyance system, pipe systems can deliver a supply which is more flexible in both duration and timing, in a way not possible CDN, so enabling intensification and diversification into higher value crops.

x. Less execution time for PIN as compared to CDN.

xi. The important targets of the modernization of irrigation schemes and digital management will be achieved when water is delivered through Piped Irrigation Network.

xii. In case of canals, the marshes and the ponds caused by excessive seepage, in course of time become the colonies of the mosquito, which gives rise to vector borne diseases and this can be minimized by adopting Piped Irrigation Network. Further salinity and water logging can be reduced.

xiii. Increase in project efficiency of the Piped Irrigation Network is about 20% as compared to CDN.

xiv. Fertilizers/chemical can also be mixed with the water.

xv. Quantity of water supplied by Piped Irrigation Network is easily measurable; hence water auditing can be accurately measured.

2. PREAMBLE TO THE AONLA SPRINKLER IRRIGATION SYSTEM IN DISTRICT BAREILLY IN UP, INDIA

At present, there is no facility available for irrigation in the canals in Tehsil Sadar and Tehsil Aonla of Bareilly district and Tehsil Dataganj of Badaun district, located between Rivers Ganges and Ramganga. The irrigation here mainly depends on ground water and rain water. For the last several years, most of the Badaun district is being irrigated by tube wells. For this reason, the situation of ground water level is very poor in most parts of Badla and Bareilly district of Aonla Tehsil, which often fails to provide most of the tube well irrigation facility due to bad ground water levels in summer. Irrigation project has been now prepared to provide irrigation facilities to the Kharif crops from canals in the area. Under the project, the gross command area is 66877 ha, the agricultural land area is 53504 ha, and the proper and sure irrigation area of Kharif crop is 37453 ha (70% of CCA). Recommended discharge for the planning of the project in clear hydrology by Central Water Commission is 1: 100 liters 10900 m^3/sec and 1: 500 of the total 13940 m^3/sec.

Under the Badaun Irrigation Project, the Champatpur branch emerges from the coastline of 4.800 km from the main canal. The length of the Champatpur branch is 34.00 km, and the length of its Rajwaha and Alpi is approximately 163.00 km. Head discharge of Champatpur Branch is proposed as 23 m^3/sec (812.13 ft^3/sec), CCA 21248 ha, and PPA 14874 ha.

As per the instructions of the UP government, adopting a modern irrigation system is proposed to be sprinkler irrigation under the pressure irrigation of the Champatpur branch system. By which irrigation can be done in more areas with less water.

In compliance with the above instructions, project for sprinkler irrigation of Champatpur Branch system has been prepared. The project has been designed with Ductile Iron pipeline for the entire Champatpur branch system in the project, which is proposd to be laid in the Main and Sub-main lines.

3. SUMMARIZED SNAPSHOT OF AONLA SPRINKLER IRRIGATION SYSTEM IN DISTRICT BAREILLY - DESIGN AND ESTIMATES AND COMPARISON AGAINST CANAL BASED IRRIGATION NETWORK SYSTEM

3.1 T-diagram layout

The T-diagram layout of the proposed Canal based design of Champatpur Branch under Badaun Irrigation Project is given in Fig-1 below. The sky coloured shaded portion in the diagram is the Champatpur Branch of Badaun Irrigation Project (currently known as, Aonla Sprinkler Irrigation System in district Bareilly).

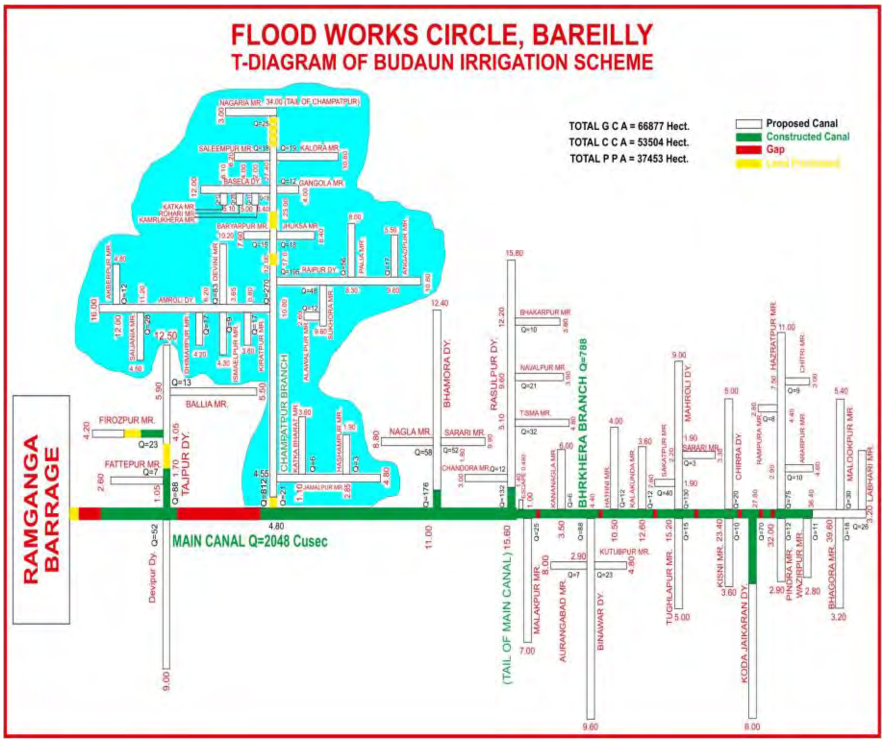

Figure 1. The T-diagram of proposed Canal based design of Champatpur Branch under Badaun Irrigation Project (currently known as, Aonla Sprinkler Irrigation System in district Bareilly)

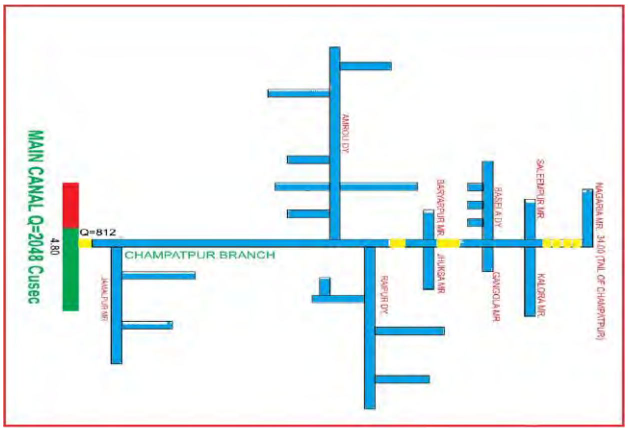

Figure 2. T-diagram layout of proposed Canal based design of Champatpur Branch (currently known as, Aonla Sprinkler Irrigation System in district Bareilly).

3.2 Salient features of the project in pipe-based design

Table 1. Location details of Aonla Sprinkler Irrigation System.

Location	
State	Uttar Pradesh (India)
District (s)	Bareilly & Badaun
Tehsils	Aonla, Badaun, Dataganj
Location	0.5 km d/s of the road bridge on Bareilly- Badaun SH-33 and about 10 km south of Bareilly city.
Nearest Rail head	i. Ramganga station on Chandausi- Bareilly loop line. ii. Bareilly junction about 10 km from the project site.
Nearest airport	15 km

Table 2. Pipeline scheme details of Aonla Sprinkler Irrigation System.

Main Canal	
Length	15.6 km
Bed width	30 m at the head
Water depth	2.20 m at the head
Bed Slope	15 cm/km
Discharge	56 m^3/sec up to silt ejector and 51 m^3/sec after that.
Lined/Unlined	0.3 km lined,15.3 km unlined
Branches - Champatpur branch	
Off-take of the Main canal at km.	4.800 km from the left bank
1. Length 2. Head discharge 3. Bed slope 4. Canal Duty per 1000 Acre 5. Solar Plant	34.00 km 23 m^3/sec as per Design 7 ft^3/sec 16.82 MW
Proposed areas under the scheme	
Gross Command Area (GCA) Culturable Command Area (PPA)	25841 ha 18001 ha
Total Cost of Project (Base Year 2018-19)	INR 8578 million
Cost/hectare	INR 0.477 million per ha.
Benefit-Cost Ratio	1.9:1

3.3 Abstract of cost for the project

Table 3. Abstract of cost for the project (without the cost of field distribution network)

Sl. No.	ITEM	COST (INR IN MILLION)
1	Preliminary	43.56
2	Land	103.59
3	Works	
A	Pipelines - Mains	2965.05
B	Pipelines - Sub-mains	1637.48
C	Cost of Solar power	629.18
	Total cost excluding GST =	**5378.86**
	Add SGST @ 6% =	322.73
	Add CGST @ 6% =	322.73
	Total Cost including GST =	**6,024.32**
	Add Centage charge @ 6.875% =	414.17
	Labour Cess @ 1% =	60.24
	Add 5% Contingency Rs. =	301.22
	Add 5% operation and maintenance for 5 years Rs. =	301.22
	Grant Total =	**7101.2 million**

Table 4. Abstract of cost for the project (with the cost of field distribution network)

Sl. No.	ITEM	COST (INR IN MILLION)
1	Preliminary	43.560
2	Land	103.59
3	Works	
A	Pipelines - Mains	2965.05
B	Pipelines - Sub-mains	1637.48
C	Cost of Field Distribution Network	1,118.63
D	Cost of Solar power	629.18
	Total cost excluding GST =	6497.49
	Add SGST @ 6% =	389.85
	Add CGST @ 6% =	389.85
	Total Cost including GST =	**7277.19**
	Add Centage charge @ 6.875% =	500.31
	Labour Cess @ 1% =	72.77
	Add 5% Contingency Rs. =	363.86
	Add 5% operation and maintenance for 5 years Rs. =	363.86
	Grant Total =	**8578 million**

3.4 Consideration of Rates

(a) The rates of cutting, clearance, earthwork – excavation, backfilling, etc. are taken from Construction Division SOR of Bareilly, Uttar Pradesh.

(b) Rates of providing, lowering, laying, aligning, fixing in position and jointing of pipes are considered by evaluating the market rates.

(c) Rates of supplying and fixing valves, actuators, flow-meters, and surge protection arrangements including thrust blocks and SCADA for the operation of individual pump house up to mains/sub-mains, Construction of Thrust Block, Valve Chambers, escape channels, etc. are taken as @ 4.0% of pipe cost.

(d) Rates for construction of structures for nalla crossings, road – canal crossings by siphoning or by construction of pedestals, approach roads to valves, etc. are taken as @ 3.0% of the cost of pipe network.

(e) Rates of supplying and installation of pumps and motors for 1.5 times of the power requirement for lifting water are taken as @ INR 25,000 per kw of power requirement including all Hydro Electro-Mechanical works as per market rate analysis.

(f) Rate of crop compensation and land is taken 0.2 million/ha while the average rate for acquisition is 12.5 million/ha.

3.5 Design criteria

(a) This cost is estimated for GCA 25841.64 ha and CCA of 18001.30 ha.
(b) Canal Duty is calculated at 7 ft^3/sec per 1000 acre.
(c) Provision for two step de-silting arrangement at the mouth of pressure pipe network and filtration arrangement at sub-chak level/diggies are incorporated in this estimate. As per the silt load measured and grain size analysis final arrangement for de-silting/ filtering would be decided.
(d) Total annual power requirement of the scheme is 16.82 MW.
(e) Capacity of Solar Power Plant will be 20 MW.
(f) Presently for estimation purpose planning on sample chak of size about 70 ha has been done.
(g) Design criteria for the pipeline have been adopted from CWC guidelines.

3.6 Cropping pattern

Selection of crops of cropping pattern depends on quantity and period of rainfall/water availability. In years of good well-distributed rainfall large area is covered under kharif crops while in years of late rainfall rabi crops are taken. This is a project for Kharif Irrigation, and in the Kharif presently Maze, Paddy, Pulses, oilseeds are shown in table 5 below.

Table 5. Cropping pattern

Sl. No.	Kharif Crop	Irrigation Intensity in Percentage
1	Paddy	20.0 %
2	Pulses	15.0 %
3	Maize	10.0 %
4	Oilseeds	15.0 %
5	Sugarcane	20.0 %
Total =		**80.0 %**

Total CCA of the project - 18001.30 ha.
ICA of the project for Kharif Season is proposed - 14401.04 ha.

Water allowance for designing the complete water carrier system including all losses has been calculated for CCA 18001.30 ha, based on peak monthly crop water requirement is 7 ft^3/sec per 1000 acre.

Note: *The intensity of irrigation is the percentage of the culturable commanded area proposed to be irrigated during either a crop season or during a year. The cropping intensity of irrigation can be more than 100%.*

3.6 Layout plan of sub-main

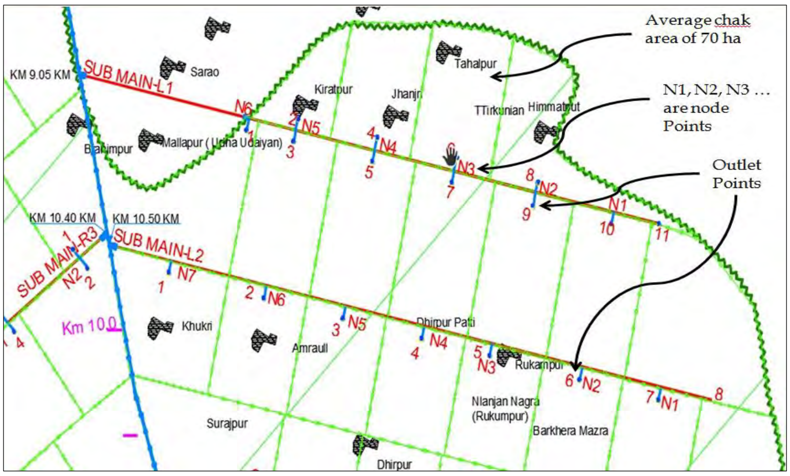

Figure 3. Layout plan of sub-main of Aonla Sprinkler Irrigation System.

The layout has been designed considering the average chak size of 70 ha, i.e., discharge from one outlet (N1, N2... in figure 3) can irrigate 70 ha land, and hydrant point is provided at every 4.0 Ha sub chak. The outlet point is preferably expected to be on khasra boundaries in the middle area within a sub chak.

3.7 Details of Pipeline

For efficient distribution of water, the whole command is proposed to be divided into two sub-areas fed with the help of two main pipelines. These sub-areas are proposed to be further fed with the help of the Sub mains/Laterals. The whole network has been designed on the concept of capitalized cost of the pipe and pumping unit along with the power required to operate the pumping unit. The pipeline has been designed on a telescopic basis, i.e., increasing towards head reach according to the increase in flow rate. As per the design pipe required for main lines, Ductile Iron Pipes confirming to IS 8329: 2000 and Mild Steel Pipes confirming to IS 3589: 2001 are proposed to be used for Main and Sub main/laterals along with required specials, valves, etc.

The pipeline/pipe network beyond outlet point is proposed to be of HDPE Pipe. The pipes confirming to IS 4984: 1995 are proposed to be used for supplying water to cultivators through the hydrant provided at sub chak area of 4.0-5.0 ha.

1. <u>RD 0.00 M to 1500.0 M of Feeder</u>

From RD 0 to 1.5 km land already acquired in sufficient width, therefore it would be economical to construct this reach as open gravity channel.

2. <u>RD 1500.00 M to Tail</u>

For rest of the reach MS/DI pipelines have been proposed to carry the water up to the off-take point of proposed sub-mains. Looking to the operation suitability two separate mains are proposed to be laid for feeding the command situated on the left side and right side of the Main respectively.

(i) Left Side (RD 1500 M to 34000 M):

From RD 1500 meter to 24000 meters one MS pipeline flowing under Pressure is planned and designed to feed the command situated on the left side of the Main. The internal diameter of the pipes is varying from 1300 mm to 2100 mm.

From RD 24000 meter to 34000 meters one pressurized DI pipeline is planned and designed to feed the rest command situated on the left side of the Main. The nominal diameter of the pipes is varying from 700 mm to 1200 mm.

From the left main about twelve sub-mains of varying discharge capacity & Head as per design requirement, off-take at different RD of the Main.

(ii) Right Side (RD 1500 M to 35100 M):

From RD 1500 meter to 21850 meters one MS pipeline flowing under pressure is planned and designed to feed the command situated on the Right side of the Main. The internal diameter of the pipes is varying from 1400 mm to 1700 mm.

From RD 21850 meter to 35100 meters one MS pipeline flowing under pressure is planned and designed to feed the rest command situated on the left side of the Main. The nominal diameter of the pipes is varying from 200 mm to 1200 mm.

On the Right main about fourteen sub-mains of varying discharge capacity and head as per design requirement, off-take at different RD of the Main. Alignments of the proposed pipe network have been planned on the relevant survey data available/ provided.

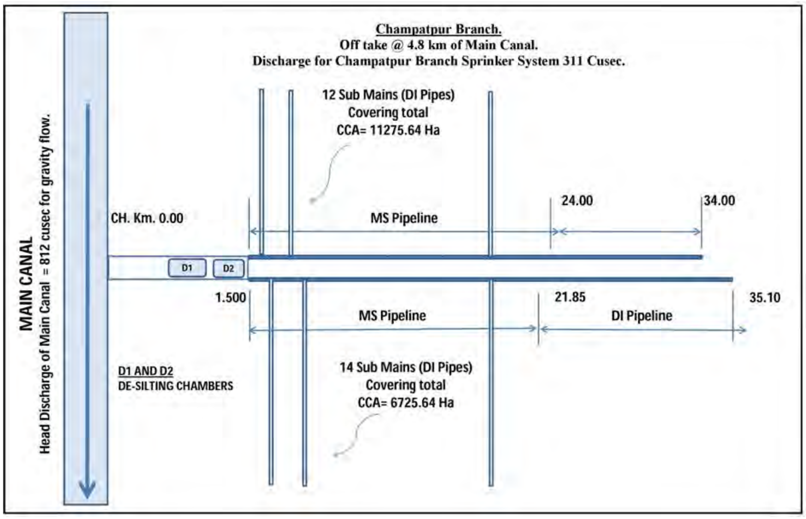

Figure 3. Layout plan of the pipeline of Aonla Sprinkler Irrigation System.

3.8 Operation and Maintenance

(a) *De-silting arrangement*: Two step de-silting arrangement at the mouth of pressure pipe network and filtration arrangement at sub-chak level / diggies are incorporated in this estimate.

(b) *Diggies & Pump Rooms*: Irrigation in the command will be provided through drip/ sprinkler (pressure). It is proposed to construct a Pump Room, Sump Well and Diggies at outlet point. Pumping unit along with control panel, valves, flow meter, hydro cyclone filter etc. will be installed in this pump room to supply water to cultivators with the help of HDPE pipe network laid about 1m below the ground level up to hydrant (Sub Chak OT) planned to be provided for 4.0-4.5 ha area.

(c) *Design and Installation of PLC-SCADA system*: In this project it is envisaged to provide PLC- SCADA to attain automation of Pipe Network and get Full/partial Control on the functions of the Pump Rooms, in the Control Room proposed to be set up at head of Sub-Main Pumping Stations. It shall provide advanced visualization and System control for quality & reliability.

3.9 Solar Power Generation

As per estimates, the demand for power for this project in one year will be 25.36 Million Units. The annual expenditure on with conventional power is around 1.9 million but it could have been brought down to nil with the solar power station. Solar based power projects have attracted the attention of State and Central Governments and also have been given priority due to:

(a) Short gestation periods, photovoltaic systems are modular in nature.

(b) Reduced transmission losses, decentralized and distributed generation systems.

(c) Use of environment friendly solar resource for power generation.

(d) Revenue will also be generated from 6 months excess generation from 20MW Solar Plant @ Rs. 40,000 per MW for one year.

(e) Badaun area has High Solar Power Generation Potential, So, the option to generate power from solar power plant could be a good alternative and more remunerative in long period.

3.9 Benefit Cost Ratio

BUDAUN IRRIGATION PROJECT CONSTRUCTION DIVISION, BAREILLY.
Project for Aonla Dataganj Sprinkler Irrigation in Districts Bareilly & Budaun
Benefit Cost Ratio

S.No.		Particulars	Pre -Project (in lacs)	Post -Project (in lacs)
A		Gross Receipts		
	1	Gross value of farm Produce	2524.37	13147.19
	2	Add dung receipts@3% of the Fodder Expenditure	75.73	394.42
		Total A (1+2)	2600.11	13541.61
B		Expenses.		
	1	expenditure on Seeds, manure hireed Labour.	781.70	1588.59
	2	Fodder Expenses@15 % of Gross value of produe	378.66	1314.72
	3	Depreciation on implements@2.7% of Gross value of prod	68.16	354.97
	4	Share & Cash Rent @ 5 % of Gross value of produe	126.22	394.42
	5	Land Revenue @ 2 % of Gross value of produe	50.49	262.94
		Total B (1+5)	1405.23	3915.65
C		NET VALUE OF PRE PRODUCE= (Total A- Total B	1194.88	9625.96
D		ANNUAL BENEFITS		
	1	Net value of Post Project		9625.96
	2a	Net value of Pre Project	1194.88	
	2 b	Net value of Soler power Revenue		48.00
	2 c	Net value of Land Savings		53033.80
			1194.88	62707.76
		Net Annual Benefits	Total Rs	62707.76
E		CAPITAL COST OF PROJECT (Rs 85014.34)		84231.36
F		ANNUAL COST		
G	1	Interest on Capital @10% of Project cost		8423.14
E	2	Depreciation @ 1% of Project cost		842.31
E	3	Annual operation & maintenance As per Project cost		3572.91
E		Net Annual Cost Total	Total Rs	12838.36
E				
		Benefits Cost Ratio =	Net Annual Benefits / Net Annual Cost	
			62707.76 / 12838.36	
			4.88	

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4. COMPARISON BETWEEN OPEN CANAL AND PIPED IRRIGATION

Table 5. Comparison between the Open Canal and Piped Irrigation System.

Sl. No.	Description of activity	Open channel system (without sprinkler system)	Piped Irrigation system (without sprinkler system)	Piped Irrigation system (with sprinkler system)	Remarks
1	Head Discharge	812 ft³/sec	311 ft³/sec	311 ft³/sec	Savings of around 500 ft³/sec in Piped Irrigation for additional area to be irrigated.
2	Total area to be irrigated	14,874 ha	18,001 ha	18,001 ha	(for pipeline system total design duty is calculated based on the CCA)
3	Cost comparison	INR 5787 million	INR 7101.2 million	INR 8578 million	Piped irrigation consists of Gravity/ Pressure mains and sub-mains, field distribution in sprinkler, 20 MW Solar Power Plant, pump house and siltation chamber/sump wells, filters and valve arrangements, electro-mechanical works, cost of operation and maintenance.
4	Cost per ha	INR 0.322 million	INR 0.395 million	INR 0.464 million	
5	Permanent Land required (in ha)	433 ha	7.88 ha	7.88 ha	In piped irrigation only RoU (right of use)/crop compensation and land is required, whereas in an open channel system, land acquisition is required, resulting in
6	Cost of Land	INR 5412.5	INR 117.714	INR 117.714	

Sl. No.	Description of activity	Open channel system (without sprinkler system)	Piped Irrigation system (without sprinkler system)	Piped Irrigation system (with sprinkler system)	Remarks
		million	million	million	enormous delays. The average rate of crop compensation and land is taken 0.2 million/ha while the average rate for acquisition is 12.5 million/ha.
7	Revenue generation through the solar plant	Nil	INR 4.8 million	INR 4.8 million	Considering 6 months excess generation of 20MW @ INR 40,000 per MW for one year.

5. CONCLUSIONS

In this manner, India is gradually shifting towards Pressurized Pipe Based Irrigation Network System integrated with Solar Plants in place of Canal Based Irrigation System as has been described above. The change is gradual, but irreversible because the Government of India is supporting this decision as a policy for implementing irrigation projects in a faster manner, at a lower overall cost and by utilizing less amount of water.

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SUBSURFACE WATER LEVEL CONTROL SYSTEM "FOEAS" AND ITS DIFFUSION

Tatsumi Tomosho[1] and Noburo Haraguchi[2]

ABSTRACT

A challenge for the irrigation of paddy fields in Japan is the compatibility between paddy rice cultivation and upland farming. The excess production of rice and low self-sufficiency of other crops have been problematic since the 1970s; their resolution requires the development of crop rotation technologies that can enable the production of both rice and other field crops in paddy fields. In 2006, the National Agricultural Food Research Organization (NARO) developed a subsurface water-level control system called "FOEAS" for the irrigation and drainage of paddy fields to enable crop rotation. By using trunk and branch pipes and an auxiliary mole drain, FOEAS allows for both under-drainage and underground irrigation. The effect of FOEAS at increasing yields of soybean and wheat has been substantiated. On account of its high drainage capability, FOEAS can drain fields shortly after rainfall. To promote its use and popularization, NARO has published a user manual in collaboration with other research centres specializing in crop cultivation technology. By 2017, FOEAS had been or was being installed on 12,500 ha of paddy fields all over Japan. Although its use was initially aimed at the cultivation of upland crops such as soybean and wheat, it is now being tested in vegetable production, and it may soon become established as an innovative technology.

Keywords: Paddy field, Subsurface irrigation, Subsurface drainage, Subsurface water-level control, Japan

1. INTRODUCTION

The excess production of rice and low self-sufficiency of other crops have been problematic in Japan since the 1970s. In 2017, the overall food self-sufficiency ratio was only 38% (rice 97%, wheat 14%, soybean 28%, vegetables 75%). Resolution of these problems requires the development of crop rotation technologies that can enable the production of both rice and other crops in paddy fields. The challenge in Japan is the compatibility between paddy rice cultivation and upland farming, because paddy fields are artificial wetlands, but upland fields should be well drained (Photo 1).

In 2006, the National Agricultural Food Research Organization (NARO) developed a subsurface water level control system called "FOEAS" (Farm Oriented Enhancement Aquatic System) for the irrigation and drainage of paddy fields to enable crop rotation.

2. FEATURES OF FOEAS

By using an underground trunk and branch pipes buried at a depth of 50 cm and an auxiliary mole drain buried at 40 cm, FOEAS allows for both under-drainage and underground irrigation (Fig. 1). Moreover, it can manage the subsurface water level on both the supply and drainage sides.

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Photo 1. Waterlogging in a paddy field: how to resolve the between paddy fields (as artificial wetlands) and upland fields (as well drained land)?

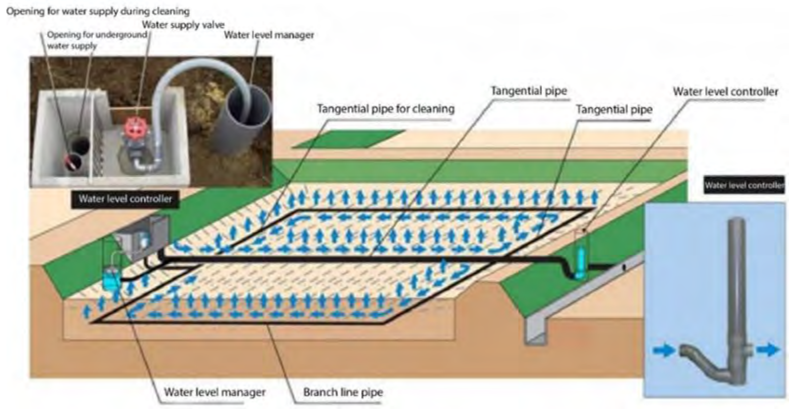

Figure 1. Outline of the FOEAS subsurface water-level control system

The drainage regulator has a concentric cylindrical structure, in which the inner cylinder moves vertically. When the actual water level is above the prescribed level, excess water overflows the inner ring and flows out of the field. The target water level can be set in the range from 30 cm below the soil surface to 20 cm above (Figs 2, 3).

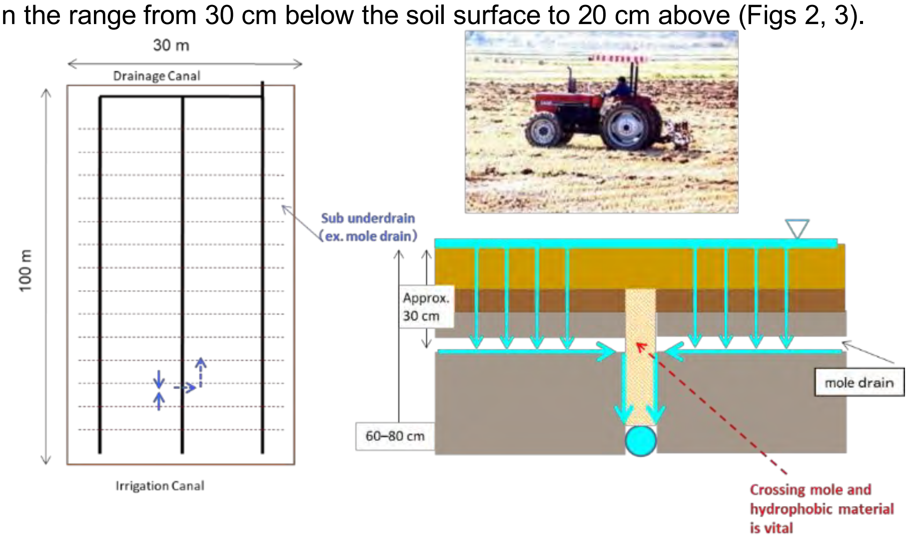

Figure 2. Combination under-drain for irrigation and drainage

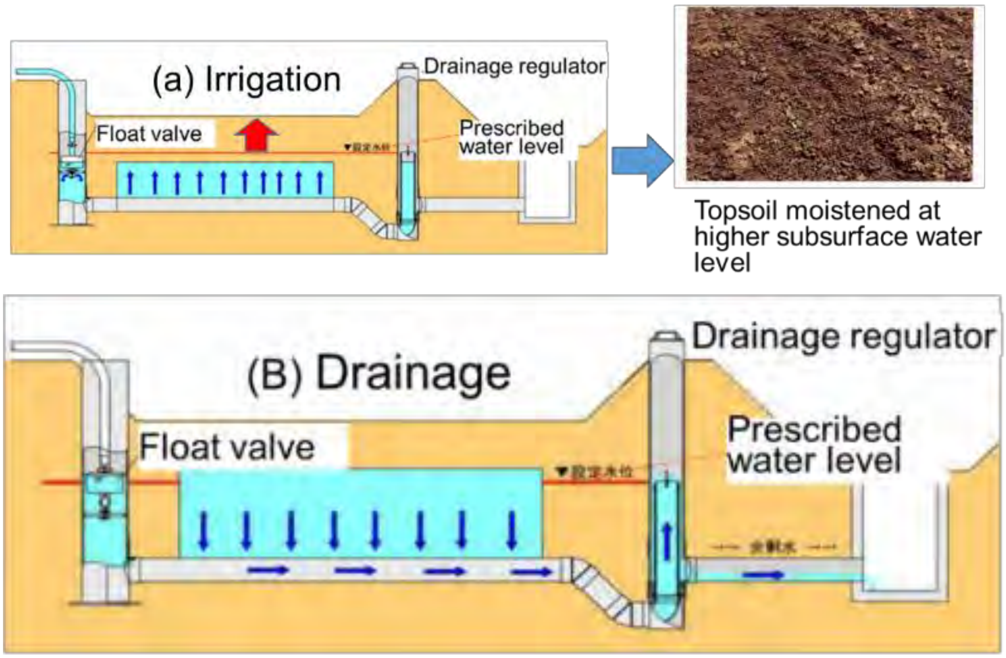

Figure 3. Subsurface water-level control by FOEAS

FOEAS directly controls the water table under the soil surface, and indirectly controls the soil moisture condition in the root zone. Supply of water from the water table to the root zone by capillary action creates suitable conditions for upland crops. For example, setting the water table 30 cm below the soil surface creates a moderate soil moisture content, which enhances germination and emergence of upland crops.

3. EFFECTS OF FOEAS

On account of its high drainage capability, FOEAS can drain fields shortly after rainfall (Fig. 4). Its ability to increase yields of soybean and wheat has been substantiated (Fig. 5; Table 1). To promote the use and popularization of FOEAS, NARO has published a user manual in collaboration with other research centres specializing in crop cultivation technology.

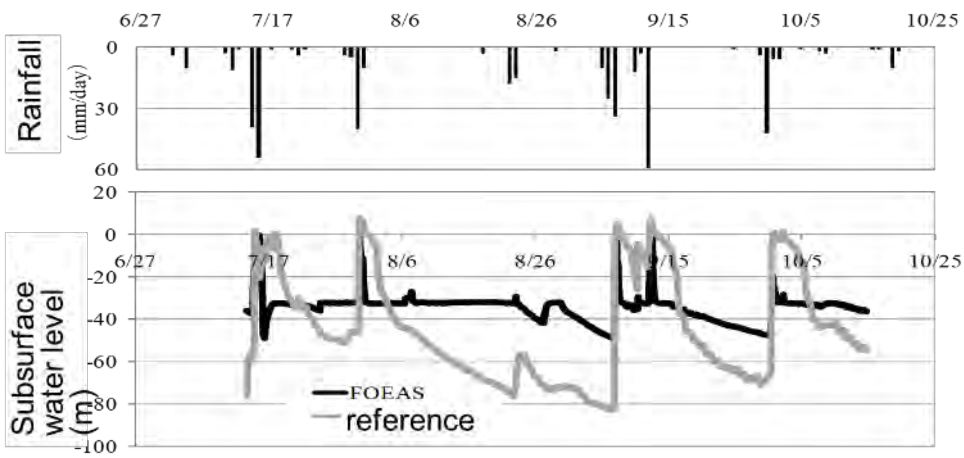

Figure 4. Combination under-drain for irrigation and drainage

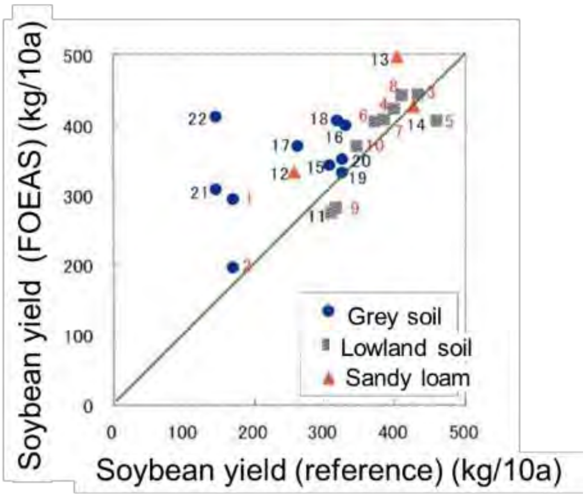

Figure 5. Effect of FOEAS on soybean yield

Table 1. Effect of FOEAS on soybean yield

	Number of experimental plots	Yield (kg/10a)		FOEAS/Reference
		FOEAS	Reference	
Soybean	19	98.5～492.0	44.7～422.0	0.97～3.27
Rice	6	404.4～581.0	310.7～546.0	1.03～1.30
Wheat	10	238.0～774.0	136.0～704.0	0.78～2.43

4. FUTURE PROSPECTS

By 2017, FOEAS had been installed (or was being installed) on 12,500 ha of paddy fields all over Japan (Fig. 6). Although the use of FOEAS was initially aimed at the cultivation of upland crops such as soybean and wheat, its use in vegetable production is currently being tested (Photo 2), and it may soon become established as an innovative technology.

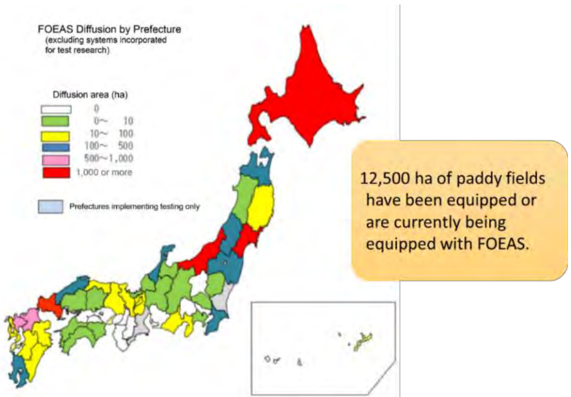

Figure 6. Diffusion of FOEAS in 2017


Onions (Miyagi Prefecture)


Broccoli (Miyagi Prefecture)


Cucumbers (Iwate Prefecture)


Sweet Potatoes (Kagoshima Prefecture)

Photo 2. Use of FOEAS in vegetable production

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ISBN 978-81-89610-27-2

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