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A READINESS ASSSESSMENT OF INDONESIAN PILOT PROJECT

CASE STUDY KEDUNGPUTRI, A PREMIUM IRRIGATION AREA, CENTRAL JAVA

Rr. Vicky Ariyanti

ABSTRACT

Modernization in irrigation has finally touched down in Indonesia with better efforts on technological advancement, institutional strengthening, and human resources enhancement. The current project in Kedungputri has proven to withhold the potential of modernization. This paper answers how ready the irrigation area status is towards the modernization ideal. The ambitious project is performed on premium irrigation or irrigation area with a reservoir as its source. It is a strategic project with its upstream Bener Dam done by the Government of Indonesia and the World Bank's SIMURP (Strategic Irrigation Modernization and Urgent Rehabilitation Project). The analysis is done through purposive sampling and qualitative methodology based on existing documents and evidence of the ongoing rehabilitation project and its complementary soft component since 2019. The readiness status will be based on the five pillars of the Indonesian version of irrigation modernization, namely water supply reliability, irrigation network reliability, water management, institutional, and human resources. A model is made based on indicators for each of these pillars. The condition in the Kedungputri is assessed based on this model. The findings show the condition of the institutional arrangements has unique and significant impacts on the readiness status, which is covered under the soft component or the three pillars namely water management, institutional, and human resources. The institutional arrangement should start at the very beginning, with an established function of an irrigation management unit. Modernization efforts should start from the soft component first. This arrangement will require a lesser upfront investment before the rehabilitation takes place and it will also make sure that the water users are more supportive of the upcoming project.

Keywords: modernization, premium irrigation, rehabilitation, readiness assessment

I. Introduction

Modernization approaches to irrigation have been implemented in developed countries for some decades now and yield results in irrigation water efficiency. Proof that modernization has taken full functions in these countries has been portrayed as successful in increasing water productivity (FAO, 1999). As for the term modernization, the effort on irrigation is defined as a combined upgrading of technical, managerial, and organizational, not only infrastructure rehabilitation. The objective is to improve resource utilization and water delivery to farms. The focus shifted from training in the 1980s to physical intervention in the 1990s, to water user associations creation in the 2000s. It also continued to include all aspects of irrigation management.

With this global trend, Indonesia, which started its original ideas on canal modernization in the 1990s recently pronounced its overdue commitment to modernizing irrigation systems. The programs mainly are rooted in loan agreements with international donors such as World Bank and Asia Development Bank (WISMP, IPDMIP, and SIMURP). All of them aimed at improving water efficiency through infrastructure rehabilitation with better water management in the early 2000s but were recently added institutional arrangements for the farmers through water user association (WUA) and internet of things (IoT) for the operation of irrigation canals (MPWH, 2018, World Bank, 2018).

Moreover, some irrigation supplied by a big dam and reservoir or so-called premium irrigation is taken as a priority over other irrigation systems as a pilot for modernization in Indonesia. One of these premium irrigation systems is Kedungputri Irrigation District, as it will be supplied shortly by Bener Dam, estimated by 2025. The dam will supply not only to Kedungputri but also to several other irrigation districts under the Bogowonto River Catchment, including those under the municipal and provincial government authorities.

As for the Kedungputri location, the irrigation canal scheme covers 4.341ha including primary, secondary, and tertiary systems (figure 1). The SIMURP project by the World Bank from 2020 to 2023 will rehabilitate the whole system and also the needed institutional arrangements plus mechanical electrical for the water gates. However, the project is handled with partnerships of four ministries, namely the National Development Planning Agency, Ministry of Public Works and Housing, Ministry of Internal Affairs, and Ministry of Agriculture. This project will encapsulate modernization from all aspects of farming. The significance of this project will be setting an example of how modernization in irrigation is performed at an irrigation district level for Indonesian cases.

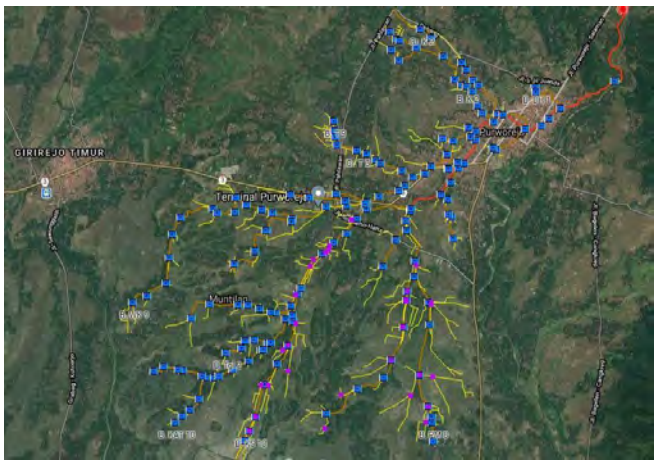


Figure 1 Kedungputri Irrigation District (BBWS SO, 2018)

The Indonesian version of irrigation modernization is aiming at developing and managing an irrigation system with five pillars. Pillar no.1 improves water security and availability; increasing the

reliability and supply of irrigation water, which is directed to issues of water conservation, protection of water sources, water allocation, water distribution, and mitigation of flood risk. Pillar no.2 rehabilitation and upgrading of infrastructure; improvement of irrigation facilities and infrastructure, which is directed to the issue of infrastructure adaptation within the framework of fulfilling services and providing optimal funding and human resources. Pillar no. 3 improvement of the irrigation management system; improvement of the irrigation management system, which is directed at the issue of water user rights, agreements on services, sustainable irrigation financial management, information management, and strengthening of coordination standards between stakeholders. Pillar no.4 strengthening of irrigation management institutions; strengthening irrigation management institutions, which are directed to the issue of the existence of One System One Management, water distribution system in irrigation networks, oriented to service, transparency, and accountability. Pillar no.5 is strengthening of human resources; empowerment of irrigation managers, which is directed to the issue of strengthening planning resources, and knowledge of infrastructure (DGWR, 2018, World Bank, 2018). These five pillars are used as tools for the readiness assessment for irrigation modernization in this study.

II. Methods

The chosen case study as an approach for this paper, along with qualitative methodology (Flick, 2008) with in-depth observation. Based on observation inspired by an ethnographic approach to an organization (Emerson, Fretz, et al., 2011, Crang and Cook, 2007). Primary data were obtained in pictures and notes. Secondary data were submitted by the Serayu Opak RBO. All data are taken based on two years (2020-2021) observations of an irrigation modernization project, using Kedungputri Irrigation District as the case. All secondary data are taken from the project office, with purposive sampling from members of the project implementation unit (PIU).

The data were analyzed based on the five modernization irrigation pillars as variables and labeled as codes with a triangulation process by linking the indicators to the proof of activities. The codes were grouped according to linked indicators and put into axial coding (Flick, 2008). Also, this coding process is done manually.

III. Results

Based on the five pillars, the readiness assessment for modernization in irrigation for this case study is divided by (i) improving water security and availability; (ii) rehabilitation and upgrading of infrastructure; (iii) improving irrigation management system; (iv) strengthening of irrigation management institutions; and (v) strengthening of human resources. All data analyzed in this section

is gathered from various sources but compiled by the Serayu Opak River Basin Organization under the Strategic Irrigation Modernization and Urgent Rehabilitation Project Project Implementation Unit (SIMURP PIU).

3.1 Improving water security and availability

This irrigation district is considered as premium irrigation as it will be supplied from Bener Dam from 2025. Although currently, the irrigation system is under national government jurisdiction, the water in this district is also supplying municipal level irrigation districts. The target of Bener Dam irrigation service covers up to 15,500ha, where Kedungputri is included as a mid-stream of Bogowonto and targeting an cropping intensity of 252% from the current 200%. The following is the target of service scheme:

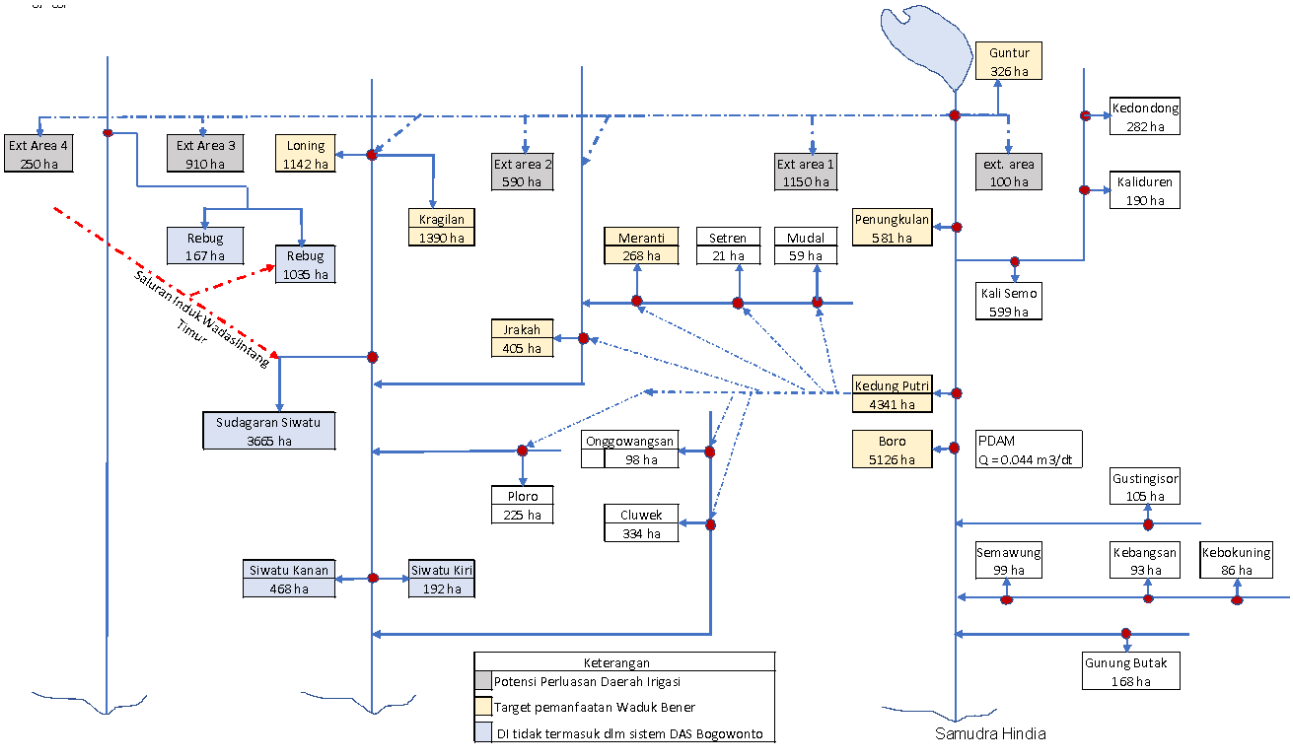


Figure 2. Bogowonto Catchment Water Allocation Scheme (DGWR, 2020)

Water allocation in Kedungutri currently is not covering the irrigation during dry season due to low discharge in Bogowonto River as seen below (figure 3 left). However, the potential of the Bener Reservoir is not only used to meet irrigation water needs in several existing dams, 1.5 m3/sec of raw water can also be used to meet irrigation water needs for the expansion of an irrigation area of 1100 ha. Water allocation for several weirs for scenarios before the operation of the Bener Reservoir in the Kedungputri needs to be given the K factor for several periods (half-monthly) during MT of 0.7 – 0.8. With this applied the Kedungputri secondary networks: Mudal, Mranti, Cluwek, Ploro, Gustingisor and Gunung Butak can be met (figure 3 right).

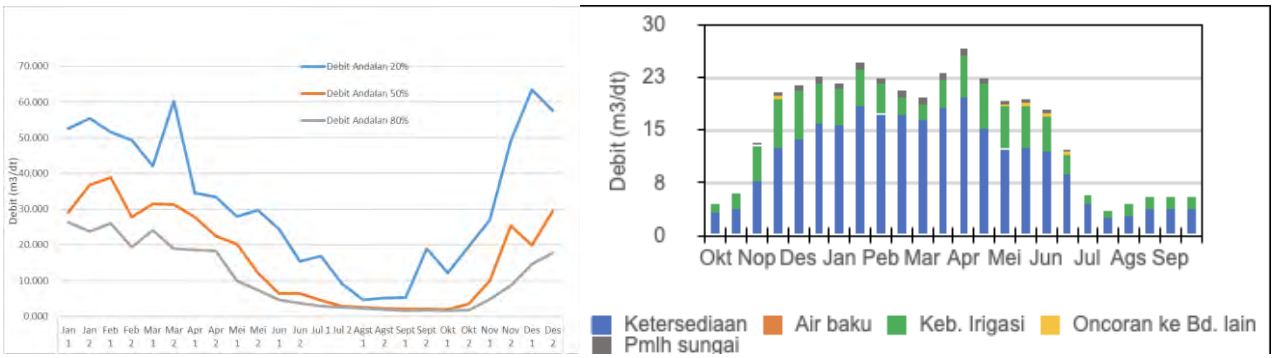


Figure 3. Kedungputri Weir's Discharge: before (left) and after (right) Bener Dam is constructed (DGWR, 2020)

3.2 Rehabilitation and upgrading of infrastructure

The main building of the Kedungputri Irrigation network system is the Kedungputri Weir, the Bogowonto River with river stone construction and is a fixed weir type. The building assets of the Kedungputri Irrigation Area from the results of the irrigation network search that has been carried out there are 631 irrigation building assets. consists of 1 weir, 21 buildings for and for tapping, 173 tapping buildings, and 437 complementary buildings, and there are 145 canal segments. The physical data of the Kedungputri are as follows:

Figure 4. Irrigation channel condition (left) and irrigation infrastructure (right)

The condition of irrigation infrastructure has started to deteriorate (figure 5), which results in a large amount of water being lost along the irrigation canal. All channel conditions are fairly high with sediment levels from these conditions needing sediment dredging to function as designed channel discharge capacity and meet the needs of the farmers.

Kedungputri Main Canal Condition Kesambi Pleden Secondary Canal Condition

Drain Gate B.KP 0 Drain Gate B.KP.1g

Figure 5. Condition of Kedungputri Irrigation District

In realizing a modern irrigation system, especially in irrigation infrastructure, it is proposed to have an electric gate for preventive measures to deal with flooding that often occurs at the Drain Gate B.KP 0 on Hm 0+00 and B.KP.1g on Hm 33+50 (figure 5). Also, based on the discharge and rainfall data at the work location, it is necessary to plan the allocation of water distribution and make a planting plan that is under the availability of water. Additionally, following applicable regulations, the calculation of performance and updating of asset condition data should at least be carried out periodically.

The following multi-year contract plan is put in a scheme (figure 6) that answers the proposed works in the rehabilitation project, which includes relining the canals, adding electric gates, volumetric measurements, and dredging the canal siltation. It will also cover not only primary canals but also secondary and tertiary canals. Examples of rehabilitation results in Kedungputri by May 2022 are the lining of the floor to the main canal and the relining of the sides, while also relining five secondary canals by end of 2021 (figure 7). A comprehensive and systematic rehabilitation based on the function of the irrigation system is enhanced with additional infrastructures of modernity in the electrical gates on the weir and six secondary gates planned to be installed in 2022 (figure 8).

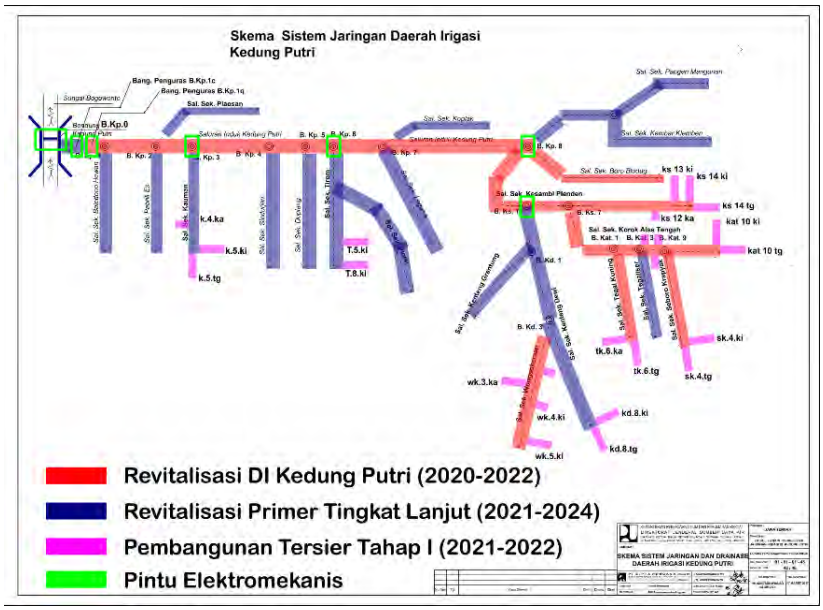


Figure 6. MYC Scheme for Kedungputri Rehabilitation

Figure 7. Lining of main canal (up) and relining secondary canals (down)

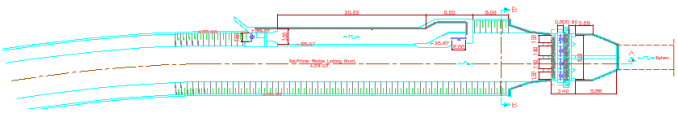


Figure 8. Ilustration Design of Mechanical Electrical Gates

3.3 Improvement of irrigation management system

The existing irrigation management system includes the schematization of the cropping intensity group and plans for the Kedungputri District (figure 9). The system follows the following assessment, those under the red-colored group 1 are the first to yield water with 1,201.79ha; secondly, blue-colored group 2 is serviced with 1,880.80ha, and thirdly, yellow-colored are group 3 is serviced with the 929,74ha. The total of the three groups cannot be summed into the total irrigation district service area as the timing is also different. Group 1 will receive the first service as it is the furthest, continued to group 2 and lastly group 3. This grouping has been accomplished by the irrigation commission.

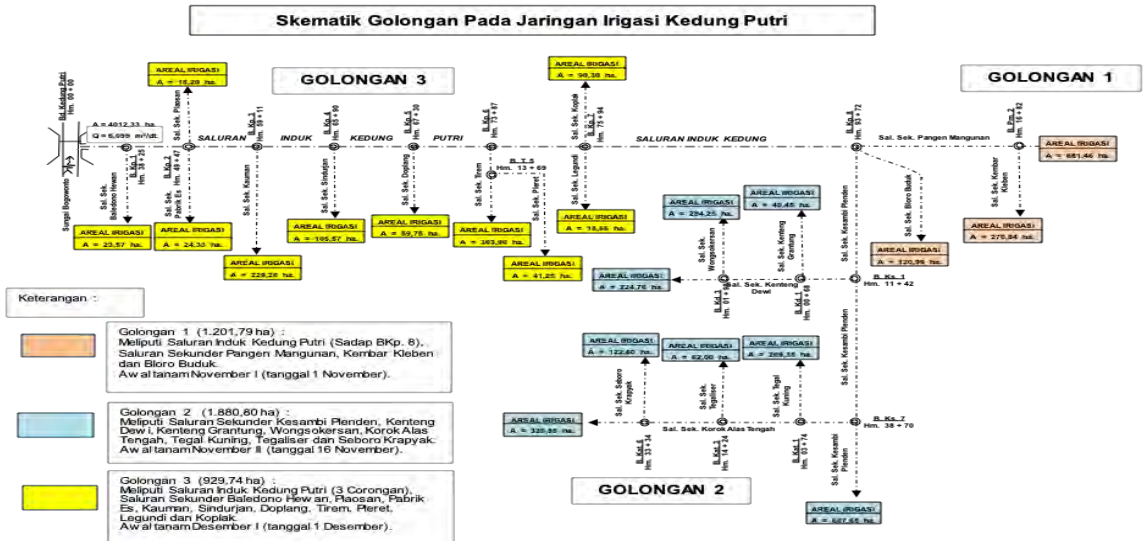


Figure 9. Cropping Group Scheme

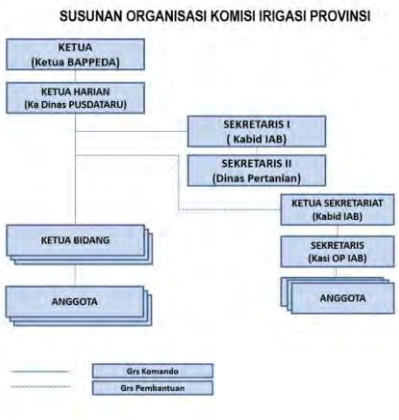
However, during the rehabilitation project, in 2021 this plan cannot be put forward as the canal needs to be dried for five months starting from August to December to give time for the primary canal lining to be completed for the whole 9km. This will happen again in 2022, as the rehabilitation project is still ongoing, but intermittently for four months starting September to December.

An improvement to the management system will be the irrigation service agreement (ISA) for this irrigation district. It is an agreement which fosters transparency in providing service for irrigation management. The ISA was established in February 2022, approved by all stakeholders: the Serayu Opak RBO (BBWS SO) as service provider, Progo Bogowonto Lukulo Water Resources Management Office (BPSDA Probolo), Public Works and Housing Agency of Purworejo and Forum of Water User Association (IP3A) Tirta Mulyo Jaya. It is still far from perfect as the water allocation stated in the agreement is still too global, and overall the cropping intensity of 200% is difficult to achieve as it is not possible to cultivate during the dry season.

3.4 Strengthening of irrigation management institutions

Currently, the Kedungputri has a complete set of irrigation management institutions, ranging from the national level at the Serayu Opak RBO, BPSDA Probolo for the provincial level, and PUPR Purworejo for the municipal level. For irrigation, they all congregate in the Provincial Irrigation Commission, where BPSDA Probolo holds the secretariat. Although the legal status of the commission is stated by the Governor's Decree No. 611/27 of 2017, the provincial level is not so close to the municipalities. An irrigation commission at the municipal level was also established for Purworejo based on the Regent's Decree No.160.18/55/2020.

These commissions' structures are based on coordination and aspiration. These commissions (figure 10) discuss water allocation plans (RAAT), global cropping patterns (RTTG), and detailed cropping patterns (RTTD), and also they implement and control the cropping plans, but their discussions are not always forwarded to the farmers. Their meetings happen every two weeks and discuss their agendas, especially on water allocation. The results of their meetings are written into Minutes of Meetings (MoMs), but not all water user associations (WUAs) have access to these MoMs. Currently, due to the COVID-19 pandemic, most all meetings were held using virtual meeting platforms, which should give access to a wider audience. However, there is also a limit in granting access only to those members of the commission. Some WUAs have representatives sitting amongst the members of the irrigation commission, but not all are willing to share the information. More efforts on strengthening should be aimed at the way information is spread to WUAs and farmers may be through chat group applications or website announcements.



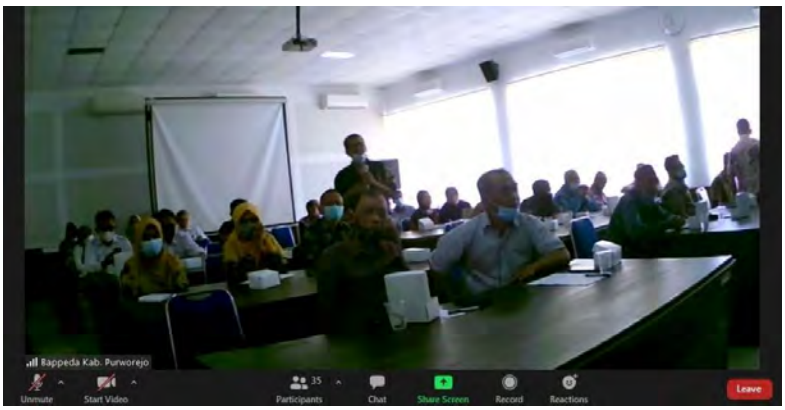


Figure 10. Irrigation Commissions

More on the institutions, the water governance cannot be solely applied to governmental agencies, they need to also include a participatory approach by addressing the needs of the water user associations. Kedungputri has one forum for water user association (IP3A), three secondary level WUAs (GP3A), and 52 tertiary levels WUAs (P3A). Each tertiary level WUA is connected with its village, making it a total of 52 villages under service by the Kedungputri Weir.

The SIMURP project also considers this aspect by establishing multiple activities to enhance WUAs' institutional management, for example by deploying community technical assistance (TPM), facilitating WUAs' legalization status, and training for WUAs revitalization, facilitating additional WUAs, and workshops for WUA capacity buildings.

3.5 Strengthening of human resources

On top of that, the project is also equipped with a river basin public campaign (figure 11), which introduces the importance of tackling the irrigation district as part of a basin. It consists of raising awareness at the river basin level by giving information on the SIMURP activities in Kedungputri, which will affect the whole Bogowonto Basin to the Serayu Bogowonto Water Resources Coordination Team (TKPSDA WS Serayu Bogowonto). The activities also include sharing sessions and printing out materials, also roadshows to members of related SIMURP partners at the provincial and municipal levels. All of these activities are facilitated by the Serayu Opak RBO where coordination between physical and non-physical activities is tackled by the Project Implementation Unit (PIU).

This campaign is also completed with training for PIU members and workshops from the national levels, not to mention numerous visits from guests who want to learn more about SIMURP project implementation under its jurisdiction. Aside from that, the PIU members continued to develop their skills in understanding each aspect of the SIMURP projects and learn how to achieve certain successful completion within the indicators set by the World Bank.

Activities such as discussions, sharing sessions, and visits from the international experts are also helping in achieving the necessary level of understanding for the PIU to maximize its function. Although all of these activities were also hindered by the COVID pandemic condition, which made most of them were done through virtual meetings (figure 11), the results of continued monitoring are still more beneficial in enhancing human resources capacity.

Figure 11. Example of Public Campaign and Workshop for TKPSDA members and PIU

However, the time has come for additional skill sets to be owned by modernized water users and irrigators. These skill sets are knowledge of information and communication technology, ability to work with big data, automated data collection, decision-making application, technical know-how of machines to carry out maintenance and interdisciplinary approaches, also personal skills to adapt

and able to change with a complete mindset for lifelong learning. A new line of workers is also needed, aside from the common water allocation operator, such as IT personnel, IT engineers, network administration, and technical support.

IV. Conclusions

Overall the five pillars of modernization in irrigation have been touched, although not yet comprehensive and are still in process. The findings for each pillar proposed a connection between irrigation modernization and facing challenges of uncertainties in the future presented as aspects of the readiness assessment is as follows:

(i) improving water security and availability; during the dry season, not all irrigation districts are supplied, but when Bener Reservoir is functioning whole area supplies during the dry season.

(ii) rehabilitation and upgrading of infrastructure; many infrastructures including weir, primary, secondary, and tertiary canals are damaged, resulting in water losses throughout the system. With the current MYC rehabilitation project (2020-2023) oriented toward a comprehensive system and the rehabilitation will be able to prevent future losses.

(iii) improvement of the irrigation management system; currently, water allocation and cropping patterns are not yet obeyed by all farmers, resulting in some of them being victimized by the canal shut down during the rehabilitation period. More coordination with WUAs in all levels of primary, secondary, and tertiary canals involving technical assistance and more open information supported by cross-sectorial stakeholders will heighten the chance of better communication. The irrigation service agreement (ISA) also improved transparency in water management.

(iv) strengthening irrigation management institutions; the current irrigation commissions with two levels at the provincial and municipal levels are not effective in coordination with the RBO and WUAs. It is recommended that a dedicated unit of irrigation management be established at the Kedungputri Irrigation District.

(v) strengthening of human resources; awareness and capacities of human resources in each stakeholder need to be further improved by monitoring and facilitating discussions and training in the light of ICT and a mindset for change.

Out of the five pillars, the first two depend on physical component investment, while the other three on non-physical or soft component investment. The findings also urge to start the soft component first, as it is less extensive in investments and will surely help more during the rehabilitation period. In gaining trust during the water shutdown, it is undoubted that it will make many farmers caught in a difficult economic standpoint when they are not well prepared.

However, all these modernization efforts will be in vain if all related stakeholders will not continue to duplicate and implement them in other irrigation districts. At the moment, the status of each of the irrigation modernization pillars is no longer at the starting point, but rather in progressive stages in Kedungputri Irrigation District. Indonesia is still a long way to achieve full modernization in irrigation, but it is ready to move forward. However, the country will see these stages as improvements towards achieving better sustainability in irrigation management and addressing future uncertainties.

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Assessment of modernization needs for the Philippine National Irrigation Systems to Support High Value Crop Production

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ABSTRACT

Publicly funded and assisted irrigation systems in the country are primarily designed and operated for rice monoculture. Water is conveyed from the source through network of canals by gravity flow. The irrigation infrastructure, technology and water management are relatively simple as rice is irrigated by continuous flooding the cropped area between 5-15 cm.

In recent years, concerned government agencies have promoted high value crop (HVC) production as a strategy to improve farmers income, nutrition, and sufficiency in major food crops; generate agriculture-based enterprise in rural areas; and adapt to decreasing water supply to agriculture. To help achieve crop diversification objectives and improve agricultural water productivity, this study investigated the case of three national irrigation systems (NIS), one each for the three major islands of the country. Its specific objective was to determine the necessary changes that will enable the three NIS, namely, Lower Chico River Irrigation System, Mainit River Irrigation System, and Tago River Irrigation System, to provide the required irrigation service for HVC production. System walkthroughs and consultations with farmers and system personnel were carried out to assess the present state of irrigation infrastructures, operation, and management as well as the constraints, challenges, and opportunities for HVC production in NIS-irrigated areas.

The result of the study showed that the operational objectives, existing system design and irrigation practice in the three NIS are mainly for lowland rice cultivation and are not compatible for HVC cultivation. Also, the result indicated receptiveness to HVC production mostly in downstream areas where farmers have been diversifying into vegetable and other less water-loving crops to cope with water scarcity. Central to the proposed changes to support HVC production are the flow control structures for the main system and on-farm irrigation technology for target tertiary areas.

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INTRODUCTION

National irrigation systems are government-owned, gravity-type system serving mainly rice areas. They serve about 933,000 ha or 47% of the total irrigated areas of the country (NIA 2020). In recent years, concerned government agencies have promoted high value crop (HVC) production as a strategy to improve farmers income, nutrition, and sufficiency in major food crops; produce for export market; generate agriculture-based enterprise in rural areas; and adapt to decreasing water supply to agriculture. The National Irrigation Administration (NIA) has adopted crop diversification as an adaptation strategy to climate change (NIA, 2020). Its scheme includes planting of cash crop after a rice cropping and intercropping rice with permanent and/or cash crops.

NIS are designed and operated for lowland rice cultivation. Unlike rice, most vegetables and HVC do not thrive well under submerged soil condition. Hence, crop diversification strategy will require changes and upgrading in the design and irrigation technology of existing NIS to achieve the soil condition and water delivery for optimum growth of non-rice cash crops and HVC. This will mean a system design and irrigation technology that allows flexible and measured water delivery and on-farm application. Also, system operation and water management will have to be precise and more efficient compared to those practiced for rice irrigation. Consequently, NIA and IA capacity for management of multiple-crop irrigation systems, including skills in operating modern flow control structures will need be enhanced.

This study was aimed at identifying key modernization needs for NIS to be capable of providing irrigation to diversified cropping and contribute to the societal goals of transforming agriculture from low productivity to climate-resilient, productive, and profitable enterprise.

MATERIALS AND METHODS

The case study systems included the three NIS, one from each major island of the country, selected by the NIA namely: Lower Chico River Irrigation System (RIS) in Luzon, Mainit RIS in Visayas, and Tago RIS in Mindanao Islands (Figure 1). Field missions were carried out on 1-5 December 2020 in Mainit RIS, 15-20 February 2021 in Tago RIS, and 12-16 April 2021 in Lower Chico RIS. The mission activities included interviews/consultation meetings with the NIA and irrigators associations, collection of pertinent Mainit RIS documents/information, and system walkthrough with the concerned field personnel. The objective is to know and understand the following aspects of irrigation: system features pertinent to O&M; system objectives and operations, flow control structures, water supply situation, level of irrigation service, system management and performance, present state of physical structures, cropping and irrigation practices by farmers, irrigation issues, potentials for crop diversification, and desired modern features for Mainit RIS. Logic design analysis based on logical design combinations (Ankum, 2001) and diagnostic tools of MASSCOTE (Renault et al., 2007) were used to identify reasons for the performance and any problem areas inherent to the design, operation, or management of the irrigation system. Based on the findings of the mission activities, options for modernization of irrigation systems were identified.

RESULTS AND DISCUSSION

The general information gathered from NIA documents for the case study systems are summarized in Table 1.

Table 1. System profiles

	Lower Chico RIS	Mainit RIS	Tago RIS
Design service area, ha	2,000	3,500	14,000
Service area location	Tuao, Cagayan	Alang-alang and San Miguel, Northern Leyte	Tago and San Miguel, Surigao Del Sur
Water sources	Chico River	Mainit River, Cabayongan River	3 rivers (Tago, Mimie, Sumo-sumo), 2 springs (Mimie, Butong)
Year of official opening	1979	1976	1986
Type of headwork/dam	Intake barrel	Ogee dam	Ogee dam (1), Barrages (2), Impounding dam (2)
Diversion capacity, m^3/s	4.75	4.37	24.13 (Tago dam)
Main canal length, km	6.82	9.458	75
Lateral canal length, km	30.81	61.77	73.7
No. of headgates		20	
No. of IA	5	8	22
No. of farmers	2,456	1,894	2,675
Main crop	Rice	Rice	Rice
Firmed-up service area	1,255	2,265	4,356
Wet cropping season	May - Sep	Nov - May	Nov - Apr
Dry cropping season	Dec - Apr	Jun - Oct	May - Oct

Source: NIA regional offices and IMO offices documents

System features pertinent to design and operations

The main intake gates for the three case study systems are manually operated. Lower Chico RIS has screw hoist, inclined-lift, slide type gates while Mainit RIS and Tago RIS have a screw hoist vertical lift, slide-type gates. The sluice gates of Mainit RIS and Tago RIS have electro-mechanical wire rope drum hoist. The canal layout of the three irrigation systems is of hierarchical. The typical diversion points along the main canals of Lower Chico and Tago RIS consisted of constant head orifice as headgates of lateral or secondary canals, spindle-type vertical steel gates for major farm turnouts and a spindle-type, vertical steel gate as water level regulator (Figure 2). Meanwhile, the typical diversion points along the main canals of Mainit RIS have a combination of broad-crested weir and spindle-type vertical gate as the headgate of lateral or secondary canals, CHO and/or spindle-type vertical gates for lateral or secondary canals for major farm turnouts, and a combination of duckbill weir with gated flush opening at the pointed tip as water level regulator and a spindle-type vertical gate immediately downstream of the weir (Figure x). Water levels at the main intakes at the dam site/headwork are monitored in the three irrigation systems by using staff gauge and/or water levels markings on the dam body and/or posts of the intake structures. Water levels at major diversion points along the canal network are monitored in Mainit RIS. However, no water monitoring is carried out along the canal network of Lower Chico RIS and Tago RIS.

Figure 1. Headwork of the case study systems (L-R): Lower Chico RIS; Mainit RIS; Tago RIS

Overall system objectives, operational objectives, and flow control method

The result of logic design analysis, which used the available system documents and information gathered during the walkthrough, interview with system personnel, and consultation with IAs indicated that the three irrigation systems were designed for rice monoculture and for 'productive irrigation' during the dry season based on 'equitable supply per hectare'. The productive irrigation objective means that water will be provided for optimum crop growth.

In Lower Chico RIS and Tago RIS, the system operational objective is 'imposed allocation' to tertiary units or irrigation service delivery points by 'adjustable flow' and with 'rotational flow' through the main system or major conveyance canals. The flow control method employed is upstream control. In imposed water allocation, the NIA system personnel decide on the final water delivery schedule, in consultation with the IAs. The 'adjustable flow' as method of water allocation and water distribution was manifested by the adjustable gates (spindle-type vertical gates) for offtakes and cross regulators at major distribution points of the original physical structure. The use of cross regulators implied 'upstream control' as the intended method for regulating water flow levels.

Figure 2. Typical flow control structures at major diversion points ((L-R): Lower Chico RIS; Mainit RIS; Tago RIS

The case of Mainit RIS is interesting. There are two sets of possible operational objectives. The first is 'imposed allocation' to tertiary units or irrigation service delivery points by 'splitted flow' and with 'splitted flow' through the main system or major conveyance canals. The flow control method used is proportional control as indicated by “passive” regulation structures at the diversion (broad-crested weirs, duckbill weir) at the diversion points. The splitted flow means that the water supply is distributed to tertiary service areas or lower-level canals in a fixed ratio by employing fixed flow broad crested weirs as turnouts. This set of operational objectives is adopted in Mainit RIS during times of abundant water supply. The second set of operational objectives is 'imposed allocation' to tertiary units or irrigation service delivery points by 'intermittent flow' and with 'rotational flow' through the main system or major conveyance canals. The flow control method employed is upstream control. The intermittent flow means delivering the water supply at either maximum flow or zero-flow or ‘on/off’ basis. Spindle-type vertical gates installed immediately downstream of the long-crested weirs are used to achieve it by setting the gates either fully closed or fully opened. This second set of operational objectives is adopted in times of low water supply.

From the perspective of the logic design framework, there was apparent coherence among the design philosophy, objectives and flow control method in the original design of the case study systems. However, with recent development in water supply availability such as lower dry season

flows attributed to climate and landuse changes and subsequent constructions of other water diversion structures upstream, run-off-the-river dams and intake barrel would not be coherent to the system objective of “productive irrigation objective during dry season” because the available water supply for irrigation has become less reliable since then.

System Management and O&M

The service area is divided into management units, each of which is represented and managed by its IA. The Lower Chico RIS, Mainit RIS and Tago RIS have 5, 8 and 22 management units in, respectively. They are under a dual system management by the NIA and their respective IA.Under the present irrigation management (IMT) contract, the O&M and management of main facilities such as dams, reservoirs, diversion works, main canals and large lateral canals is a responsibility of the NIA while the O&M and management of secondary facilities and structures from medium-sized lateral canals, smaller canals, turnouts, farm drains, down to terminal irrigation structures is a responsibility of the IA. There were some variations from this responsibility assignment: in Lower Chico RIS, O&M of a longer stretch of the main canal is a responsibility of IA. In Tago RIS, canal repairs is a shared responsibility of NIA and IA while repair of all gates along the canal network a sole responsibility of the NIA. Adjustment of lateral headgates and water distribution monitoring along the lateral canals are a joint responsibility.

The flow into the system is controlled by adjusting the main intake structures and/or the sluice gates at the headwork. The gate keepers upon the instruction of the system head operates the intake gates according to the planned irrigation schedule and real-time water supply situation. The start of wet season and date of the opening of the intake gates are agreed upon by the NIA and IA in regular pre-irrigation season meetings. The main intakes are opened to divert water into the irrigation service area and are closed when irrigation water is not needed, especially during continuous heavy rainfall, river flows at critical flood level, impending typhoons, and during terminal drainage to ready the rice field for harvest. In general, the intake gates are operated twice during the dry season. It is opened at the start of the dry season until the start of the terminal drainage when it is fully closed to stop irrigation. The sluice gates are lowered to check water and facilitate diversion during periods of low river flows and are lifted open during flushing out of sediment and critical high river flow levels. The Lower Chico RIS and Mainit RIS each have one gate operator and canal operator while Tago RIS have three each of these operators.

Cropping seasons and irrigation practices

There are two cropping seasons in the three systems: the first cropping season or wet season and the second cropping season or dry season (Table 1). The service areas of Lower Chico RIS and Tago RIS are divided into two and three irrigation zones, respectively for the purposes of water delivery. In general, the three irrigation system practice continuous irrigation during the wet season and irrigation rotation is adopted during the dry season. The cropping season basically start simultaneously in Lower Chico RIS while it starts in slightly staggered pattern from upstream to downstream in Tago RIS, with each of the irrigation zones starting few days or about a week ahead or behind the others. In Lower Chico RIS, irrigation rotation is by lateral, starting with laterals of the upstream irrigation zone. Meanwhile irrigation rotation in Tago RIS is by lateral, by IA or by main farm ditch. In Mainit RIS, irrigation rotation is by main canal for an irrigation period of about one week and ensuring that the water level at the main canal and lateral headgates taking turn are at full operating capacity level.

System performance

The actual area irrigated by the Mainit RIS and Tago RIS for the past five years (2016 – 2020) ranged from 84-97% and 60-83% of their firmed-up service area (FUSA), respectively. The national average ranged from 74-86%. For the same period, the average area irrigated in Mainit RIS was practically the same for the dry season (92%) and the wet season (91%). Meanwhile, the area irrigated in Tago RIS was higher during the wet season (76%) than during the dry season (71%). The percentages of irrigated differed among the management units (Figure 3).

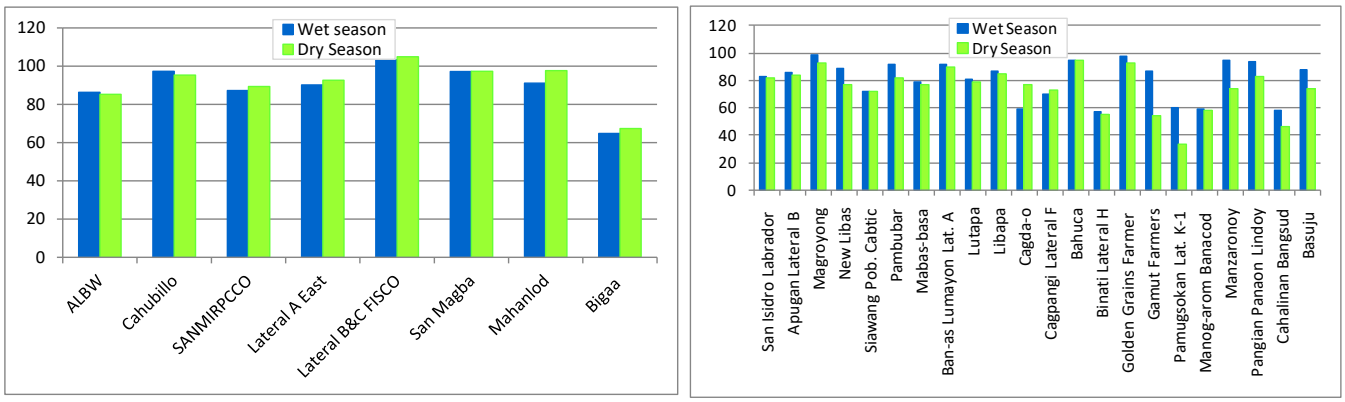

Figure 3. Five-year average percentages of FUSA irrigated in the different IA/management units for the two cropping seasons (L-R): Mainit RIS; Tago RIS

Physical Capacities

The results of the comparison between the actual capacity and the required capacity in performing of the irrigation systems basic functions of conveyance, diversion, division, water level regulation, flow measurement, storage and discharge transfer suggested that Lower Chico and Tago RIS have the most aspects of their functional capacity decreased (Table 2).

Table 2. Functional capacity of the irrigation systems (Present VS Required)

Functions	Lower Chico RIS	Mainit RIS	Tago RIS
Diversion (canal)	<	≅	<
Division (canal)	n/a	≤	n/a
Storage (canal)	<	<	<
Conveyance	<	≅	<
Sediment control	<	≅	<
Discharge transfer	<	≅	≅
Water level control	<	≅	<
Flow measurement	<	≅	<
Safety	<	<	<
Communication	≅	≅	≅
Water reuse	≅	≅	≅
Transport/access	≅	<	<
Diversion (headwork)	<	<	<
Storage (headwork)	<	<	<

The reduced capacities were mainly due to damaged/non-operational/missing gates of flow control structures; insufficient number/lack of flow control, measurement and safety structures; and eroded canals. The results indicated that Mainit RIS has fairly well maintained canal network, hence, basically maintained capacities. However, its capacity to divert water from the river had decreased due to significant siltation upstream of its dam. In view of the present need and future requirements, the capacity that would need to be increased relates to division, storage, safety, water reuse, access, and diversion functions.

IA consultation

The results of the IA consultation showed that water scarcity during the dry season was experienced in majority of IA management units of the three irrigation systems as well as floodings, except in Mainit RIS (Table 3). Majority of the management units in Lower Chico RIS and Tago RIS planted rice and non-rice crops while half of the management units in Mainit RIS practiced rice monocropping. The great majority of the management units of Lower Chico RIS and Tago RIS had their whole service area planted and adopted more than one coping strategy for water scarcity, which included irrigation rotation, planting non-rice, less-water loving crops, reduction in cropped area, and adjusting planting dates. In Mainit RIS, only a third of management units received full irrigation of their service area in both cropping seasons and half adopted more than one coping strategy for water scarcity. Majority of management units had no flood adaptation strategy except do-nothing/waiting for flood to subside, do-no-plant, or adjust the planting date based on guesswork. More than 80% of the management units in Lower Chico RIS and Tago RIS and 50% in Mainit RIS indicated their willingness to diversify their crops.

Table 3. Key information gathered from the IA consultation

	Lower Chico RIS	Mainit RIS	Tago RIS
Wet season, too much water	6/6	1/6	11/14
Dry season, scarce water	6/6	6/6	12/14
Rice monocropping	2/6	3/6	6/14
Whole area planted, 2 cropping	4/6	--	13/14
Whole area irrigated ≥ 1 cropping	--	2/6	--
>1 coping strategy for water scarcity	9/13	6/6	12/14
Do-nothing on flood	4/6	--	13/14
Willing to diversify crops	5/6	3/6	12/14

The most common issues raised by the representatives of each IA management unit relate to canal, flow control structures and flooding/drainage (Figure 4). Limited diversion capacity and damages to its main intake structure was a common concern in Lower Chico RIS. The canal-related issues included eroded banks and damaged/collapsed embankments, high seepage/leakage, heavy siltation, insufficient length/density, and slope/elevation error. The cited problems with the flow control structures included damaged/non-functional gates, presence of ungated illegal turnouts, use of tamper-prone slab/stoplog gates, illegal checking, tampering/vandalism of gate locks and cumbersome manual gate operation, and insufficient number. Flooding was due to river overflows, silted/blocked creeks/natural waterways and lack/insufficient drainage system.

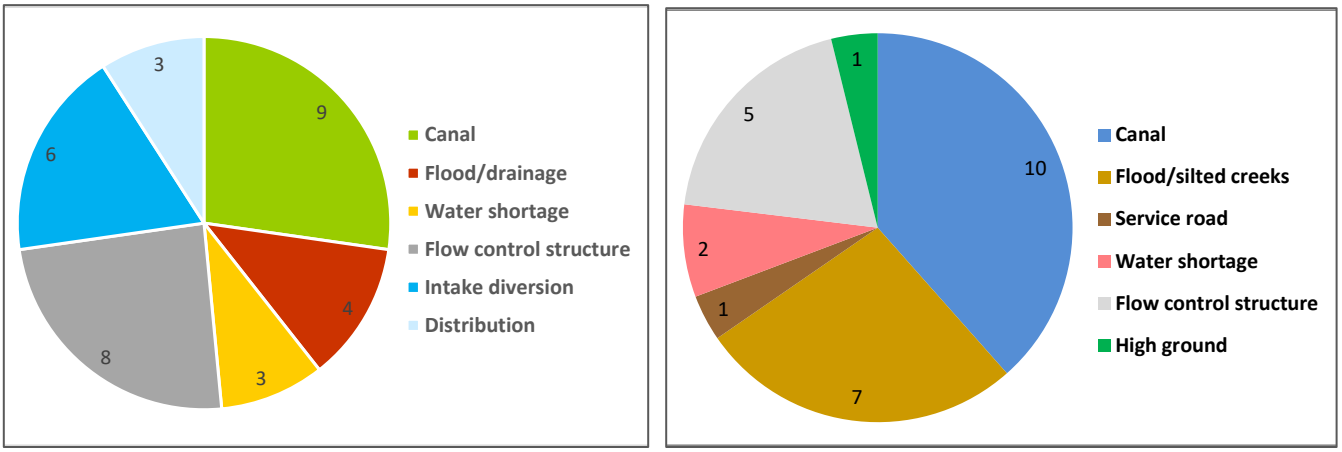

Figure 4. Aspects of irrigation with issues raised by representatives of IA (L-R): Lower Chico RIS; Tago RIS

Irrigation issues: system personnel perspective

The concerns system personnel of Lower Chico RIS included tampering and cumbersome manual operation of the main intake gates, heavily scoured base of the main intake structure's protective, and sediment-laden water supply resulting in frequent desilting need of the settling basin. The main issues with the canal and drainage network were as follows: non-functional offtake gates at the Trifurcation, cumbersome manual operation of the big check (Bagumbayan) structure, silt-laden flood water from the mountain depositing silts in the canals, heavily silted drainage channels and blocked drainage outlet causing inundation of the service area, and municipal drainage discharging into irrigation canals and eroding the canal walls, and lack of dedicated backhoe and dump truck for canal dredging/desilting.

Meanwhile, the dam-related and O&M issues raised by the Tago RIS personnel included the following: worn out, cumbersome manual operation and non-operational mechanisms of sluice and main intake gates; lack of critical flood water level warning device; scouring; damaged concrete blocks and curtain wall; excessive seepage at sluice gate rubber seal; lack of silt ejector; insufficient water supply in the dry season; and quarrying. The main issues with the canal and drainage network are as follows: oversized canal for the present irrigation requirement of the service area; excessive seepage along the main canals; presence of informal settlers along the embankments of the main canals; deteriorating and non-functional/defective flow control structures; some inappropriate flow control structures; flooding exacerbated by silted and constricted natural waterways; lack of sufficient drainage network; and some dilapidated service roads, among others.

Irrigation modernization options

The desired improvements of IA and NIA respondents for their respective systems included mostly rehabilitation of damaged/non-functional physical structures; installation/construction of additional and improved flow control structures (gated, automatic, with lock), dam (in Lower Chico), canals, silt ejector, modern flow monitoring system, and service roads; and provision of drainage system, O&M equipment (backhoe, dump truck, repair tools), solar-powered water pumping units, among others.

Modernizing the three study systems to support HVC production will require reengineering their physical structures, operation, and management. It will require redesigning and retrofitting of dams/intake structures, canal network, and flow control and monitoring structures in such a way that the level of flexibility, reliability, frequency, and precision of control of water delivery required for optimum growth of HVC can be achieved. In the case of the three case study systems where there is significant preference for rice, irrigation modernization aimed at supporting HVC production will need to proceed in phases. A pragmatic approach is to start on downstream areas where farmers are already diversifying to vegetables and HVC production and are the most receptive to HVC production and adoption of water-efficient irrigation technology since they are prone to water shortages. To improve water availability to these areas, control of water along the main conveyance system (main canals down to headgates/turnouts of tertiary areas or IA management units) must be maintained by using appropriate, more advanced flow control structures. The main conveyance system can be used like a reservoir. Water tanks upstream of HVC production areas will serve as temporary storage of irrigation water pumped from the main conveyance system or supplemental sources such groundwater and creeks/rivers. Similarly, check gates can be used to impound drainage water for reuse. Groundwater irrigation has great potentials as evidenced by some water pumping units seen during the system walkthrough, hence solar-powered shallow tubewell irrigation development can be pursued to provide a more reliable source of water for HVC. Dredging of natural drainage and construction of additional drainage canals is necessary to provide unsaturated soil moisture condition favorable for most HVC. If micro-irrigation technology will be used for HVC, filtration system is a must as irrigation water is usually silt laden. Capacity enhancement programs for NIA and IA on operation of more advance irrigation technology and manage modern irrigation system must be implemented.

AKNOWLEDGEMENTS

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ESTABLISHMENT OF DIGITAL TERRAIN MODEL OF AN IMPOUNDING RESERVOIR WITH ECHO-SOUNDER AND DRONE

Joongu Lee[1], Moonsuk Lee[2], Kangwon Choi[3] and Hyunsu Kim[4]

ABSTRACT

The storage of reservoir is gradually decreased due to the sedimentation from watershed area. The effective survey method and date base system are desperately and continuously needed to improve the irrigational facilities management and shortage of water resources. This research team developed a drone and an unmanned vessel to satisfy this requirement.

DTM(Digital Terrain Model) of impounding reservoir was composited with spatial coordinates information acquired by echo-sounder and drone. The echo-sounder was applied to obtain terrain coordinates at the underwater part of impounding reservoir and the coordinates of the other part which is dried was surveyed by drone attaching GPS camera. The effective storage capacity is driven from contour lines that are able to be drawn on DTM. The unmanned vessel developed by research team, implemented single beam and a small common boat attaching single beam were both applied to survey underwater terrain coordinates at the same reservoir. The merits and demerits of these equipment were summarized.

Keywords: Echo-sounder, Drone, DTM(Digital Terrain Model), GCP(Ground Control Point), DWL(Dead Water Level), FWL(Full Water Level), ESC(Effective Storage Capacity)

1. Introduction

This study was proceeded to find applicability of latest technologies to the modernization of reservoir management and to review their effency. If the topographical information on bed floor of the reservoir can be managed in time series, it will be more accurate to understand the utilizable storage capacity and to effectively respond to disasters such as floods. The digital terrain information of whole bed floor of reservoir was completed by drone for dried part and by echo-sounder for underwater part. The applicability of unmanned vessel was also reviewed to acquire economically terrain information of a numerous large and small reservoirs.

2. Target Reservoirs

Three reservoirs were selected for the pilot application by size. The small size BURDLE, the middle size OTAE and the large size BULGAP reservoir which is located in Hwaseong-si, Gyeonggi-do, Sangju-si, Gyeongsangbuk-do, Yeonggwang-gun, Jeollanam-do, ROK respectively are targeted. Their locations were shown in Fig. 2.1. The brief information of them were provided in Table 2.1~3 and Fig. 2.2~7.

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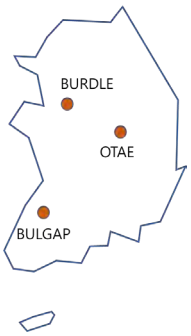


Fig. 2.1 Location of pilot reservoirs

Fig. 2.2 BURDLE reservoir sight

Fig. 2.3 Intake facility of BURDLE

Fig. 2.4 Drone image of BULGAP reservoir

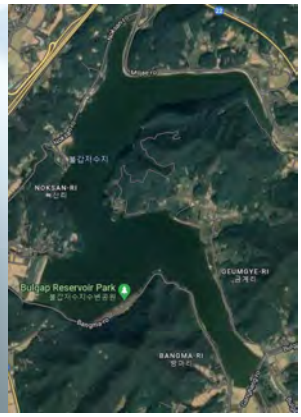


Fig. 2.5 Satilite image

Fig. 2.6 Satilite image of OTAE

Fig. 2.7 Emergency gate of OTAE

Table 2.1 Information of BURDLE reservoir

Embankment Height	Total Storage (10^3 ㎥)	Effective Storage (10^3 ㎥)	Dead Storage (10^3 ㎥)	Full Water Area (ha)
4.7m	284.6	283.7	0.6	15.3
Embankment EL. (EL.m)	Flood Water Level (EL.m)	Full Water Level (EL.m)	Dead Water Level (EL.m)	Unit Storage

10.02	8.03	7.53	4.5	280 ㎜

Table 2.2 Information of BULGAP reservoir

Embankment Height	Total Storage (10^3 ㎥)	Effective Storage (10^3 ㎥)	Dead Storage (10^3 ㎥)	Full Water Area (ha)
19.8m	16,890	15,200	1,690	202
Embankment EL. (EL.m)	Flood Water Level (EL.m)	Full Water Level (EL.m)	Dead Water Level (EL.m)	Unit Storage
35.6	33.6	32.4	16.0	506 ㎜

Table 2.3 Information of OTAE reservoir

Embankment Height	Total Storage (10^3 ㎥)	Effective Storage (10^3 ㎥)	Dead Storage (10^3 ㎥)	Full Water Area (ha)
16.8m	8,729	8,291	438	139
Embankment EL. (EL.m)	Flood Water Level (EL.m)	Full Water Level (EL.m)	Dead Water Level (EL.m)	Unit Storage
89.9	87.9	86.9	76.8	665 ㎜

3. The acquisition of topographic information

3.1 topographic information obtained by drone

3.1.1 Used drone type

Domestic model, REMO-M and Swiss model, e-Bee were applied at this research. The specifications of the two models were shown at Table 3.1 and Fig. 3.1.

Table 3.1 Specification of Remo-M and Sensefly

Contents	Drone1	Drone2
Model	Remo-M	Sensefly
COM	Rep. of Korea	Swiss
Dimension	Width 1800mm x Length 1440mm	Width 960mm x Length 800mm x Height 140mm
Weight	3.5kg	0.7 kg
Battery	20.75V	11.1V, 2100mAh
Flight speed	80km/h	36~57km/h
Flight time	90min	40 min
Camera	20.1MP, SONY QX1	16 MP IXUS/ELPH

< REMO-M > < e-Bee > < GNSS recevior for GCP survey >

Fig. 3.1 The two models applied and GPS recevior

3.1.2 GCP survey

GCP(Ground Control Point) surveying refers to ground survey conducted at field to obtain reference points result necessary for aerotriangulation and detail stereo-restitution. GCP surveying was performed using the VRS(Virtual Reference Station) network positioning survey method, which is one of the GPS-RTK(Global Positioning System-network Real Time Kinematic) methods. GPS-RTK can measure an accurate position of several millimeters by eliminating various errors that occur during GPS

positioning in a relative positioning method.(Park, J. K. & Park, J. H., 2015) GCP surveying serves as a base point when registering each independent image in the production of orthomosaic.

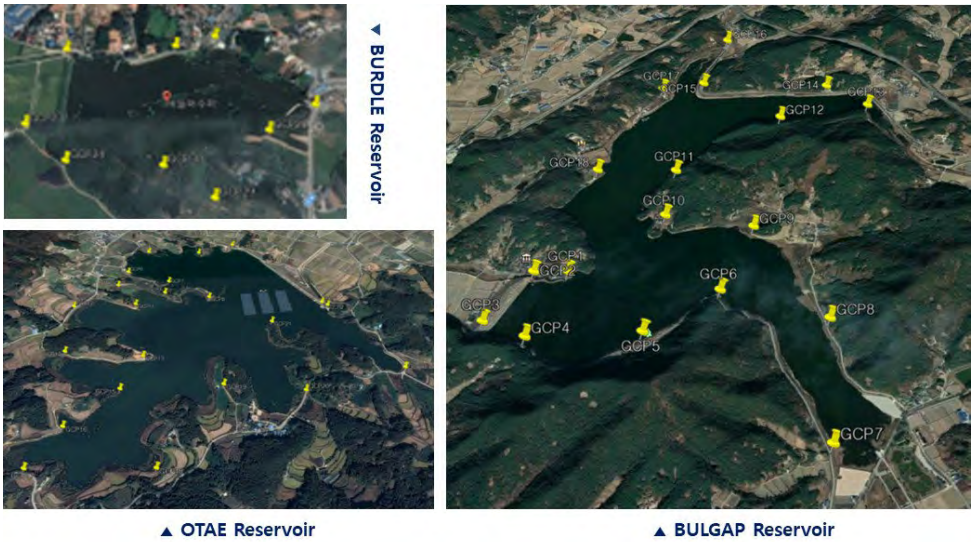


Fig. 3.2 Plan view of GCP survey plan

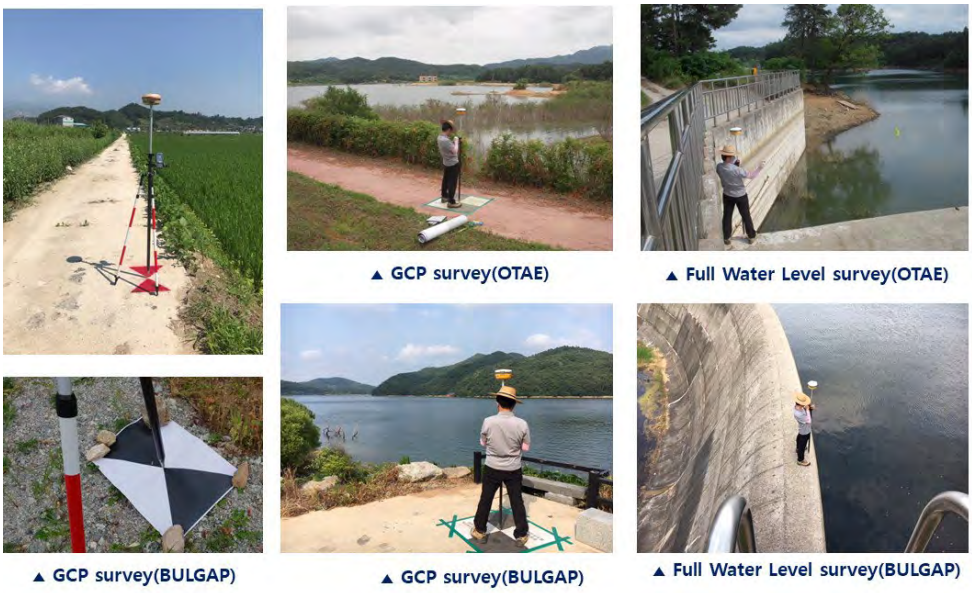


Fig. 3.3 GCP surveying sight

The GCP survey plan decided indoor for field work was shown as Fig. 3.2. Fig. 3.3 is a picture of GCP surveying in the field.

3.1.3 Drone flight

A typical fixed-wing drone flight field work sequence is shown as in Fig. 3.4. It proceeds in the order of checking the shooting route of the shooting area, setting flight parameters, selecting a takeoff and landing point, uploading a flight mission, starting and taking off the drone, aerial photography and landing, collecting the aircraft and downloading logging data and images. In BULGAP reservoir, the redundancy(longitudinal 80%, horizontal 80%) and flight height were readjusted

according to local circumstances as there was a hill with an elevation 150m. The pictures on the right of Fig. 3.4 shows the work being carried out in order for drone flight in the field.

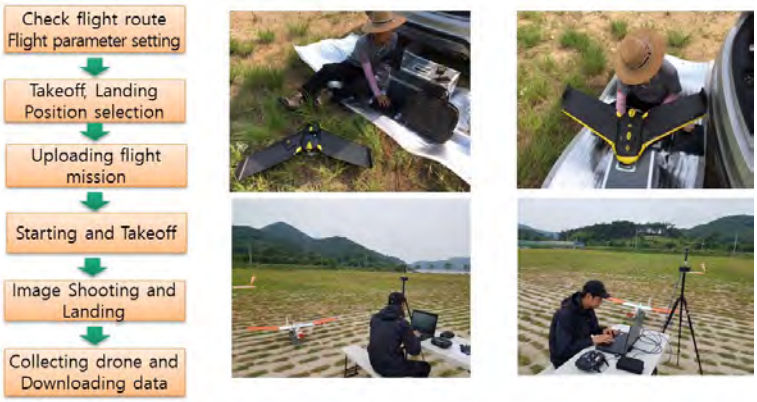


Fig. 3.4 Drone survey work flows and flight work sight

3.1.4 Image registration

In general, Photoscan and Pix4D are used, but in this study, Pix4D was used in both models. 3D point data is generated from the registered photo, and the digital surface model(DSM) is created through this. Orthomosaic and DSM are produced by the same process as Table 3.2.

Table 3.2 Orthomosaic generation workflow

Input Photos Align Photos	• Acquisition photos and input them
↓	
Input Ground Control Point	• Conduct a survey according to WGS84 EPSG 5186 (Jungbu Origin) and input the coordinates of each point
↓	
Point Cloud and Mesh Generation	• After extracting keypoints from each photo, connect adjacent photos to create point clouds and meshes
↓	
Orthomosaic and DSM Generation	• Editing and revising unnecessary point clouds to create optimal orthomosaic and DSM
↓	
Quality Inspection and Editing	• After generating an orthomosaic, check the non-shooting area and whether there is a photo mismatch • Inspect all photos for defects
↓	
Resulting	• Tiling the finished orthomosaic and deleting unnecessary areas

3.1.5 DTM generation

DEM(Digital Elevation Model) was produced through post processing program, Pix4D, and DTM(Digital Terrain Model) was driven by matching orthomasaic and survey results which are acquired from control point survey and GCP survey. These processes are shown in Fig. 3.5.

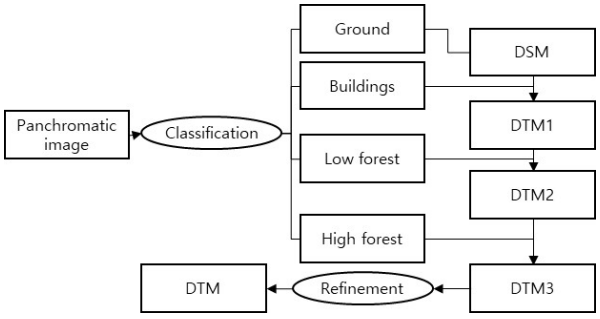


Fig. 3.5 DSM, DTM generation process

3.1.6 Contour line generation

Contour lines can be created in a number of ways. The automatic creation method by Pix4D and the extraction method using the image editing programs Global Mapper, QGIS, etc. are mainly used. More accurate contour data can be produced by DTM which is created with filtering unnecessary surface data(building, tree, other structures, etc.). Drone work product and contour line of BULGAP were shown in Fig. 3.6.

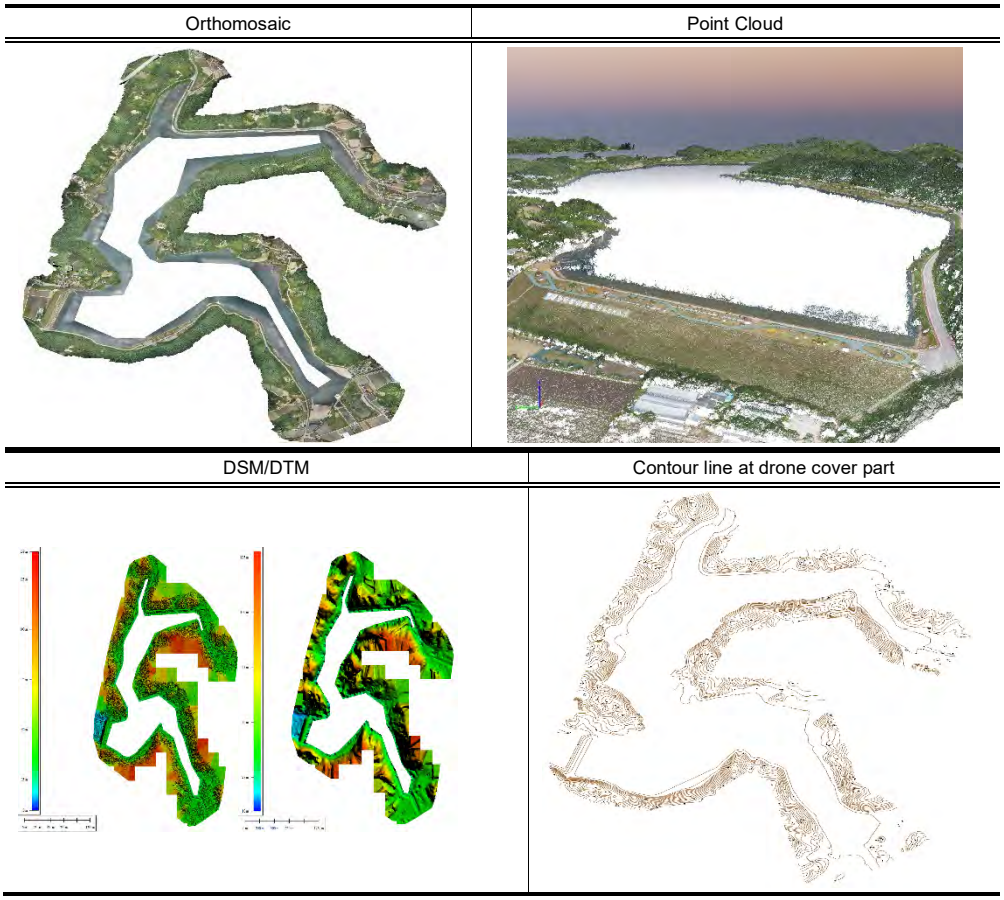


Fig. 3.6 Final outputs of drone works

Table 3.3 Applied manned and unmanned water depth survey systems

Equipment		Model	Specification
Manned Echosounder	Echosounder	ODOM Hydrotrac Echosounder	- 200 kHz – 1 cm 0.1% of depth - 33 kHz – 10 cm 0.1% of depth

	Global Positioning System (GNSS)	Trimble R10	- Network RTK : Horizontal : 8mm+0.5ppmRMS : Vertical : 15mm+0.5ppmRMS
	S/W	Hypack	- Water depth data acquisition and processing - Water depth data generation
Unmanned Echosounder	Echosounder	EchoLogger ECS400	- 100 kHz – 1 cm 0.1% of depth
	Global Positioning System(GNSS)	KORIDA K9-T	- Network RTK : Horizontal : 10mm+1ppmRMS : Vertical : 20mm+1ppmRMS
	S/W	Origin	- Water depth data acquisition and processing - Water depth data generation

3.2 Topographic information acquired by echo sounder

3.2.1 Water depth survey equipment

Water depth survey equipments used in this study are largely an echo sounder, precision satellite telemetry for positioning and data processing software. Equipmets exceeding the performance specified in the domestic 『Public surveying work regulations』 were put in, and their specifications are shown in Table 3.3.

3.2.2 Water depth survey process

The general procedure of water depth surveying consists of first step, equipment setting and calibration, second step, acquisition of depth data, and the final step, water depth data generation through the sounding data obtaining and data treatment. The next procedure is the construction of topographic information based on the previous steps results. The detailed procedures are shown in Fig. 3.7.

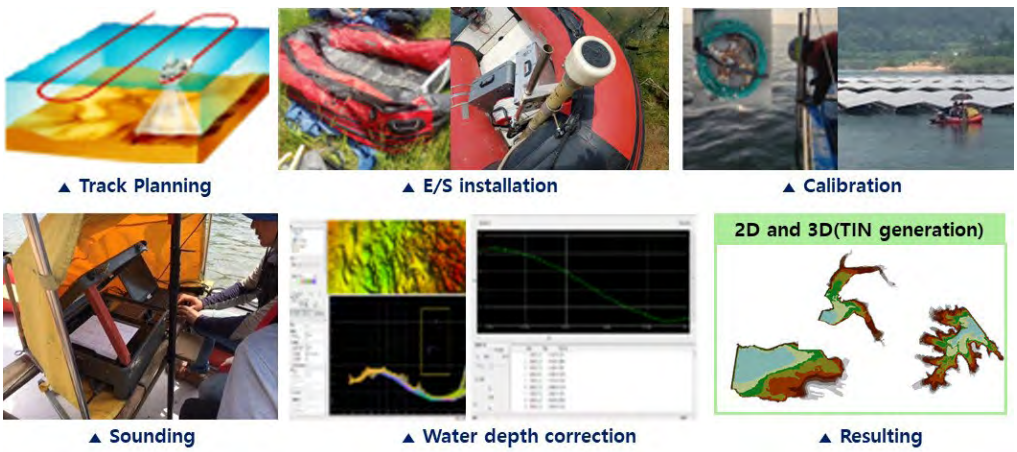


Fig. 3.7 Water depth survey process

3.2.3 Water depth survey

A. Manned survey vessel

A single beam was installed on a two-seater rubber boat, and water depth was surveyed by an expert. Fig. 3.8 is a picture of the field work scene. In this study a dedicated S/W for water depth data processing called Hypack was used to process the data acquired in the field.

The final result which is reservoir bed floor elevation is induced through water level correction and filtering outliers using raw data that is position data, water depth data, water level data, and etc..

▲ Vessel Launching ▲ OTAE Reservoir ▲ BULGAP Reservoir

Fig. 3.8 water depth survey with manned boat

B. Unmanned survey vessel

Like the drone, the unmanned surveying probe applied in this study consists of a communication unit, a control unit, a driving unit, and a payload, and was manufactured with the same communication equipment and control parts as the drone.

The contrast with the drone is in the driving part and the payload. In the case of the driving part, propellers and motors that can secure propulsion on water and increase fuel efficiency are applied, rather than propellers to secure lift. A high-capacity battery of 40,000 mAh or more was employed. For the payload, a single-beam precision echo sounder that meets 『 the public surveying work regulations 』 was applied. Fig. 3.9 is a view of water depth survey using an unmanned vessel. Table 3.4 shows the areas where depth measurement is possible using an unmanned vessel.

In the case of Willowji, 30% of that of manned ships was applied due to aquatic vegetation, and in the case of Bulgapji, 30% of the area with the deepest water depth was applied for reliability comparison, and the maximum possible (91%) of Ota Reservoir was applied.

In the case of BURDUL, 30% of that of manned ships was applied due to aquatic vegetation, and in the case of BULGAP, 30% of the area with the deepest water depth was applied for reliability comparison, and the maximum possible survey part (91%) of OTAE Reservoir was applied.

Table. 3.4 Surveying area with unmanned vessel

Reservoir	Working Area	Working area by image
BURDLE	- Full Water Area : 15.3ha(RIMS) - Surveying area with Manned : 11.6ha - Surveying area with Unmanned : 3.2ha (30%)	
BULGAP	- Full Water Area : 202ha(RIMS) - Surveying area with Manned : 251.6ha - Surveying area with Unmanned : 74.4ha (30%)	
OTAE	- Full Water Area : 139ha(RIMS) - Surveying area with Manned : 113.3ha - Surveying area with Unmanned : 103.4ha (91%)	

▲ Vessel Launching ▲ BULGAP Reservoir ▲ OTAE Reservoir

Fig. 3.9 water depth survey work sight with unmanned vessel

4. Reservoir capacity calculation

4.1 Capacity comparision

To analyze the accuracy of water depth survey by unmanned vessel, the topographic data obtained by each of the two surveying methods were used to calculate and compare the capacity of the same water surface area. In the case of OTAE Reservoir, it was analyzed that the unmanned ships were large, about 2% at high water level, about 4% at medium level, and about 7% at low level.

4.2 Effective storage calculation

4.2.1 BURDLE Reservoir

According to the Rural Infrastructure Management System (RIMS, Hereinafter referred to as RIMS) managed by the KRC(Korea Rural Community corperation), the BURDLE reservoir is registered as 4.50 EL.m at the dead water level(DWL), 7.53 EL.m at the full water level(FWL), and 284,000 ㎥ of effective storage capacity(ESC) (see Table 2.1). However, according to the surveyed data in this study the floor was detected at 5.0 EL.m or higher, and the crest of spillway which is a rubber weir type was measured to be 7.4 EL.m. The surveyed data-based effective storage obtained by drone and ES was measured to be 28.3% smaller than RIMS data with an effective storage of 204,000 ㎥ (see Table 4.1). It was judged that there may be errors in measurement and the effects of sedimentation, and errors may have been embedded in the elevation or storage at the time of completion. The DWL that is the lowest level of outlet could not be accurately confirmed as a small reservoir, and the capacity curve is shown in Fig. 4.1. The contour line was expressed as Fig. 4.2. The comparison between RIMS data and current measurement data was done as Table 4.2.

Table 4.1 Area-capacity computation of BURDLE reservoir

Number	Elevation(m)	2D Area(㎡)	Capacity(10^3 ㎥)(Manned)
1	4.50	0	0
2	5.00	8.55	0.001425
3	5.50	48,457.28	12.1178825
4	6.00	77,381.32	43.5775325
5	6.50	113,290.84	91.2455725
6	7.00	124,702.35	150.74387
7	7.40	141,516.64	203.987668

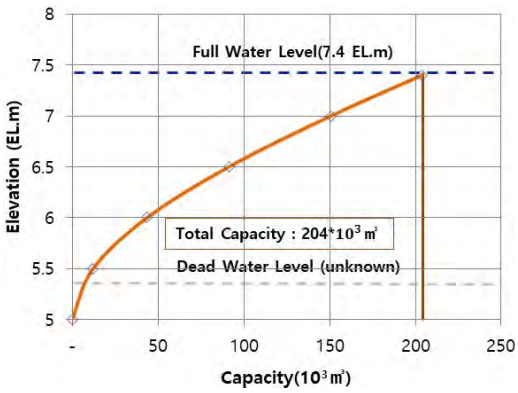


Fig. 4.1 Capacity curve of BURDLE

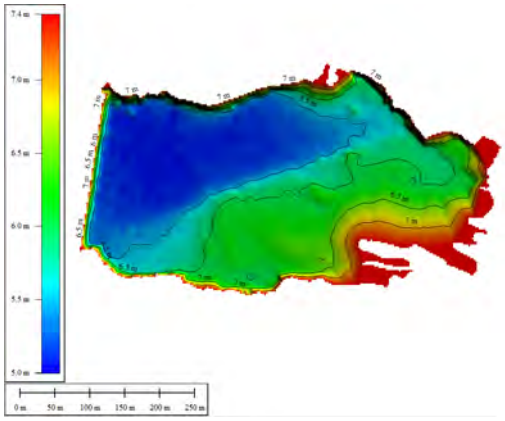


Fig. 4.2 Contour of BURDLE

Table 4.2 The comparison of RIMS and this survey results(BURDLE)

Contents	Dead Storage (10^3 ㎥)	Effective Storage (10^3 ㎥)	Embankment Height (EL.m)	Dead Water level (EL.m)	Full Water level (EL.m)
Drone, ES	-	204 (71.7%)	-	-	7.4 (△0.12)
RIMS data	0.6	283.7	10.02	4.5	7.52

4.2.2 BULGAP reservoir

This reservoir was under project design that enhance the capacity of flood control. The mater plan of this project was done at 2017. According to the RIMS, DWL of 16.0 EL.m, FWL of 32.4 EL.m, ESC of 15,200,000 ㎥ were recorded. However the master plan report was comparing the two follow records. FWL of 34.9 EL.m and ESC of 18,137,000 ㎥ are listed on hydrological investigation report at 2010 yr.. FWL of 32.4 EL.m and FWL of 17,406,000 ㎥ are shown on water depth survey report at 2016yr.. The crest elevation of spillway was 35 EL.m and ESC was 17,225,000 ㎥ in this study. These are differ from RIMS as 2.6m height and 2,025,000 ㎥ volume(11.76%)

In case of capacity, it can be seen that the same expert as the water depth survey engineer in 2016 conducted the depth survey with the same equipment that is single beam echo sounder in 2018, and compared with the capacity at the time, there is a difference of 181,000 ㎥ (1.1%). According to the report of master plan at the time of 2017, there was a difference in elevation of the water level (-2.6m), and it was suggested that the need to be supplemented based on the national control point when establishing the project implementation plan was suggested. When compared with the survey report at 2016, a difference of 1.1% occurred in the capacity, which is within the tolerance of 20cm (±368,524 ㎥) in the 『public surveying work regulations』 and is judged to be due to the influence of the measurement error and sedimentation.

Table 4.3 Area-capacity computation of BULGAP reservoir

Number	Elevation(m)	2D Area(㎡)	Capacity(10^3 ㎥) Manned(2018yr.)	Capacity(10^3 ㎥) Manned(2016yr.)
1	19	-	-	-
2	20	72,381	38.262	41.134
3	21	186,063	174.916	184.050
4	22	320,116	437.802	443.249

5	23	461,508	845.454	856.200
6	24	646,816	1,422.035	1,445.894
7	25	788,546	2,150.251	2,197.965
8	26	917,966	3,015.978	3,096.742
9	27	1,057,296	4,019.374	4,131.070
10	28	1,172,011	5,139.498	5,295.016
11	29	1,328,387	6,409.640	6,615.666
12	30	1,515,903	7,861.232	8,095.528
13	31	1,639,333	9,449.004	9,705.714
14	32	1,778,937	11,169.492	11,450.161
15	32.4	1,842,620	11,897.461	12,183.167
16	33	1,911,881	13,023.730	13,312.600
17	33.60	1,968,849	14,188.532	14,478.522
18	34	2,007,568	14,983.748	15,275.411
19	35	2,033,888	17,225.117	17,406.000

Table 4.4 Comparison of this time survey results and two years ago results

Contents	Effective Storage Capacity(10^3 ㎥)		
	2018 (a)	2016 (b)	Difference (c=a-b)
2018yr. VS 2016yr.	17,225	17,406	- 181 (1.1%)
-	2016 (d)	RIMS (e)	Difference (f=d-e)
2016yr. VS RIMS	17,406	15,220	2,186 (14.4%)

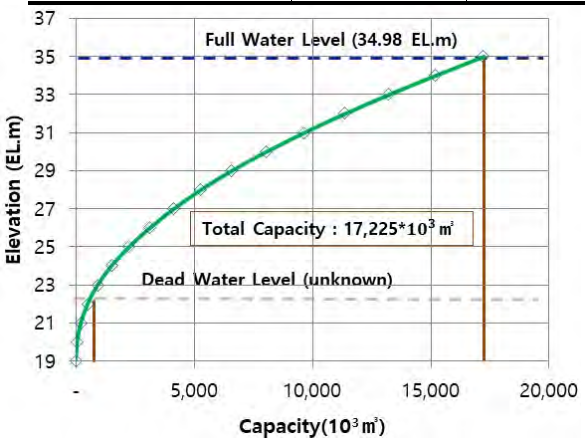


Fig. 4.3 Capacity curve of BULGAP

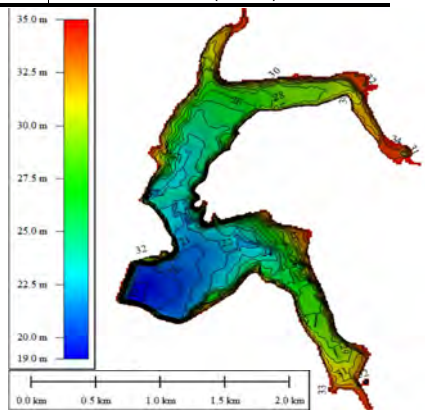


Fig. 4.4 Contour of BULGAP

Table 4.5 The comparison of RIMS and this survey results(BULGAP)

Contents	Dead Storage (10^3 ㎥)	Effective Storage (10^3 ㎥)	Embankment Height (EL.m)	Dead Water level (EL.m)	Full Water level (EL.m)
Drone, ES	-	17,225 (102%)	38.26 (△2.66)	-	34.98 (△2.58)
RIMS data	1,690	15,200	35.6	16.0	32.4

4.2.3 OTAE reservoir

The capacity of OTAE from the lowest height of 73.74 EL.m to the highest height, 87 EL.m, was calculated. According to the RIMS, the DWL of the OTAE reservoir is 76.8 EL.m, the FWL is 86.9 EL.m, and the ESC is 8,291,000 ㎥. The measured ESC in this study was 8,181,000 ㎥, which was 111,000 ㎥ smaller than the statistic amount,

showing a difference of about 1.3%. Compared to the time of construction, this difference may be due to the accumulation of sediments and the error occurred during survey, accumulated in the calculation process, anyway the this survey results were analyzed to be relatively good.

Table 4.6 Area-capacity computation of OTAE reservoir

Number	Elevation (m)	2D Area(㎡)	Capacity(10^3 ㎥) (Manned)
1	74	7,375	2.46
2	75	81,350	46.82
3	76	200,500	187.75
4	77	288,875	432.43
5	78	361,975	757.86
6	79	473,100	1,175.40
7	80	596,800	1,710.35
8	81	729,700	2,373.60
9	82	862,675	3,169.78
10	83	974,200	4,088.22
11	84	1,057,000	5,103.82
12	85	1,134,725	6,199.68
13	86	1,249,325	7,391.71
14	86.9	1,355,700	8,563.97

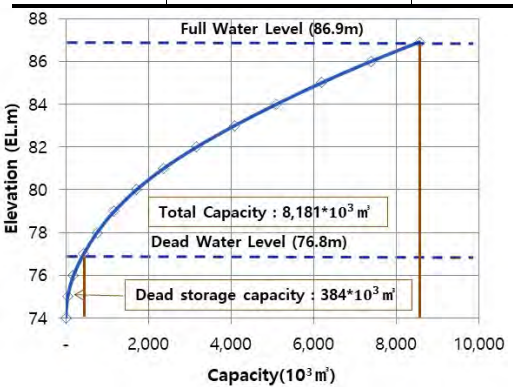


Fig. 4.5 Capacity curve of OTAE

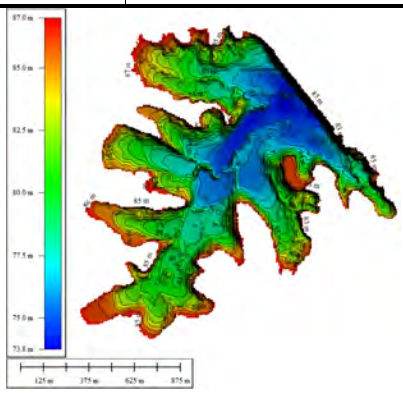
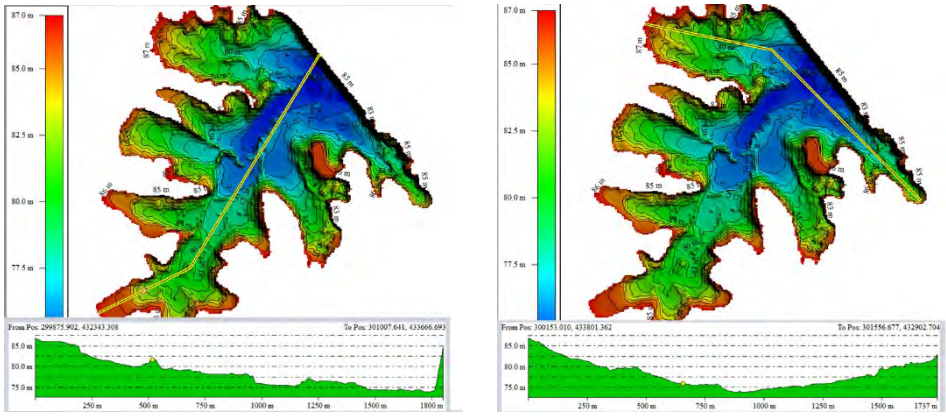


Fig. 4.6 Contour(TIN) of OTAE

Table 4.7 The comparison of RIMS and this survey results(OTAE)

Contents	Dead Storage (10^3 ㎥)	Effective Storage (10^3 ㎥)
Drone, ES	384(87.7%)	8,181(98.7%)
RIMS data	438	8,291



< OTAE reservoir section A > < OTAE reservoir section B >

Fig. 4.7 Randum section profiles

5. Results analysis and contemplation

5.1 Comparison of manned and unmanned vessels

The advantages and disadvantages of manned and unmanned vessels can be summarized as shown in Table 5.1.

Table 5.1 Comparison of manned and unmanned vessels

Contents	Unmanned vessel	Manned vessel
Merits	High safety	The speed of operation is faster than that of unmanned vessel
	Good work convenience	Possible to respond to unexpected situations and risk factors
	Can work in low water depths	Less affected by weather than unmanned vessel
	Easy to operate	Easy to check data reliability
Demerits	The speed of work is slow compared to the manned vessel	May pose a safety hazard to workers
	Difficulty recognizing obstacles such as plants	Difficulty in installation and operation of equipment
	High restrictions on weather conditions such as wind	Working depth is deeper than that of unmanned vessel

5.2 Reliability verification

In the case of OTAE Reservoir, the range measured by unmanned vessel was 103.4ha, which is 91% of that of manned vessel(see Table 3.4). The range of water depth for unmanned vessel was distributed between EL.74m and 84m, so the capacity per 1m depth is calculated and compared at both of manned and unmanned(see Table 5.2).

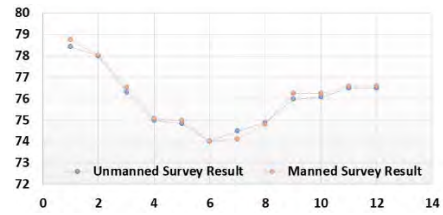
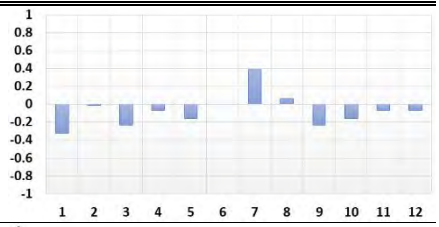
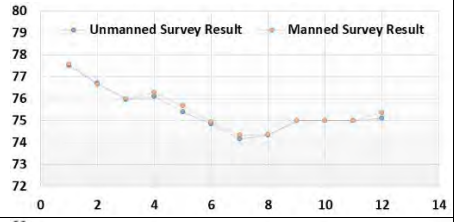
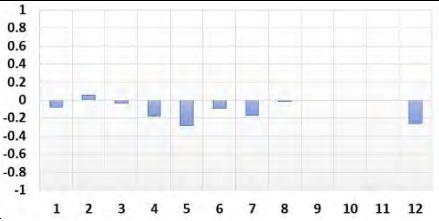
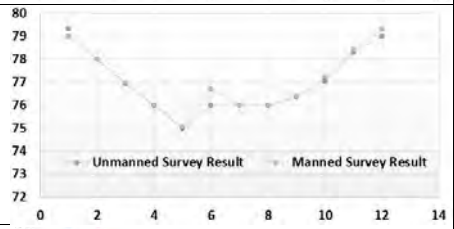
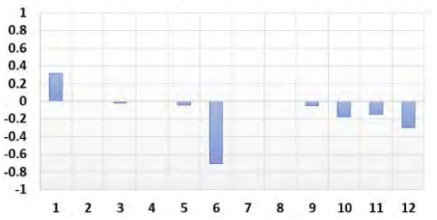
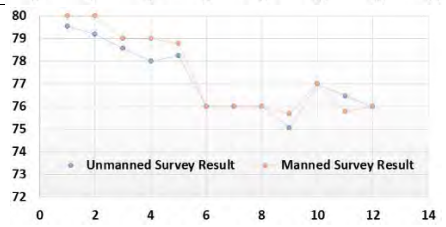
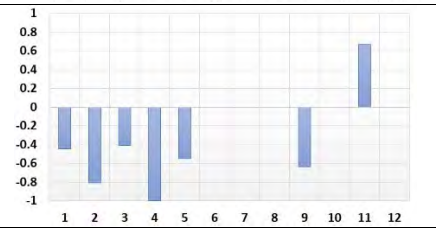
As shown in Table 5.2, as a result of comparing the capacity within a depth of 84 EL.m, it was found to be within the tolerance of 172,269 ㎥ (20cm).

Table 5.2 Acuracy evaluation of unmanned method at OTAE

No.	EL.(m)	Unmanned vessel		Manned vessel		diff.Vol(%)
		Area(㎡)	Volume(㎥)	Area(㎡)	Volume(㎥)	
1	75	56,510	33,019	50,829	28,516	4,503(15.8)
2	76	152,337	155,160	134,675	137,809	17,351(12.6)
3	77	287,655	410,122	280,712	381,915	28,207(7.4)
4	78	353,507	735,616	340,187	696,785	38,831(5.6)
5	79	469,855	1,162,979	441,505	1,097,355	65,624(6.0)
6	80	581,874	1,699,121	556,686	1,614,562	84,559(5.2)
7	81	710,462	2,360,822	711,019	2,268,890	91,932(4.1)
8	82	845,997	3,153,397	829,879	3,051,660	101,737(3.3)

9	83	860,904	4,014,000	860,605	3,907,512	106,488(2.7)
10	84	861,349	4,875,235	861,395	4,768,740	106,495(2.2)

Table 5.3 Comparison of manned and unmanned survey results with profiles

No.	Profile	Differences
1st line		
2nd line		
3rd line		
4th line		

X-axis : Number, Y-axis : Elevation(EL.m)

To verify the reliability of the unmanned vessel, the profiles of four arbitrary cross-sections were compared as shown in Fig. 5.1.

As shown in Table 5.3, the maximum deviation was 1.00 m(4th line) and the minimum deviation was 0.00 m.

The standard deviation of the difference between the two methods was analyzed to be 0.23 m, which is close to 0.20 m, the maximum allowable error of water depth surveying in the 『Public Surveying Work Regulations』.

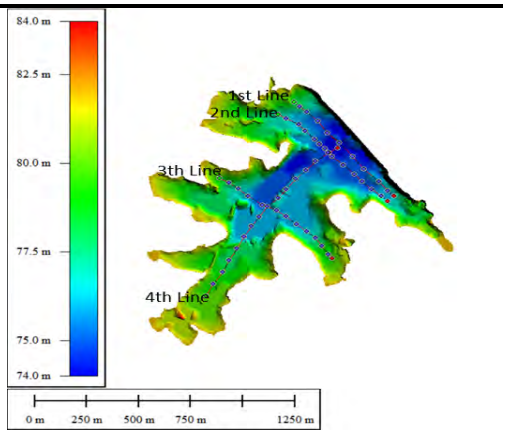


Fig. 5.1 Location of verification profile

6. Conclusion

6.1 Reservoir bed floor terrain information establishment

◦ The orthomosaic, digital surface model(DSM) and digital terrain model(DTM) of land part of reservoir were created by using data acquired by drone and the contour lines was extracted from this DTM.
◦ The track water depth map, grid water depth chart and contour map of underwater part of reservoir were created from data acquired by echo sounder, single beam.
◦ 2D and 3D DTM were produced by combining the topographical information of the land and underwater parts.

6.2 Capacity calculation

◦ Using the contour maps obtained through the drone and the echo sounder, the dead storage capacity, which is the amount of water below the dead water level, and the effective storage capacity, which is the amount of water above the dead water level and below the full water level, were calculated respectively.
◦ BULGAP reservoir construction project was approved in 1983 and completed in 2004. There was a difference of about 2.6m between the elevation of spillway crest by drone survey and the elevation of the full water level at RIMS. However, it was judged that the change will be made based on the national reference point in the ongoing『the flood control capacity enhancement project』.
◦ There was a decrease of about 1% based on the total storage capacity according to the comparison of data measured this time and the data measured in 2016.

◦ IT was found that the effective storage capacity of OTAE reservoir have decreased by about 1.3% compared to RIMS data.
◦ At the same time, it was found that the dead storage capacity have decreased 12.3% compared to RIMS data.

◦ At the BURDLE reservoir, there was also difference at full water elevation about 0.12 EL.m and at total storage capacity about 28.3% decrease.

6.3 Reservoir topographic information establishment with unmanned vessel

◦ An unmanned vessel with single beam was compared to a manned vessel.
◦ While it has the advantage of being easy to carry and securing the safety of workers, it has the disadvantage of requiring a separate support such as a drone to extract the track boundary when it is far from the view.
◦ It was considered that the device would need to be supplemented in the future, such as installing a camera.

◦ In the case of OTAE reservoir, the difference between the capacity obtained by the manned vessel and the capacity acquired by the unmanned vessel was 2% at high water level, about 4% at medium level, and about 7% at low water level.

6.4 Expected effects and practical measures

◦ It was judged that it would be possible to manage the irrigation water and contribute to disaster preparedness by measuring the actual effective storage capacity of the agricultural reservoir, which has been built for a long time.
◦ It is thought that the topographic information can be used as important information when performing projects other than the intended purpose, such as calculating the appropriate location and possible area for floating solar power.

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Modernization of East Fork Irrigation District – A Case Study
Hood River, Oregon, USA

1. Introduction

1.1. Irrigation in the West

In the contiguous U.S., most agricultural areas west of the hundredth meridian require irrigation to grow crops or provide pasture for livestock. In these 17 western states (the West[1]), there are approximately 180 million acres (73 million hectares) of farmland, of which approximately 20 percent (40 million acres or 16 million hectares) are irrigated using nearly 73 million acre-feet (9 million hectare-meters) of water per year (USDA 2017a). As a result of this water use, these lands generate almost $97 USD billion worth of agricultural products annually.[2]

The majority of water used for agriculture in the western United States moves through up to century-old irrigation systems. These systems of dams, diversions, ditches, and pumps deliver water from reservoirs and streams to irrigate 13.7 million acres (5.5 million hectares) of land across the West (USDA 2014). This infrastructure is often owned and operated by irrigation districts, ditch companies, improvement districts, or other quasi-municipal entities responsible for delivering water (collectively referred to as irrigation districts in this case study). Climate change, new policies, and ageing infrastructure have led to a new focus on modernizing irrigation infrastructure.

Irrigation modernization efforts in the West encompass a broad range of on-the-ground actions including: replacing open canals with buried, pressurize pipelines that conserve water by eliminating seepage and evaporation; installing fish-friendly hydropower facilities along pressurized pipelines; converting inefficient water application methods on-farm to more efficient methods; providing upstream fish passage past a diversion dam and opening miles of aquatic habitat for resident and anadromous fish; or any number of other on-the-ground actions (Figure 1).

Farmers Conservation Alliance's (FCA's) Irrigation Modernization Program (IMP) helps agricultural producers and irrigation districts understand and select a suite of actions aimed at modernizing their systems, identify the projected outcomes of those actions, develop the partnerships necessary to fund and implement those actions, and communicate the impacts of those actions to the broader community.

This case study analyzes the development of the current IMP within East Fork Irrigation District (EFID or the District) in Oregon, USA and describes how the District has moved through FCA's IMP. This study assesses the current status and potential impacts of irrigation modernization on energy, water, environmental, economic, and social metrics, and evaluates the relationship between hydropower development and irrigation modernization efforts. While this case study is specific to Oregon, it still provides a broad perspective on irrigation modernization around the West.

1.2. East Fork Irrigation District Overview

1.2.1. Irrigation Modernization in the Hood River Basin

EFID is located in Oregon's Hood River Basin in the Pacific Northwest region of the United States. The relatively small basin, approximately 482 square miles or 1,248 square kilometers, is located in north central Oregon, bounded by Mount Hood to the south, the Columbia River to the north, the

[1] Defined as Arizona, California, Colorado, Idaho, Kansas, Montana, Nebraska, Nevada, New Mexico, North Dakota, Oklahoma, Oregon, South Dakota, Texas, Utah, Washington, and Wyoming.

[2] Data represent all land area irrigated in Arizona, California, Colorado, Idaho, Kansas, Montana, Nebraska, Nevada, New Mexico, North Dakota, Oklahoma, Oregon, South Dakota, Texas, Utah, Washington, and Wyoming.

Cascade Mountain Range crest to the west, and by Surveyors Ridge and the Wasco County line to the east (Figure 2).

Hood River County (herein referred to as the County) sits within the Hood River Basin. Average annual temperatures in the County are 44.6 °F (7 °C) and average annual precipitation is 58.3 inches (148.1 cm) (NOAA 2019). As of 2018, the County's population was 23,428 with a 4.8 percent growth rate from 2010 to 2017— almost half of what Oregon's total growth rate was over the same period (9.4 percent) (U.S. Census Bureau 2018). Education, health care, and social assistance compose 20 percent of employment in the County while agriculture, forestry, fishing and hunting, and mining make up 16 percent.

The Hood River region produces one-third of the United States' winter pear crop along with other tree fruit crops, and the County is the largest producer of pears in the nation (Columbia Gorge Fruit Growers 2019). In 2012, total agricultural product sales in the County were $77 million. Tree fruits, including pears, apples, and cherries, represented 94 percent of the total market value of products (USDA NASS 2012). Agricultural production and related tourism are some of the regional economic drivers.

Within the Hood River Basin there are five irrigation districts that deliver water to farms, ranches, and orchards. East Fork Irrigation District (EFID), Farmers Irrigation District (FID), and Middle Fork Irrigation District (MFID) are the three largest districts in the basin, while Dee Irrigation District (DID) and Mt Hood Irrigation District (MHID) are smaller. Over the last 20 years, FID and MFID have collectively invested tens of millions of dollars to convert open canals to closed pipelines, and currently both districts are almost completely piped and provide pressurized, on-demand water to their water users. Much of the modernization of district infrastructure was possible following the installation of in-line hydropower facilities, which created a positive feedback loop between hydro revenue generation and modernization; FID and MFID began to generate revenue from hydropower, which provided the districts the capital to fund more infrastructure modernization projects. These modernization projects increased water efficiency throughout the irrigation system, allowing a larger percentage of water to be directed to hydropower generation. More water directed into the hydropower facilities has enabled the two districts to generate more revenue to invest in infrastructure modernization projects, continuing the loop. These modernization projects also have allowed the districts to decrease their diversion rates, become more resilient to climate change, and increase streamflow.

1.2.2. East Fork Irrigation District Characterization

EFID is the largest irrigation district in the Hood River Basin and is currently in the process of modernizing its infrastructure. The District operates a single diversion on the East Fork Hood River (Figure 2), and relies on natural streamflow derived from snowmelt, springs, and the glaciers on the slopes of Mount Hood to provide a supply of water to 990 water users. The District conveys diverted water through an 82.8-mile-long-system (133 km) of canals and laterals that were first built in the late 1800's. The District encompasses 9,596 acres (3,883 hectares) of irrigated land with an average farm size of 47 acres (19 hectares). The most recent survey of crop types, from 2008 to 2009, indicated that orchards with high-value crops (pears, cherries, apples) comprise approximately 75 percent of the irrigated acres within the District (EFID 2011).

Physical and Ecological Context: EFID is located 10 miles (16 km) from the foot of Mount Hood in the middle and lower Hood River Valley, a broad north-sloping bench through which the Hood River cuts a steep canyon. Most irrigated land consists of gently sloped terrain between 550 feet (167 m) and 1,000 feet (304 m) in elevation. There is a drop of over 1,400 feet (426 m) between

the District's diversion on the East Fork Hood River and the lowest irrigated properties near the City of Hood River.

EFID holds senior water rights[3] and diverts a maximum flow rate of 117.36 cfs (3.3 cubic meters per second) for irrigation purposes under its water rights, with an annual estimated volume diverted of 28,829 acre-feet (35 million cubic meters [m^3]). The District typically diverts water for its water users between mid-April and September, with diversion rates declining as water supplies decrease throughout the summer. During late summer, EFID typically diverts 75 to 85 percent of the streamflow of the East Fork Hood River.

The Hood River Basin has a high diversity of native anadromous fish, including summer- and winter-run steelhead trout, spring- and fall-run Chinook salmon, and Pacific lamprey, as well as other native resident species. The abundance and range of anadromous fish has declined from historical levels. The United States Endangered Species Act (ESA) establishes a national program for the conservation of species listed as threatened and endangered, and the preservation of the habitats on which they depend. Three fish populations in the East Fork Hood River are listed as threatened under the Endangered Species Act (Lower Columbia steelhead, Chinook, and coho salmon). State and federal agencies as well as the local Native American tribes (the Confederated Tribes of Warm Springs [CTWS]) have been involved in work to support fish populations in the river. To support these efforts, and because streamflow downstream from EFID's diversion during the irrigation season typically falls short of what is necessary to adequately support fish populations, the District manages its diversion to maintain a minimum streamflow of 15 cfs (0.42 m^3/s) in the river per an agreement with the CTWS.

2. Need for Modernization in East Fork Irrigation District

The impetus to modernize irrigation infrastructure in EFID is driven by several factors including climate change, operational inefficiencies, and environmental and community interests.

2.1. Climate Change

The District's water supply is fed by snow and glacial melt on Mount Hood, rain, and spring sources. Snowpack in the Hood River Basin has decreased since the 1920s, and Mount Hood's glaciers have receded since the mid-1900s or earlier (Lillquist and Walker 2006). Glacial recession and declining snowpack are expected to continue as a result of warmer temperatures predicted with the changing climate and lower natural runoff in the spring and summer months when water uses are greatest (Reclamation 2015). Drought has occurred in 3 of the past 14 years and has required EFID, by voluntary request to its water users, to curtail water deliveries by 25 percent throughout the peak irrigation season to avoid depleting streamflow in the East Fork Hood River at its diversion.

During these dry years, voluntary irrigation curtailments have been sufficient to avoid mandatory water cutbacks within the District (EFID 2020). Typically, irrigators who grow low-value crops such as hay and pasture have cut back water use during curtailments, which often results in missing the last hay cutting (Highland Economics 2020). This management response has minimized the adverse

[3] A senior water right refers to the priority in which water right holders can demand water in times of shortage and is based on the Prior Appropriation Doctrine. Throughout the West, a water right holder with the oldest water right (i.e., senior water rights) will be the last to shut off water in times of low streamflow and can fulfill their water right regardless of the needs of junior water users. If water is available beyond the water right of the senior user, the next most senior water right may use water available until that right is fulfilled. This continues until there is either no more surplus or all water rights are satisfied.

effects that dry years could have on high-value orchard crops. Because fruit trees are remarkably sensitive to shortages in irrigation water, growers prioritize sufficient irrigation for these crops to avoid impacts to yield, quality, and the establishment period for young trees (Fereres et al 2012).

A recent study from U.S. Bureau of Reclamation (Reclamation) suggests that, by the year 2030, the timing and character of available surface water in the Hood River Basin will be altered by climate change, impacting EFID's water supply (Reclamation 2014). As surface water patterns shift, EFID is expected to see water supply shortages of approximately 22 percent[4] from July to September during 10th percentile water years, which are anticipated to occur roughly 1 out of every 10 years. Even greater shortages are expected to occur during the 0 to 10th percentile years. Based on the number of the District's irrigated acres that have low-value and high-value crops[5], these water shortages could result in economic losses of $172,000 and $22,008,000, respectively, in the 10 percent of years that these water shortages are expected to occur (Highland Economics 2020).

2.2. Operational Inefficiencies

EFID manages and maintains 17.9 miles (28.8 km) of open unlined canals and 64.9 miles (104 km) of pipeline. Two-thirds of the existing piping is non-pressure rated. Because the conveyance system is not pressurized, more water than needed (up to 16.6 cfs (0.47 m^3/s) must be diverted to ensure that the District can deliver water to its users. This excess water spills from the ends of the District's system (i.e., from a "end spills" at the end of canal or pipe). Approximately 30 individual end spills discharge warm water, glacial silt, pesticides, and other contaminants from the District's system into lower Hood River tributaries. The lack of system pressurization requires the diversion, end spills, and overflows to be manually adjusted daily. It also requires that water users purchase, maintain, and operate pumps to distribute water onto fields.

Lesser but additional water losses may occur from seepage along the District's open and unlined canals. Measurements of seepage losses within the District have been inconclusive due measurement problems associated with the large number of turnouts to water users along the canals. Evaporation losses in EFID's system are minor (Wharry 2016).

Recently upgraded diversion infrastructure consists of an Obermeyer inflatable weir, a vertical-slot fishway, and steelslide headgates. A sand-settling trap is used to manage the river's periodically high glacial silt and/or landslide-caused sediment load. High sedimentation can lead to flooding and damage infrastructure (Gallino and Pierson 1984). The sand-settling trap is under-sized and sediment is often swept into the delivery system, creating a maintenance challenge for both the District and its water users. Sand and sediment often clog filters and emitters, wear sprinkler nozzles, and limit the use of efficient on-farm irrigation systems. Coanda fish screens are integrated at one end of the sand-trap facility to keep fish and debris out of the District's conveyance system. This screen design does not meet federal fish screening criteria[6], increasing potential regulatory risk

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[4] The Reclamation (2014) study suggests that EFID would experience a reduction in water supply by approximately 10 to 12 percent from July to September in a 10th percentile water year. This study did not account for the additional water that EFID leaves instream, according to an agreement with the Confederated Tribes of the Warm Springs Reservation, to maintain 15 cfs instream in the East Fork Hood River, but it did account for a 2.1 cfs instream water right. After accounting for the additional water that EFID leaves instream as a result of the agreement with CTWS, the District's total water supply shortage is estimated to be approximately 22 percent in a 10th percentile water year (Highland Economics 2020).

[5] For the purposes of this analysis, pears were used as the high-value crop.

[6] Federal fish-screen criteria include guidance about the structure and placement of the screen depending on the site location, appropriate approach velocity (local velocity component perpendicular to the screen face) given a range of

for the District. The current system also lacks telemetry (i.e., remote) monitoring capacity. The District depends on live streamflow, it has no reservoir storage. Concerns over drought and climate resiliency have prompted the District to consider developing reservoir storage in the future.

2.3. Environmental Interests

The health and recovery of federally listed fish species in the Hood River Basin is of interest to and monitored by federal, state, and local environmental stakeholders. An evaluation of the population viability status for ESA-listed fish species in the Hood River Basin concluded that coho salmon, spring Chinook salmon, and summer-run steelhead populations currently have a very high risk of extinction, while winter-run steelhead have a moderate risk of extinction (NMFS 2013; ODFW 2010). Low streamflow, including reduced flows due to irrigation withdrawals, are identified as a primary limiting factor for the recovery of listed salmon and steelhead in the basin (NMFS 2013).

Pacific salmon are also a premier cultural icon of the Pacific Northwest region of the United States, contributing educational, recreational, and community values. Of particular importance are the contributions of Pacific salmon to tribal traditions and religious practices (Bottom et al. 2009). The First Salmon Feast is part of the Columbia Basin tribes' traditional religion, and the Feast celebrates spring Chinook, the first salmon to return of the year, and the central role that salmon and water play in tribal health and culture (CRITFC 2019). Salmon and steelhead populations have declined in recent decades due to habitat degradation and other factors; however, since 1991, the CTWS has been working in the basin to rebuild these populations for conservation purposes and to provide consistent harvest opportunities (CTWS 2019).

2.4. Community Interests

The broader community in the Hood River area has a strong interest in irrigated agriculture and associated infrastructure modernization efforts. Hood River County encompasses EFID and has authority over land use decisions within county boundaries. In 2015, the County and the Bureau of Reclamation (a federal agency) partnered to prepare the 2015 *Hood River Basin Study* (Reclamation 2015). This study assessed future water supplies and demands in the region and identified potential alternatives for meeting those demands. The five irrigation districts in the region recognize the importance of irrigated agriculture to the local economy and are working with the broader community to plan for future conditions.

3. Approach to Modernization

In 2016, the District approached FCA to enroll in the Irrigation Modernization Program (IMP). As described above, this program is a comprehensive and customized approach to modernizing irrigation systems and includes developing a modernization strategy and finding funding to implementing projects.

The following sections provide further description about how EFID has moved through the IMP process.

3.1. Identification of the District's Modernization Goals and Objectives

Following enrollment in the IMP, and prior to beginning any analyses, FCA and the District worked together to first identify the District's modernization goals and objectives as well as the District's

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anticipated water flow patterns, appropriate sweeping velocity (velocity component parallel to screen face) given the location of the screen, appropriate screen openings given the fish that are present in the waterbody, and screen construction and materials. Each of these criteria are meant to protect fish from undue harm.

priorities. All projects carried out within an irrigation district must have approval from the district's board of directors. Developing a clear understanding of what district staff and the board envision for modernization is an important step in creating a strategy for modernization and assuring that there is full buy-in and support for the modernization process. EFID's board of directors identified the following goals and objectives for the District related to irrigation modernization:

- Increase resilience for handling drought and climate variability
- Reduce operations and maintenance needs and costs
- Reduce/eliminate water losses
- Improve streamflow conditions in the East Fork Hood River for threatened fish species and other aquatic life
- Irrigate 200 acres (81 hectares) of new agricultural land
- Improve sediment management and irrigation water quality
- Conserve energy and reduce on-farm operational costs by reducing the need for pumping
- Reduce public safety risks of open canals
- Maintain an economical irrigation water supply for water users
- Mitigate projected declines in snowpack and associated summer streamflow through the construction of a reservoir

3.2. Development of the System Improvement Plan

After the District established its goals, objectives, and priorities, FCA began developing a System Improvement Plan. The System Improvement Plan is a technical analysis and identifies how a district could modernize its physical infrastructure. FCA used a variety of data acquisition methods to assess the District's existing infrastructure, water loss, energy conservation and generation potential, and fish screening and passage solutions.

3.2.1. Technical Analyses Conducted

FCA, EFID, and their contractors collected and evaluated data to accurately map and hydraulically model EFID's infrastructure to design a pressurized delivery system and estimate costs for the proposed improvements. As outlined below, they collected water loss data and two types of spatial data.

Water Loss Assessment: FCA coordinated a water loss study conducted by GMA Hydrology, Inc. during the summers of 2016 and 2017. The study measured seepage losses and excess end spills associated with EFID's infrastructure. Using the study results, FCA developed water conservation estimates and identified project phasing for system modernization. EFID's System Improvement Plan (Appendix A) contains a summary of the water loss assessment and the complete data set of flow measurements.

Light Detecting and Ranging (LiDAR): FCA contracted Quantum Spatial to collect LiDAR data for EFID in the fall of 2017. FCA used this LiDAR data to create a three-dimensional layout of EFID in order to develop a hydraulic model of the District's irrigation system.

Geographic Information System (GIS): Using existing GIS data of system elements collected through a 2016 field survey performed by District staff and FireWhat, Inc., in the fall of 2017, FCA created a geodatabase of EFID's existing water delivery system. FCA worked with the District to update, correct, and verify EFID's existing GIS and water accounting data, and prepared a geodatabase for modernization alternatives.

Hydraulic Model: In early 2018, FCA developed a hydraulic model of the EFID system. A hydraulic model is a digital representation of the pipes, valves, and pressures needed to design a fully modernized irrigation system. FCA modeled EFID's canals, laterals, and existing pipelines with EPANET hydraulic modeling software in order to design a modernized conveyance system. A summary of the hydraulic modeling results appears in EFID's System Improvement Plan.

Assessment of Hydroelectric Energy Potential: In 2017, FCA contracted NLine Energy, Inc. (NLine) to complete an in-conduit hydroelectric energy assessment for 20 locations throughout the EFID delivery system. NLine selected six locations to conduct a more in-depth preliminary feasibility determination based on the site's technical, environmental, regulatory, and financial feasibility for hydroelectric project development. The preliminary assessments associated with each of the six locations are provided in EFID's System Improvement Plan. NLine conducted a further, site-specific analysis at one of these locations in 2019.

3.2.2. System Improvement Plan and Modernization Components

FCA developed a System Improvement Plan for EFID in spring of 2018. The plan includes a high-level, 10-percent engineering design and cost estimates for: piping open canals and laterals; replacing existing pipelines for pressurized water deliveries; an estimate of energy conservation associated with pressurized deliveries; pressure reduction needs; hydropower production; and upgraded sediment management and fish screening. FCA developed this plan based in part on the design parameters provided by EFID staff, and on data collected throughout the IMP process.

A fully modernized EFID system would replace 17.5 miles (28.2 km) of the District's 17.9 miles (28.8 km) of open canals and laterals with large-diameter pipe and would replace 43.5 miles (70 km) of existing non-pressurized pipeline with pressure-rated piping. District turnouts would be upgraded to provide pressurized water to water users, eliminating the need for on-farm pumping. Pressure-reducing valves would be added, where necessary, to control pipeline pressures. Buried pipe would be overlain with a gravel maintenance track bordered with native grasses and other native vegetation. A fish screening facility that meets federal criteria would replace the existing Coanda fish screen. The District's capacity to separate glacial silt and sand from the irrigation water delivered to water users would be enhanced through the installation of a new fish screen. While outside the scope of this analysis, under the District's desired approach to modernization, a 5,000-acre-foot (6 million m^3) storage reservoir and a telemetry system to monitor flows within the system would be developed over the next twenty years.

EFID has considered the results of preliminary analyses to determine whether an in-conduit hydroelectric project possesses the technical, regulatory, environmental, and financial merit for further hydropower development (NLine Energy, Inc. 2019). The analyses identified a 1.25-MW-rated Pelton turbine in-conduit hydropower generating station(s) that would provide a carbon-free energy source and a revenue source for the District. EFID has indicated that they prefer not to install hydroelectric power capacity at this time, due to marginal projected financial returns;

however, this case study still considers potential hydroelectric power development as part of irrigation modernization.

The total project cost, including construction, engineering, administration, and technical assistance for piping and the sediment basin is estimated at $70.1 million (Highlands Economics, LLC 2020). The hydroelectric facility cost is estimated to be $4.3 million (NLine Energy, Inc. 2019) and the fish screen replacement cost estimate is $787,000 (Farmers Conservation Alliance 2018).

Once the SIP was completed, it was presented to the District board of directors for their approval.

4. Modernization Strategy Development and Resulting Benefits

Following the System Improvement Plan, FCA worked with the District to develop a comprehensive Modernization Strategy, which incorporated the technical analyses outlined above to evaluate benefits and disaster preparedness, assess ecosystem services, identify strategic partnerships, complete a financial analysis, develop a funding plan, and identify communication tools. This document is designed to assist irrigation districts with engaging key stakeholders and identifying funding paths to put projects in the ground.

4.1. Modernization Benefits

The sections below highlight several of the benefits identified in the development of the Modernization Strategy.

4.1.1. Water Resource Benefits

Modernization would convert EFID's open system to a pressurized system. The pressurized system would provide water users an on-demand water supply[7] so that they can use water as needed. Correspondingly, it would eliminate end spills from the system and reduce system water loss in EFID from an estimated 18.3 percent to nearly zero. The delivery system would be efficient and water deliveries more reliable.

Through the conversion of its open canals and pipelines to a pressurized delivery system, the District would no longer need to divert an excess of 16.6 cfs (5,300 acre-feet (5.3 million m^3) of water per year in order for water users to receive their total duty of 3 acre-feet per acre (0.37 hectare-meter per hectare) per year. EFID can use Oregon's Allocation of Conserved Water Program[8] to allocate a portion of this saved water to instream use in the Hood River and its tributaries, to support and enhance aquatic habitat, and a portion to out-of-stream use in the District, to shore up existing water supplies and irrigate additional lands. As of April 2019, EFID has already allocated 1.2 cfs (0.03 m^3/s) of water saved through previous piping projects to out-of-stream use and 1.58 cfs (0.04 m^3/s) to the East Fork Hood River using the Oregon Allocation of Conserved Water Program, with an additional 0.5 cfs (0.01 m^3/s) for instream use pending review (OWRD 2015).

[7] Irrigation systems that are not modernized with pressurized systems require that water users schedule water and take water when it is made available by the irrigation district. Despite water delivery schedules, when water is available is not necessarily congruent with when the water is needed by users. The result is water usage that is inefficient.

[8] Oregon's Allocation of Conserved Water Program allows users who conserve water to dedicate a portion of that conserved water to new, beneficial uses while the remaining portion is allocated to the state for instream use. The percent of conserved water allocated to each use is determined based on the funding mechanisms used to complete the water conservation project. Following completion, a new water right is issued to the user with the original priority date reflecting the reduced quantity of water being used with improved technology. Correspondingly, a new water right is issued to the state for instream use.

Currently planned modernization projects will allow the District to allocate 75 percent of the water saved through modernizing its system to restore streamflow in the lower East Fork Hood River, the highest priority stream reach for streamflow restoration in the entire Hood River Basin. EFID currently releases an interim minimum flow of 15 cfs at its diversion pending an agreement with CTWS for a permanent minimum flow. A CTWS study recently determined that a minimum of 27 cfs (0.76 m^3/s) was needed below the EFID diversion to improve fish passage conditions for threatened spring Chinook salmon. Water savings and instream allocations through EFID's modernization projects will allow the District to satisfy its flow agreement with CTWS as well as legally protect the water instream in the East Fork Hood River through the Oregon Allocation of Conserved Water Program.

Low snowpack has limited EFID's irrigation water supply in 3 of the last 14 years (2005, 2015, and 2018). The District has asked water users to voluntarily curtail water use by 25 percent to help it maintain streamflow for threatened salmon and steelhead in the East Fork Hood River downstream of the diversion. Curtailment has begun as early as mid-July and extended through the peak summer demand period. Through past conservation projects and voluntary curtailment by water users, EFID was able to maintain at least 15 cfs (0.42 m^3/s) in the river at its diversion during the 2015 and 2018 droughts, up from 5 cfs (0.14 m^3/s) during the 2005 drought. In prior drought years, the river would sometimes go dry below the EFID diversion.

Eliminating water losses in the system through piping and pressurization will reduce the effect of future water shortages, reducing crop yield losses and providing economic benefits to agricultural producers and the surrounding region. Demands on water resources in the basin are expected to increase as climate change and population growth continue (Reclamation 2015). With modernization, future water supply shortages due to drought and climate change, will be reduced from 22 percent of demand without piping and pressurization to approximately 11 percent of demand with piping and pressurization (Highlands Economics 2020).

Additionally, eliminating end spills will improve water quality in the affected tributaries by eliminating the discharge of contaminants. Leaving this saved water instream will also contribute to improved water temperatures in the East Fork Hood River. Compared to the average August streamflow in the 2015 drought, streamflow would increase by up to 38 percent at the confluence; the minimum daily August flow would increase by up to 60 percent (NRCS 2019). These benefits have and will continue to provide a critical value for environmental interests, such as the Oregon Watershed Enhancement Board and CTWS, which can promote investment in modernization in EFID.

4.1.2. Environmental Benefits

Modernization would increase streamflow in the East Fork Hood River, improving habitat, fish passage, and water quality conditions during the irrigation season for various life stages of ESA-listed steelhead trout, and Chinook and coho salmon as well as for rainbow and cutthroat trout and other resident native fish and aquatic species. In addition, the project would support measures included in the Lower Columbia River steelhead and salmon recovery plan.

4.1.3. Agricultural Benefits

The conserved water going to EFID would be used in dry water years (approximately 10 percent of the time) to enhance the reliability of water supply for existing irrigated lands. Increased agricultural production benefits from having additional water for existing irrigated acres are estimated to have an average annual net benefit of approximately $1.6 million (Highlands Economics 2020). These

benefits would enable EFID's water users to invest in additional on-farm and District improvements as desired.

Modernization is projected to save EFID water users approximately $348,000 annually in operation and maintenance (O&M) costs as compared to current costs (Highland Economics, LLC 2020). This includes $193,000 annualized savings for pump maintenance/replacement costs, $86,000 annualized patron pump energy cost savings, and $69,000 annualized savings in water user's screen-cleaning costs. Modernization is expected to save the District itself an additional $250,000 annually in O&M costs compared to its current costs (Highland Economics, LLC 2020).

4.1.4. Energy Resource Benefits

Currently, the District has no revenue other than water rates charged to water users, totaling approximately $1 million annually. As noted earlier, EFID has identified the potential to install a 1.25-MW-rated Pelton turbine with an annual energy generation potential of 3,777 MWh. Estimated annual net revenue for the hydroelectric project is $94,000 to $106,000. The estimated project cost is $4.3 million (NLine Energy, Inc. 2019). A 3-phase circuit exists 3,300 feet northwest of the proposed station and would require reconductoring 3,300 feet of 2-phase circuit, trenching, and other equipment all included in the project cost estimate. No other known constraints were identified by the local utility, Hood River Electric Co-Op. Additionally, an estimated 1,169 MWh of electricity would be saved through modernization by providing pressurized water deliveries and reducing on-farm pumping.

4.1.5. Economic Benefits

Investing an estimated $70 million in EFID would support construction sector jobs and income and would have economic ripple effects throughout Hood River County (Farmers Conservation Alliance [in progress]). Modernization in EFID would support approximately 75 jobs and $3 million in average income over a ten-year construction period. Over the long-term, these investments would support increased agricultural production. Average annual total economic activity supported by EFID's agricultural production includes approximately 1,600 jobs and $66.1 million in average annualized income (Farmers Conservation Alliance [in progress]).

4.2. Stakeholder Engagement and Project Funding

4.2.1. Stakeholder Engagement

Strategic partnerships at the federal, state, and local levels are critical to successfully implementing EFID's Modernization Strategy. EFID can maximize the benefits of District modernization by working collaboratively with partners on infrastructure improvements, on-farm irrigation efficiency, and water resource planning. In addition, EFID can continue to engage in basin-wide collaborative processes that may also help to promote the implementation of the District's Modernization Strategy. By continuing to engage with its existing partners and identifying the best way to engage with new partners to expand the pool of funders, EFID will be able to implement its Modernization Strategy as efficiently as possible.

The stakeholders that EFID has been engaging with for funding, permitting, and support are listed below.

Federal

United States Department of Agriculture (USDA): Natural Resources Conservation Service (NRCS)

United States Bureau of Reclamation (Reclamation)

National Oceanic Atmospheric Administration (NOAA) Fisheries

Tribal

Confederated Tribes of Warm Springs (CTWS)

State

Oregon Water Resources Department (OWRD)

Oregon Department of Environmental Quality (ODEQ)

Oregon Watershed Enhancement Board (OWEB)

Oregon Department of Fish and Wildlife (ODFW)

State Historic Preservation Office (SHPO)

Local

Hood River County Board of Commissioners

Hood River Soil and Water Conservation District (SWCD)

Non-governmental Organizations

Hood River Watershed Group

4.2.2. Funding and Finance

The majority of project funding will likely come from federal investments. EFID has submitted a request for $27 million through federal financial assistance as part of the Watershed Protection and Flood Prevention Program (Public Law 83-566). A preliminary draft Watershed Plan Environmental Assessment has been prepared for National Resources Conservation Service to satisfy National Environmental Policy Act[9] requirements for the EFID Infrastructure Modernization Project and is currently undergoing review and finalization.

To supplement the grants, the District will likely finance a portion of the project using a low-cost Clean Water State Revolving Fund (CWSRF) loan. The District is currently paying off two CWSRF loans ($2 million and $1.5 million) for the Central Lateral Pipeline project that was completed in 2008. As of September 2018, a balance of $569,000 remained on the $2 million loan with a payoff date of June 2023 and $377,000 on the second loan with a payoff date of September 2028. The District has little-to-no capital reserves to contribute to modernization. Throughout modernization, the District will provide in-kind assistance, which will include construction labor to replace a portion of the sublateral pipelines. In addition, as mentioned above, District water users will realize decreased operational costs from the 1,169 MWh of energy saved from providing pressurized water deliveries and hence reducing on-farm pumping.

5. Project Implementation

In the fall 2020, the District will begin construction for piping a 5.9-mile (9.5 km) section of open canal. To date, $3.6 million in grant funds have been raised to complete this piping project.

[9] The National Environmental Policy Act (NEPA) is a law that requires federal agencies to assess and evaluate the environmental, social, and economic effects of a proposed action prior to making a decision. NEPA also provides opportunities for public review and comment on those evaluations.

Construction will take place during the non-irrigation season. While traditionally EFID and many districts across the West have used materials such as polyvinyl chloride (PVC) and steel for piping, this project will use high-density polyethylene (HDPE). The District selected this material because this material is resistant to pressure from water hammer and has high tensile strength (Najafi et al. 2015). During installation, HDPE pipes are welded together; therefore, the need for expensive fittings and thrust blocks is minimized. HDPE pipe is easy to install, bendable, retains its properties between -220ºF (-140ºC) and 180ºF (82ºC), and has a design life of 100 years. It is also less susceptible to damage due to freezing water as compared to other piping materials. In Oregon, there are an increasing number of irrigation districts that are adopting HDPE as their preferred material.

6. Barriers and Challenges to Modernization

EFID faces a suite of challenges both specific to the District, as well as challenges seen across the majority of districts in the West that are trying to modernize irrigation infrastructure.

6.1. EFID-Specific Challenges

EFID is a relatively small irrigation district with a five-member board and five full- or part-time staff. While the District's staff and board are both active and capable, they have not had the capacity or resources to fully engage in large-scale irrigation modernization.

From a funding perspective, all of the District's income is generated from water rates charged to the water users of the District. This limitation has created a challenging financial barrier that disincentivizes change, because, up until now, the majority of the costs of improvements to the District have been borne directly by the water users.

Currently, the District has no hydropower generation to provide a diversified source of income. Although there is the potential to install a 1.25-MW in-conduit hydropower plant in its system, hydroelectric power generation would be secondary to providing agricultural water deliveries in the District, and EFID would only operate this power plant if it were otherwise diverting and delivering water for agricultural purposes. An initial assessment of this project suggested that a hydropower plant may not provide a positive cash flow given projected initial funding sources, revenue streams, construction costs, and operating costs.

The District's location in a small community creates a social setting in which "everybody knows everybody." This community context, in turn, makes potentially unpopular decisions hard to implement. Furthermore, the District has high-sediment transport rates in its waterways, which increases the complexity in the existing and proposed irrigation systems. Together, these factors have resulted in the District making slower, incremental adjustments rather than undertaking system-wide modernization.

6.2. Broad Challenges for Modernization

Limited match funding, federal and state regulations, and changing demographics of water users are all challenges that not only EFID is facing, but districts across the West are facing.

Although federal funding available for modernization has increased recently, particularly from the USDA's Watershed Protection and Flood Prevention Program, all federal funding programs require non-federal match funding. This requirement creates challenges because limited options are available at both the state and local levels to secure match funding sources. Additionally, the application processes for federal funding sources can be very rigorous, complicated, and highly competitive. This process can put smaller districts, with limited resources, at a disadvantage.

Any district that successfully secures funding, must also navigate a complicated system of local, state, and federal regulations. For example, because most districts were built in the early 1900s, they are eligible to be designated "historic" or have sections of their infrastructure listed on the National Register of Historic Places. These designations can limit a district's ability to improve or otherwise alter this infrastructure. Before modernizing, districts have to work with the State Historic Preservation Office to complete surveys and come to an agreement of how to move forward. This process, as well as other permitting processes, can be costly and time-consuming causing modernization projects to be delayed or not occur at all.

In EFID and across many districts that are located near small towns or cities, the make-up of the water users is also changing. Along with serving agricultural producers, as they traditionally have done, districts are now serving water users who are new to farming or have purchased land to pursue a rural lifestyle but not actively farm the land. Additionally, as urbanization occurs, district infrastructure now weaves through houses, neighborhoods, and lands that do not have water rights and are not served by the district. A number of these water users and landowners also tend to not be interested in modernization as they view the irrigation canals and ditches as desirable water features that cross their property. This shift can be a challenge to districts because it complicates easements and right-of-way issues as well as increasing the likelihood of litigation against piping projects.

7. A Way Forward

The following are variety of opportunities that would allow EFID and other districts in Oregon and the West to advance modernization at a faster pace and larger scale.

7.1. Diversified Revenue Streams

Past experiences in other districts clearly demonstrates that hydropower revenue streams help districts to move away from funding one-off projects every one-to-three years through grants and smaller loans, to funding comprehensive, multi-phase projects over 20 years. If policies and pay-back periods for hydropower generation would make hydro installation more feasible and financially viable, EFID and other irrigation districts would be better able to leverage the local, state, and federal funding for modernization efforts.

Additionally, a significant barrier to improving telecommunication and energy infrastructure in rural areas is the great expense associated with siting, right-of-way, engineering, permitting, and installation of infrastructure. Irrigation modernization projects already cover most of those costs, which could improve the feasibility of installing fiber optic and electric transmission/distribution lines if these projects could be done simultaneously. Exploring other revenue streams, such as these, or other ways in which to leverage private capital, will help decrease the reliance on the limited funding sources that currently exist.

7.2. Inter-District and Broader Basin Analysis

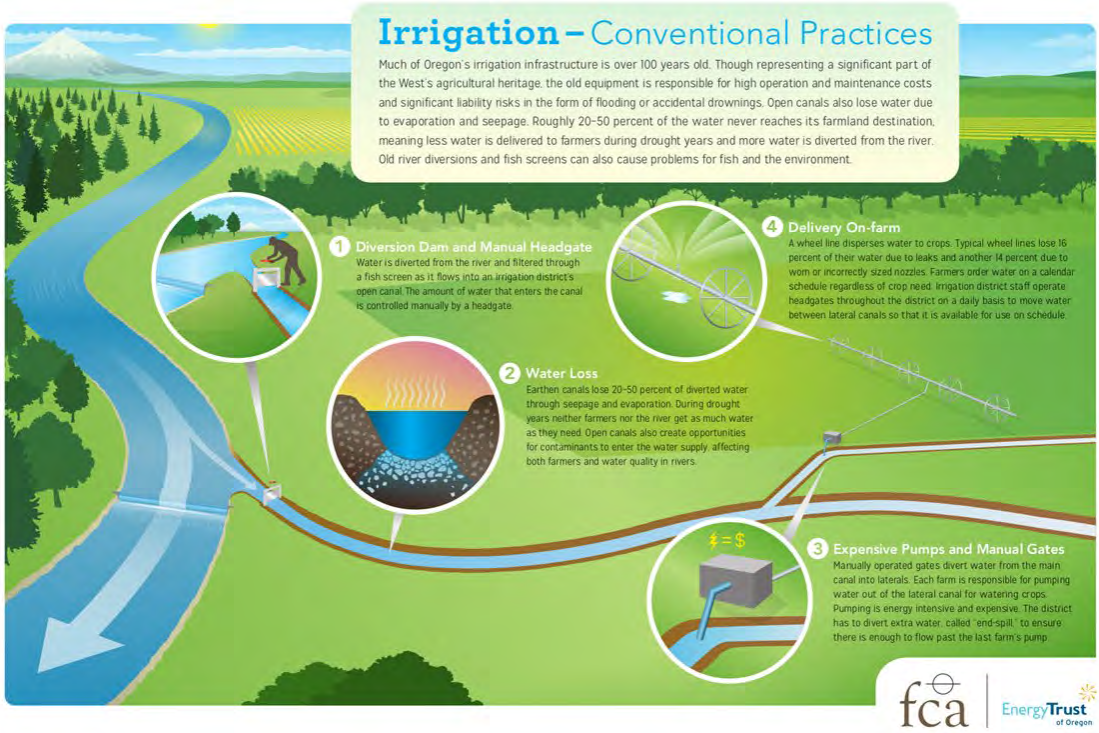
Irrigation modernization strategies have historically focused on efforts within a district boundary, and opportunities exist between districts and at broader spatial scales. With the appropriate tools and funding in place, broader evaluations on a basin-wide scale could potentially reveal large benefits for all stakeholders. In addition, connecting water conveyance within and between irrigation districts with telemetric services could provide improvements in irrigation network optimization.

7.3. Education and Outreach

To FCA's knowledge, there is no existing, widely offered, comprehensive irrigation manager training program. This creates a situation in which an irrigation manager either has to learn everything on the

job, which can take years, or must come from a mentoring situation, which is becoming rarer as younger generations move away from the family farm (van Vliet et al. 2015). Neither of these situations support the type of innovation that is necessary to initiate, fund, and implement a comprehensive irrigation modernization plan. Furthermore, without formal irrigation manager training, new technologies and funding opportunities go unnoticed or are missed. Developing a widely offered training program could provide an opportunity to enhance capacity among district staff and accelerate irrigation modernization.

Outreach to the general public about irrigated agriculture and modernization of outdated infrastructure could also provide an opportunity to remove some of the barriers and misunderstandings. Showing successful examples of and creating programs dedicated to irrigation modernization could help ease concerns about public safety, property values, and ecosystem services. Currently, there is no single outreach program or strategy; each district handles outreach differently and some do not do it at all. By standardizing outreach efforts, district water users and stakeholders can begin conversations from a mutual level of understanding, which could promote productive communication.



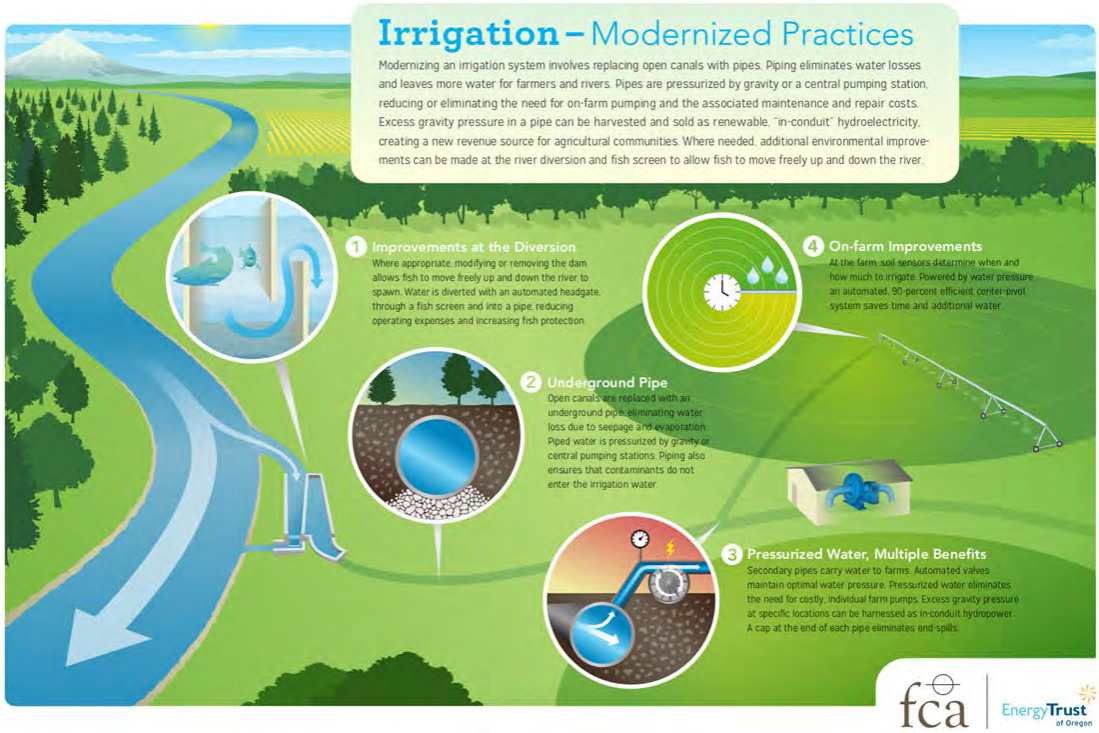


Figure 1. Conceptual diagram of the differences between a modernized and non-modernized irrigation district.

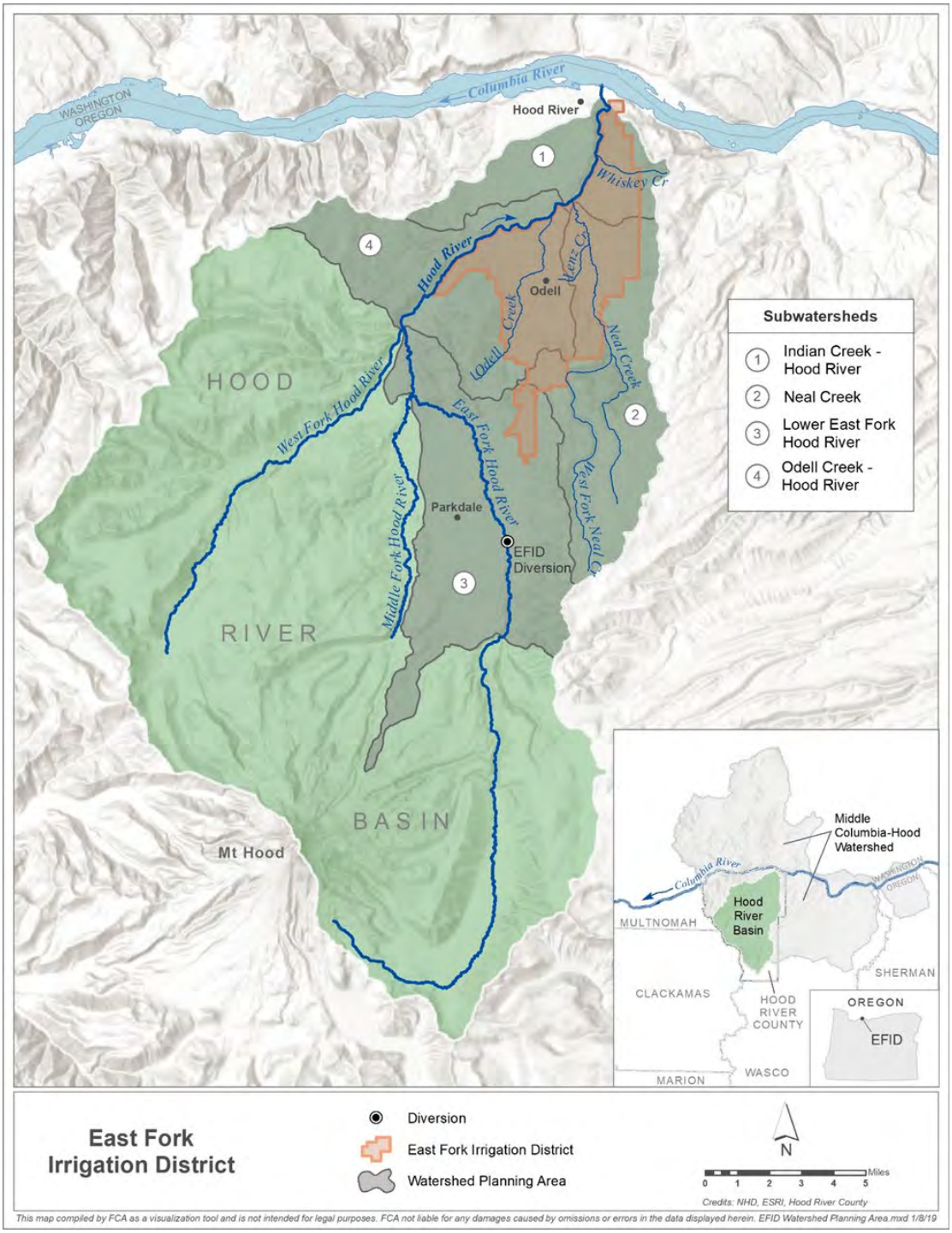


Figure 2. East Fork Irrigation District area map.

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RMCG

Modernizing a pressurised pipeline supply system for high value agriculture in Asia.

ICID International Workshop on Modernizing Irrigation and Drainage Services
Adelaide, Australia - 6th October 2022

1 Overview

1.1 AUS EXPERIENCE

Irrigation systems around the world have traditionally relied upon gravity to collect, store, transport and apply water to the crop. Water was only pumped in pipes in exceptional circumstances such as lifting water from a river, or pumping to irrigate high land, or extracting groundwater. Gravity was the preferred method as the operating and energy costs were very low.

Historically, Australia developed many irrigation areas and systems across the southern Murray Darling Basin area from the late 1800's to 1970's - all based on gravity. Today, Australia's irrigation systems within the Murray Darling Basin (MDB) can be grouped into five main types:

i. the four largest areas comprise traditional canal systems each covering up to 300,000ha with mainly rice, cereals, cotton, pasture for livestock, and some horticulture
ii. the lower Murray where pumped systems (about 20 systems supplying between 250ha and 5,000ha) located in the Sunraysia district based around Mildura and in the Riverland district supply water into concrete lined canals for high value horticulture (wine, table and dried grapes; citrus, stone/pome fruits: vegetables etc)
iii. local groundwater extraction – this is scattered across the MDB with about 12- 20 different main aquifers each supplying up to 50,000ML to all sorts of crops.
iv. more recent developments in the northern part of the MDB where individual farmers have large on-farm storages (up to 2,000ML each) that harvest floodplain flows for their own use mainly irrigating cotton.
v. Individual river pumpers throughout the MDB but with a large concentration located adjacent to the Riverland and Sunraysia districts where large properties (up to 5,000Ha each) irrigate mainly almonds, and another concentration on the Murrumbidgee river irrigating cotton and a variety of other crops.

This paper draws on the experience of the modernised pumping systems found in the Sunraysia and Riverland districts. They involve the use of significant energy both in the pumped pipe supply systems and on-farm with sprinklers and drip systems. It is these pumped piped schemes that have the most application to Asia with their development of modernised irrigation systems to supply high value horticulture.

Irrigation areas in southern MDB – need to mark up Sunraysia and Riverland

1.2 OBSERVATIONS OF THE ASIAN EXPERIENCE.

Large irrigation systems in Asia are often centred around rice paddy fields interspersed with permanent crops, vegetables and some cereals/maize. Generally the rice paddy irrigation is based on a network of continuously flowing gravity canals, with multiple rice crops per season, some being rain-fed and some irrigated. The use of rice paddy farm layouts generally limits the supply system to gravity canals.

By contrast in Vietnam and other Asian countries the irrigation of permanent tree crops, vegetables and flowers now relies on sprinklers and drip systems involving on-farm pumped, pressurised piped systems. These systems and crops require a much higher level of service which is generally difficult to deliver from traditional canal supply systems. Thus these farmers often convert to a groundwater source or direct pumping from a river or storage, even though the cost of extraction is higher. This means they can get the water when and how they want to, called "*water on demand*". There is some flexibility about when the farmers need the water called "*almost water on demand*". The farmers often have very modern and efficient on-farm irrigation systems (remote automatically controlled etc) which is in stark contrast to the inefficient and outdated supply system.

There is increasing demand to modernise and provide irrigation supply systems to enable higher value crops, increase water use efficiencies and address water scarcity and climate change issues. Often the priority is to focus on the on-farm system and the need to educate farmers to adopt more efficient systems. However, the main limitation to productivity and water use efficiency is the design and operation of the supply system. If the supply system provides a good level of service then very quickly the farmers will take advantage and become more efficient.

1.3 PARADIGM SHIFT

The adoption of a pressurised modernised pipeline supply system requires a paradigm shift. This is because most irrigation system design engineers and system operators are very experienced in traditional canal design and operation. However, a modernised pipeline design is fundamentally different and challenges many of the “norms” of canal operation. For example, full integration from the storage through to the sprinkler without storage tanks or local farm storages, and direct pipe connections to the farm system challenges the operators’ sense of control over the system.

Modernised pipeline systems require new skills such as automatic pressure controlled variable speed pumps which provide water on demand, simplifying operations and reducing pumping costs. Equally, the use of “ring mains” and interconnecting pipes to provide an integrated network rather than the traditional canal “tree type” design requires new design skills as does the use of a network computer design program like “epanet”. Engineers and operators who are used to an urban water supply system make the transition readily. Getting an understanding of the paradigm shift required is the most challenging part of “modernising” a supply system for high value horticulture. Overcoming this paradigm challenge should not be underestimated.

1.4 AUSTRALIA’S INVOLVEMENT IN WEIDAP

The various large development banks are all investing heavily in modernised/rehabilitated irrigation supply systems across Asian countries. This very large investment provides a major mechanism to ensure that water management is able to respond to water scarcity, climate change and the need for increased living standards.

The Asian Development Bank (ADB) brought together a number of small groups from each of 6 Asian countries that were considering various irrigation modernisation projects. This group undertook a study tour in December 2016 sponsored by AWP (Australia Water Partnership) of examples of modernised irrigation schemes in Australia. One of the groups came from Vietnam’s WEIDAP (Water Efficiency Improvement in Drought affected Provinces) project. This group identified that Australia had relevant expertise in the design and operation of supply systems for high value horticulture. Thus in 2016 Vietnam and ADB jointly invited AWP to support their $120million ADB loan funded WEIDAP project that was in its feasibility development phase.

A group of Australian water experts funded by AWP have provided technical support to the WEIDAP project over the last 5.5 years from the feasibility stage, through the detailed design stage and now starting to support the construction and implementation.

1.5 WHAT IS WEIDAP

Water security is a growing concern in Vietnam, particularly in drought-affected provinces. The 2015 -2016 El Nino drought and associated saltwater intrusion affected some 400,000 ha. of cropland to varying degrees of productivity loss. Urban and rural water supplies were also significantly impaired resulting in around 2 million people lacking access to water in 2015. In response, the Government is taking active measures to improve water use efficiency and water productivity, focusing especially on the agriculture sector since it consumes the bulk of surface and groundwater.

The Government is preparing an investment project of $120 million to modernize irrigation water management in five drought-affected provinces, with support from the ADB. The WEIDAP project was originally planned to commence in early 2018 and be fully operational by early 2024. However, Covid has significantly delayed progress. The outcome of the Project will be climate resilient and modernised irrigation systems providing flexible and affordable services to beneficiary farmers in the five participating provinces, covering about 12,000 ha of high value crops.

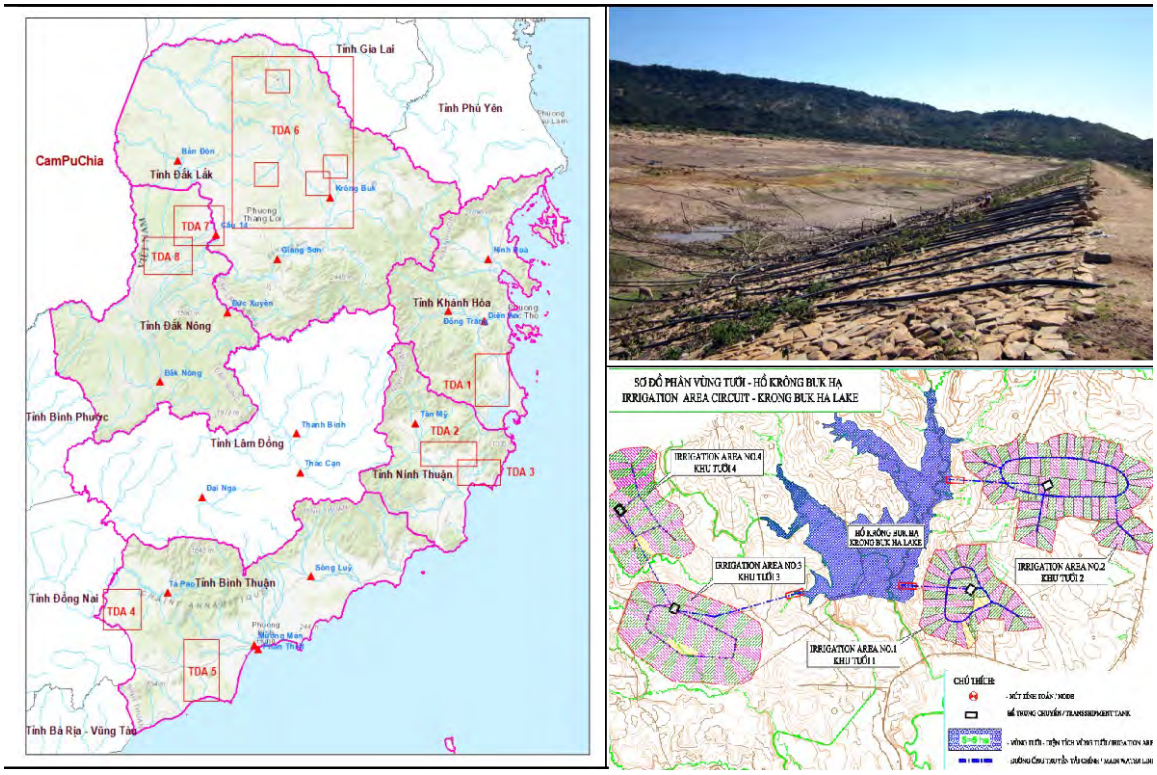
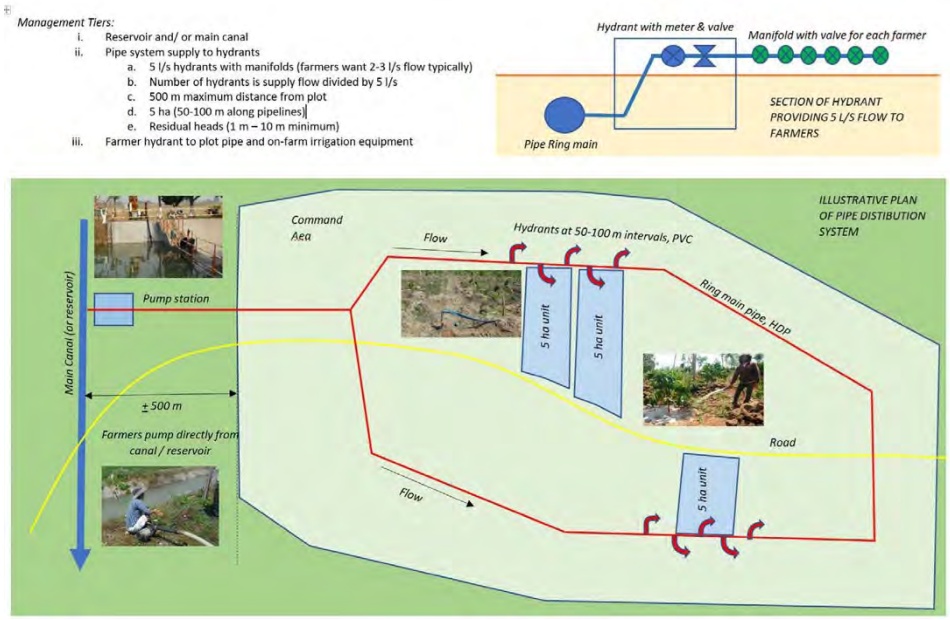


Fig 1. Schematic Diagram of Modernised Piped Irrigation System as proposed



1.6 ADOPTION OF A PRESSURISED PIPELINE SUPPLY SYSTEM

A major part of the WEIDAP project involves pumping water to individual farms for use in high value horticulture (vegetables, black peppers, dragon fruit, coffee, cashews, mango) where the farmers are already using sprinkler/drip and hand held hoses to irrigate their crops.

Vietnam initially considered the use of concrete lined canals, but with Australian expert assistance and much debate and exchange of information they decided to adopt a modernised approach to a pipeline system that included a pressurised pipeline system where the farmer directly connected to the supply in a very similar manner to an urban water supply system.

1.7 WEIDAP JOURNEY SO FAR

The modernisation of the supply system in WEIDAP started with the feasibility study in 2016/17, a study tour of Australia by Vietnam in 2017, development of design guidelines and workshops to train the local designers and the PPMU (Project Management Units), the detailed design in 2020-22 with repeated changes and training of the designers to ensure modernised systems were implemented. A pilot project within another ADB loan funded project in the Don Duong District of the Lam Dong Province, was designed and constructed during 2020/22. This system was a modernised pressurised pipeline supply system serving approx. 100ha area. This system provided lots of valuable lessons for WEIDAP and enabled the WEIDAP project to observe a similar system within Vietnam.

The construction phase is about to begin and the associated projects like the development of crop watering monitoring program, the development of water resource planning, entitlements and an allocation system, plus the monitoring of groundwater to enable conjunctive use. The calculation of a water charging system for each project in accordance with the new Law on Hydraulic Works (Water Law) will follow. AWP experts will continue to provide assistance in all of these stages.

1.8 RESISTANCE TO MODERNISING THE PIPED SUPPLY SYSTEMS

There are a number of reasons why funding agencies, provincial governments, designers and system operators fail to adopt a modernised system. The most obvious reason is that it is something new and unfamiliar. The modernisation of the supply system requires substantial capital and the “tried and proven” method is perceived to be the “safe” option even if the alternative is cheaper and provides a better level of service.

The major stumbling blocks experienced in Australia and in Vietnam are concepts like:

- Variable speed pumps are new and appear more expensive – even though they can be smaller in a modernised system
- Allowing farmers to connect directly into the system means the operators feel like they are losing control

Vietnam has adopted most of the concepts of modernised pressurised pipeline supply system within its urban water supply systems. However the concept of allowing “urban water supply” principles within the irrigation supply system is yet to be adopted.

2 A modern pressurised pipeline system

2.1 WHERE PIPELINE SUPPLIES SHOULD BE CONSIDERED

i. Permeable soils/horticulture – pressurised pipe supply

Horticulture should be developed in areas with permeable soils where sprinkler/drip irrigation will be adopted on the farms. The provision of a pressurised piped supply system is desirable as it provides the level of service needed to achieve the productive potential of the crops.

ii. Large head (steep falling ground) enabling gravity pipe

A gravity pipe can be cost effective in steep falling ground as an alternative to either earthen canal or expensive concrete lined canal. In these cases a pump is not necessary or may be required for some individual farmers to increase the pressure.

iii. Whenever there is need to pump water as part of the supply system

Many supply systems require a pump to lift water from a river or from groundwater. The capital cost of the pump system is relatively large and so the marginal cost of then piping the water to the field is relatively small. Therefore, whenever a pump is used, a piped supply should be considered, particularly as it will provide a better LoS than a canal supply system.

iv. Uneven topography

Canals are generally limited to following the “contour” of the land which can be disruptive and inefficient (with many twists and turns). Whereas pipelines can follow a direct line and be designed in an efficient distribution pattern. So in uneven topography pipelines can be very cost effective.

v. Whenever the farm systems are pressurised (drip or sprinkler)

It is difficult to achieve a good level of service to a farm with a sprinkler or drip irrigation system when using a canal system without having an intermediate storage which is inefficient, expensive and consumes valuable land, an automatically controlled canal system that maintains supply volumes and levels (which does exist in some Australian canal systems) and excess flows in the canal that result in inefficient water use of the system

vi. Supplying permeable soils with gravity farm systems

Sometimes pipelines are used in permeable soils supplying gravity farm irrigation system. However, the size of the pipe is generally larger than if it was supplying sprinkler/drip farm system and thus is generally less cost effective than canals. Further, a gravity irrigation system is not recommended in the long term on-farm with permeable soils if productivity and water use efficiency are to be maximised.

vii. Supplying areas <2,000ha

Pipelines are often used to supply areas of <2,000ha. Velocities in pipelines should be kept between 1-2.5 m/sec so that energy losses are not too large, while siltation of pipes is avoided by keeping velocities above a minimum. This means that the largest practical pipe size (600mm to 1,000mm diameter) typically delivers up to 1.5m^3/sec which is sufficient to supply up to 2,000ha of irrigated land depending on the crop type and local climatic conditions. Larger areas (up to 1,000ha) can be supplied if a networked system with ring mains and interconnecting pipes are used.

2.2 ADVANTAGE OF DIRECT FARM CONNECTIONS TO A PRESSURISED SUPPLY

2.2.1 DIRECT FARM CONNECTIONS ARE A BETTER OPTION

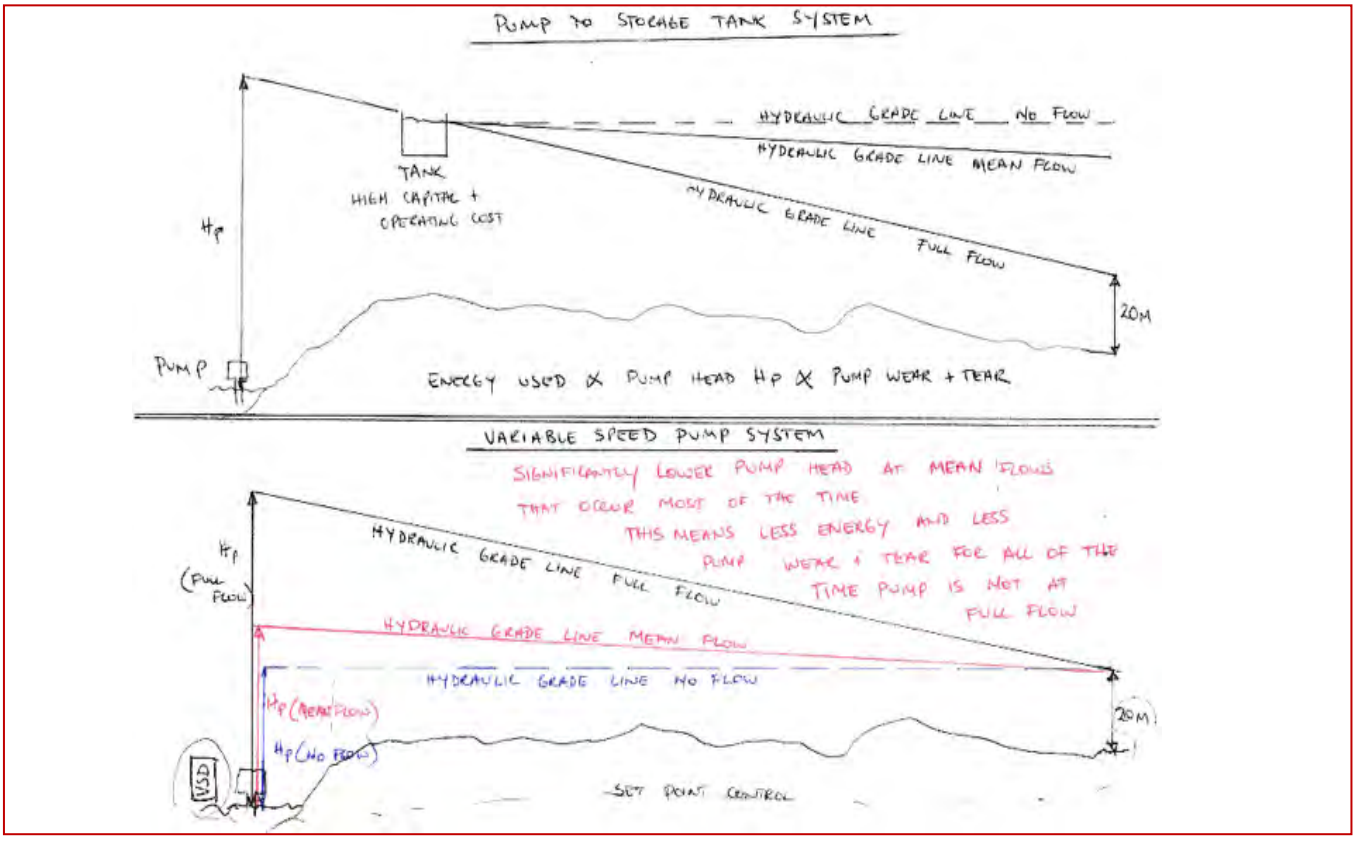
The use of direct connections to a pressurised supply means a farmer does not need to pump. A pressurised supply is almost always more efficient than having double pumped systems. Sometimes a farmer is irrigating land some distance from the supply point and/or is irrigating high land. In this situation it is often better for the individual system to supplementary pump rather than operating the whole system at a higher pressure just to accommodate a couple of individual farmers' needs. However this supplementary pumping can still occur with a direct connection to the supply point.

2.2.2 STORAGES SHOULD RARELY BE USED

Storages are not an efficient part of a piped system:

i) **Local storages with direct farmer pumping:** Often the pipeline supplies an on-farm storage that the farmer then must repump from. This can be avoided by the use of a pressurised delivery system that the farmer connects directly to. If the supply pressure is sufficient then the farmer no longer needs a storage or a pump, which greatly improves overall efficiency and cost.

ii) **Header tanks with gravity pipes:** Traditional pipeline distribution systems incorporate a header tank and then a gravity pipe to the farm. A direct connection to a pressurised delivery system reduces costs and improves levels of service as shown in the diagram below:



2.2.3 PIPELINE ROUTES ARE SIMPLER

A pressurised pipeline with variable speed device to control the flow and maintain pressure, does not need to follow the highest land or any particular contour. Practical routes using road alignments and avoiding gullies can be used.

2.3 SCADA IS A MUST

SCADA systems should be based around the following features:

- Considered as two systems ie one about the system operator and one about the customer/farmer
- The system operation has two elements:
  - **automatic pump control** by pressure sensors and monitoring flows, and
  - monitor water levels, volumes, pressures displaying real time data but **use alarms that reports on exception**
- Monitoring of customer water use data – this requires infrequent small packets of data provided in real time to central computer
- Used for data collection – optimize future capital investment/maintenance, understanding of customer use

SCADA systems should be kept simple and tailored around the practical needs of the users rather than being integrated into a single complicated system.

2.4 MUST DESIGN USING EPANET COMPUTER PROGRAMS

EPANET is a public domain, water distribution system software package developed by the US Environmental Protection Agency. It is strongly recommended for the design of water supply systems. A critical part of the system is deciding at what points to monitor the pressure levels and which one (or several) point is selected to control the VSD (Variable Speed Drive) (sometimes called an inverter). This is undertaken by constructing the hydraulic grade line (HGL) for both full flow and zero flow conditions. An example of the output required is shown in Appendix 1

2.5 DETERMINING THE CAPACITY OF A SYSTEM IS CRITICAL

The capacity of a pressurised irrigation system depends upon the following four factors

a. Crop demand in the peak month
b. Hours per day of irrigating in the peak month
c. Minimum flow rate per farmer to enable efficient farm irrigation
d. Level of service or the number of farmers irrigating at one time

Thus, when determining the capacity of a pipeline there is four key points that need to be considered

i. Individual farm outlet– typically min. 5l/sec for sprinklers and 10-20l/sec for furrow
ii. Hydrant size for the Local group of farmers (tertiary system)- this depends upon how many farmers per hydrant irrigate at the one time – eg 5-10 farmers/hydrant or 5ha with one irrigating at a time – say 5l/sec
iii. Village or regional scale (secondary system) – up to 300 - 450mm diameter pipe ring main at 2m/sec flow rate delivering 1l/sec/ha for 300 - 600ha or up to 5,000ha with 1000mm diameter ring main.
iv. Large system (Primary system) – supply to areas greater than 5,000 ha are usually canals not pipes.

2.6 FOUR APPROACHES TO LOS, WHICH AFFECT SYSTEM DESIGN AND OPERATION

When designing a piped supply system there are generally four approaches to the way farmers can access the water when supplying a sprinkler or drip farm system. The method chosen has a large impact on the required system capacity and hence the cost. It also has a large impact on the LoS the farmer receives and this in turn affects the potential productivity of the farm.

1. Water on demand – very expensive to construct

The system can be designed so that every farmer can operate at the same time. This means that the pipe needs to be sized as a multiple of the number of outlets times the flow per outlet. Typically for sprinkler and drip systems this means that the pipe is about 4 times the peak crop daily flow requirement throughout the system. This is a very expensive option but does give the highest LoS to the farmer. It is not generally recommended because of the cost to construct.

2. Laissez faire – bit more expensive but simple option though some winners and losers

Another option is to construct the system with enough spare capacity above the average daily peak crop demand, so that most of the farmers can be supplied at the same time. There are some periods when there is not enough pressure and so some farmers will opt to irrigate outside the peak periods in order to be assured of sufficient pressure. This is similar to many urban household water supply systems where during peak periods the pressure can drop. The main part of the pipe needs to be at least 1.5 to 2 times the average daily crop demand. This system is still reasonably expensive but it does have the advantage of being easy to operate. It does not provide the same high degree of LoS to every farmer but is considered more than adequate.

3. Almost water on demand – recommended and cost effective with high LoS

There are three ways of managing a "almost water on demand" system ie

(i) Fully automated on-line water ordering: By using fully automated on-line water ordering, it is possible to program the system so that farmers can order water in advance with minimal warning but sufficient control to prevent over demand and pressure reduction for some farmers. This system is used widely in Australia and results in farmers having "*almost water on demand*" with some minor restrictions (wait for an hour or two) in peak demand periods. This method is deemed unnecessarily complicated and unnecessary.

(ii) Prepaid – instant ordering: An alternative to on-line water ordering is to have a simpler pre-paid meter which effectively operates as an instant ordering system that can have programmed control to limit the availability of supply according to system capacity at the time. This gives a much lower level of service than either the fully automated on-line system or the hydrant systems with local sharing. However if the pre-paid is combined with a larger pipe size (and extra cost) then the LoS can be relatively high. It is much harder for the farmer to automate their farm system under a prepaid system unless there is an ability to pay in advance and specify the time of delivery as part of an automated ordering system.

(iii) Hydrants with local sharing: A lower cost and practical option is to supply the water to hydrants with a manifold of supply points (one for each farmer) where there is sufficient

capacity for every hydrant to operate at the one time but locally there needs to sharing among the 5 or so local farmers. Typically, a hydrant will supply 5l/sec and thus service 5ha (say 5 farmers each with 1 ha) at 1l/sec/ha average crop demand. It is critical that the overall system has capacity to supply every hydrant at the one time, it is important that extra hydrants are not added as this would undermine the system. *This method is deemed the most applicable to Asian situation*

4. Traditional rostering – minimum size - not recommended

The design capacity to deliver "minimum system" is generally based on:

- Tertiary part of the pipe (last 5-10 farmers) having capacity for 1 farmer operating at a time
- Rest of the system having a capacity to meet at least 1.1 to 1.2 times the average daily peak crop demand
- Using minimum pipes in a tree type configuration

There are two ways of managing a "minimum size" system ie

(i) Fixed Rostering: Each farmer is allocated a certain number of hours per day at a particular time of the day in a rostered rotational system. This approach can be effective, though it limits the farmer to irrigating at a particular time. It does not allow flexibility and does not readily allow for farmers growing different crops.

(ii) Water User Group: Instead of a roster it is possible to use a local water user group and to develop weekly a "daily" roster to provide some more flexibility. This could be operated with on line computer technology but requires supervision to make sure farmers only irrigate when they are required. This system is open to lack of governance and some farmers taking water out of turn.

2.7 OTHER CONSIDERATIONS

2.7.1 WATER CHARGING[1]

Water charging has generally not been implemented in most irrigation schemes throughout Asia. However, many countries are gradually introducing new Water Laws which include the provision for water charging to recover some or all of the cost of water delivery and system maintenance.

It is the Australian experience that water charging introduces a level of accountability to both the organisation supplying water (and setting charges) and to the farmers receiving the service. This is because the farmers scrutinise the operations of the organisation supplying water ensuring costs are kept to a minimum and ensuring that the LoS meets their needs. Conversely the farmers are challenged to only demand the LoS that they are prepared to pay the cost of.

[1] Toulmin, M., McLeod, J., Chorazyczewski, Y., Rendell, R., & Warne, G. (2019). *Rural Water Charging: An Australian Perspective*. Canberra: Australian Water Partnership

2.7.2 WATER MEASUREMENT IS CRITICAL TO OPERATIONS

Water measurement is a key element in good water management both in farm and supply system operation. Piped systems are much easier to measure than canal based supply systems. Modern technology also enables real time monitoring of meters that can be accessible both to the system operators and to the individual farmers via “apps” on most mobile phones.

2.7.3 ROLE OF WATER USER GROUPS IS DIFFERENT

Traditionally the management and operation of the tertiary canal system has been handled at the local level by some form of water user group. This has been found to very effective due to the need of traditional gravity systems for good communication and water sharing with considerable labour inputs required. However, with modern piped supply systems, it is possible to operate the system with technology without much local labour input. In many ways it can be thought of as similar to the electricity supply system or the phone system. Thus the role of the Water User Group changes considerably and in many cases may not even be required in an operational sense.

Appendix 1: Characteristics of a modernised pressurised irrigation system

Australia has evolved over 50 years to reach the current modernised systems. The characteristics of a modernised system are:

a. **pumping stations** using a “floating platform” to locate pumps and motors, a fully submersible pump and motor, or a vertical spindle submerged pump located in a pumping pit depending upon the change in reservoir levels.
b. a **mix of pumps** comprising typically
    - One pump for very small systems
    - Two pumps for medium size where one pump is 35% of maximum design flow and the second is 75% of the maximum design flow
    - Three pumps where the mix of pumps is approx. 1 by 25% and 2 by 50% of maximum design flow.
c. **pump selection** controlled by digital flow meters (located just downstream of the pump) and pump speed controlled by pressure sensors in the field
d. the selection of the **control point** (ie where the pressure is maintained at as constant) will vary with each specific system. Sometimes the control point is at the beginning of the system (typically a high point) or it could be at the end point, but often it is in the middle somewhere especially in a system that has a ring main.
e. pipelines utilise **HDPE pipes** that can be welded in the field
f. Pumping station design that **avoids suction lines** if possible. Whilst this is decided on an individual site basis, however a key consideration is that a pressurised pipeline supply systems need a pumping station that can be readily automated. In particular, maintaining pumps in a “primed” (lack of air in the suction line) state ready for instant actuation, by the

use of vacuum pumps and foot valves are to be avoided. These systems invariably fail or require an excessive amount of time before the pump can commence operations.

g. **direct connection** between the main pump and the farmers irrigation system ie there is no need for storages, header tanks or farmers pumps

h. **sufficient pressure** is provided to operate the farmers irrigation system – though there may be a small area of high land that requires the individual farmer to provide supplementary pumping

i. all flows to the farm should be **metered** with real time monitoring using mobile phone networks, if not each farm at least to the local hydrant serving say 5ha

j. the farmer has "**almost on demand irrigation**" ie can irrigate almost whenever they wish

k. the system has **hydrants** to which farmers connect their system

l. the **number of hydrants** is carefully matched to the capacity of the pump system and the peak irrigation demand on the farms

m. each hydrant offtake can incorporate a **manifold** which provides a number of individual oftakes from each manifold

n. the **size of the offtake** to hydrants is also carefully designed to ensure that all customers have sufficient pressure and flow to operate ie one hydrant is not capable of taking more than their share of the flow

o. the **flow rate provided for each individual farmer** connection is based upon the flow required to operate the farm system. In Asia with small properties (<2ha) the flow rate required is typically 3-5l/sec as this is the flow required to efficiently operate a small sprinkler or drip or hand held hose system.

p. The **overall system capacity** is determined by considering a number of factors including peak daily plant water demand, the number of hours per day of operation and the level of service to the farmer ie can all farmers irrigate at the one time or do they need some rotation or planning. Typically a 1l/sec/ha average across the whole system is adopted.

q. the **design of the pipeline** uses computer programs (eg "epanet") to optimally size the pipes and ensure adequate head at the hydrants.

r. A **hydraulic grade line for both full flow and no flow** operating conditions should be graphed to determine the pressure control point location.

s. The **pressure at the offtakes** should be determined for both full flow and no flow conditions to determine the available level of service provided to the farmers and also to enable design of the hydrants.

t. Pipelines utilise interconnecting "**ring mains**" to equalise pressure and flows to maintain a high level of service to the farmers. The design of the piped delivery system is simplified by the use of "ring mains" because they provide a simple automatic method of maintaining uniform pressure throughout the system without the need for complicated water sharing or rostering of users. Designers are often reluctant to use ring mains because of the perceived additional pipe cost. However, it is possible to reduce the size of the pipes overall as it provides an increased LoS ie it enables a more uniform pressure despite which combination of irrigators are using the system at any one time. Therefore, the total cost of the system should not be increased with the appropriate sizing and use of ring mains

u. the system **operates automatically** with minimal labor and operating control

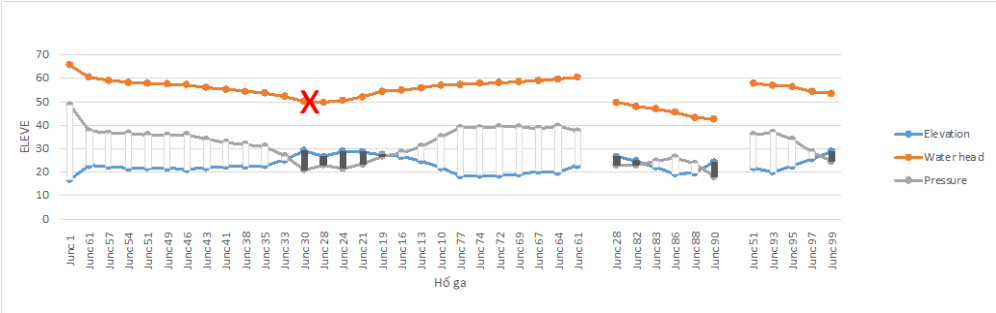
v. **filters are NOT provided** but rather individuals install their own filtering system to meet their own needs and undertake the necessary maintenance.

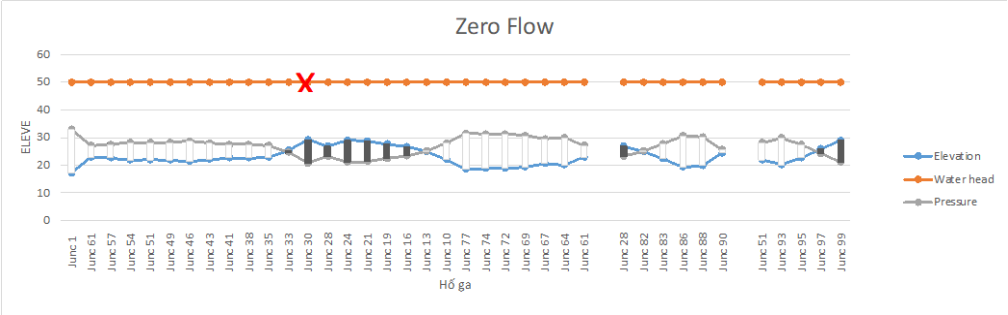
Appendix 2 Example hydraulic grade calculations

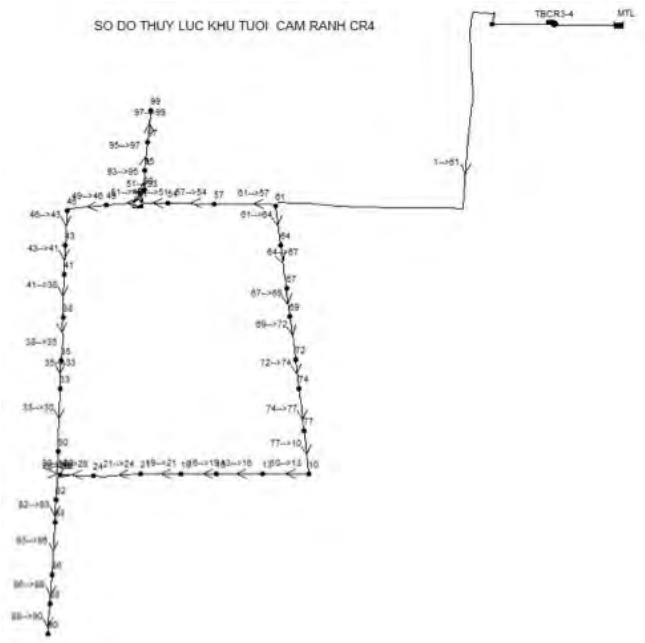
HYDRAULIC CALCULATION TABLE OF VERTICAL PUMP STATION: Q=154 l/s
(PUMPING STATION CR4)

SPECIFICATIONS AT NODES							SPECIFICATIONS IN PIPES						
Node	Elevation	Base Demand	Head	Pressure	Elev of pipe	Cột nước đầu ra khi trừ đi tổn thất	Pipe	Length	Diameter	Diameter	PN	Flow	Velocity
	m	LPS	m	m	m	m		m	mm	mm		l/s	m/s
Junc 1	17	0	65.72	48.72	15.60		Pipe 1—>61	1406	396.6	450	PN8	155	1.25
Junc 61	22.95	0	60.49	37.54	21.65		Pipe 61—>57	201	277.6	315	PN8	81.71	1.35
Junc 57	22.56	5	59.2	36.64	21.26		Pipe 57—>54	150	277.6	315	PN8	76.71	1.27
Junc 54	21.8	5	58.34	36.54	20.50		Pipe 54—>51	98.2	277.6	315	PN8	71.71	1.18
Junc 51	21.92	0	57.84	35.92	20.62		Pipe 51—>49	101	277.6	315	PN8	51.71	0.85
Junc 49	21.79	5	57.56	35.77	20.49		Pipe 49—>46	132	277.6	315	PN8	46.71	0.77
Junc 46	21.26	5	57.26	36.00	19.96		Pipe 46—>43	122	198.2	225	PN8	41.71	1.35
Junc 43	22.05	5	56.09	34.04	20.85		Pipe 43—>41	100	198.2	225	PN8	36.71	1.19
Junc 41	22.58	5	55.34	32.76	21.38		Pipe 41—>38	150	198.2	225	PN8	31.71	1.03
Junc 38	22.56	5	54.47	31.91	21.36		Pipe 38—>35	150	198.2	225	PN8	26.71	0.87
Junc 35	22.87	5	53.84	30.97	21.67		Pipe 35—>33	100	141	160	PN8	21.71	1.39
Junc 33	25.33	5	52.34	27.01	24.33		Pipe 33—>30	218	141	160	PN8	16.71	1.07
Junc 30	29.26	5	50.33	21.07	28.26	X	Pipe 30—>28	89.6	141	160	PN8	11.71	0.75
Junc 28	26.82	0	49.9	23.08	25.82								
Junc 24	28.9	5	50.54	21.64	27.90		Pipe 61—>64	138	277.6	315	PN8	-73.29	1.21
Junc 21	28.7	5	52.23	23.53	27.70		Pipe 64—>67	151	277.6	315	PN8	-68.29	1.13
Junc 19	27.52	5	54.48	26.96	26.52		Pipe 67—>69	100	277.6	315	PN8	-63.29	1.05
Junc 16	26.69	5	55.01	28.32	25.49		Pipe 69—>72	151	277.6	315	PN8	-58.29	0.96
Junc 13	24.89	5	55.96	31.07	23.69		Pipe 72—>74	100	277.6	315	PN8	-53.29	0.88
Junc 10	22.04	5	57.19	35.15	20.84		Pipe 74—>77	150	277.6	315	PN8	-48.29	0.8
Junc 77	18.49	5	57.49	39.00	17.19		Pipe 77—>10	150	277.6	315	PN8	-43.29	0.72
Junc 74	18.78	5	57.85	39.07	17.48		Pipe 10—>13	150	198.2	225	PN8	-38.29	1.24
Junc 72	18.79	5	58.15	39.36	17.49		Pipe 13—>16	150	198.2	225	PN8	-33.29	1.08
Junc 69	19.34	5	58.67	39.33	18.04		Pipe 16—>19	115	198.2	225	PN8	-28.29	0.92
Junc 67	20.5	5	59.07	38.57	19.20		Pipe 19—>21	132	141	160	PN8	-23.29	1.49
Junc 64	20.09	5	59.76	39.67	18.79		Pipe 21—>24	154	141	160	PN8	-18.29	1.17
Junc 61	22.95	0	60.49	37.54	21.65		Pipe 24—>28	107	141	160	PN8	-13.29	0.85
Junc 28	26.82	0	49.9	23.08	25.82		Pipe 28—>82	95.7	141	160	PN8	-25	1.6
Junc 82	24.93	5	48.03	23.10	23.93		Pipe 82—>83	78.1	141	160	PN8	-20	1.28
Junc 83	22.3	5	47.02	24.72	21.30		Pipe 83—>86	183	141	160	PN8	-15	0.96
Junc 86	19.36	5	45.63	26.27	18.36		Pipe 86—>88	100	96.8	110	PN8	-10	1.36
Junc 88	19.77	5	43.4	23.63	18.77		Pipe 88—>90	107	96.8	110	PN8	-5	0.68
Junc 90	24.43	5	42.74	18.31	23.43								
							Pipe 51—>93	54.1	141	160	PN8	20	1.28
Junc 51	21.92	0	57.84	35.92	20.92		Pipe 93—>95	67.9	141	160	PN8	15	0.96
Junc 93	20.19	5	57.14	36.95	19.19		Pipe 95—>97	100	96.8	110	PN8	10	1.36
Junc 95	22.61	5	56.63	34.02	21.61		Pipe 97—>99	111	96.8	110	PN8	5	0.68
Junc 97	25.8	5	54.39	28.59	24.80								
Junc 99	28.94	5	53.7	24.76	27.94								

Full flow



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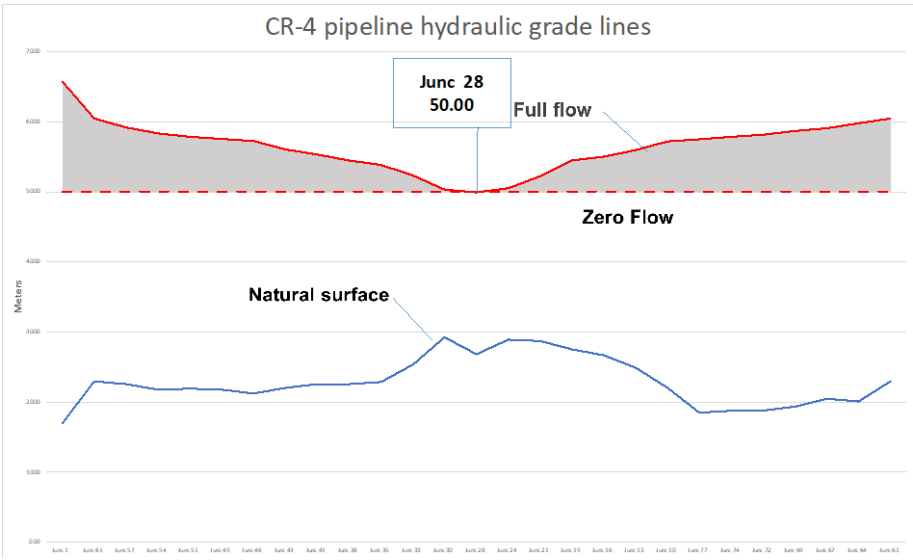
CR-4 pipeline hydraulic grade lines
Junc 28
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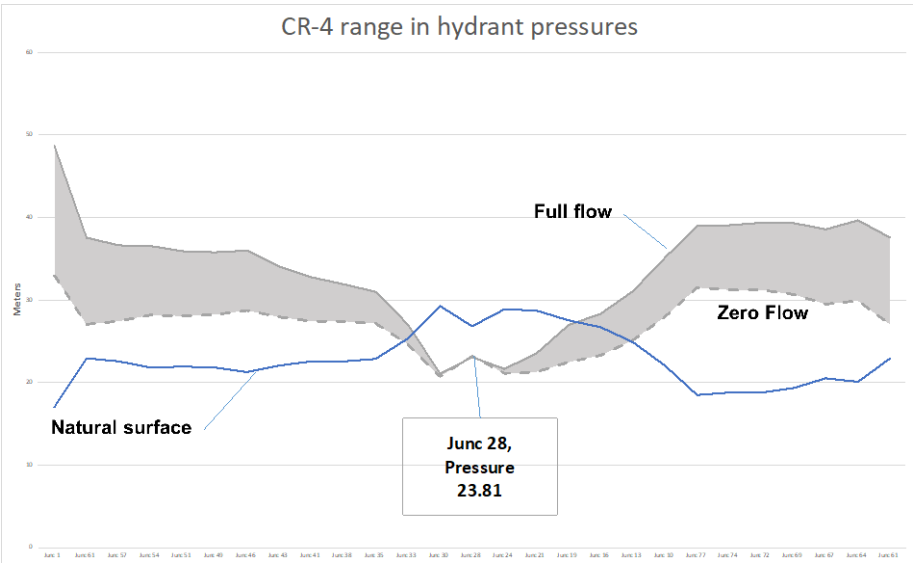
Full flow
Zero Flow
Natural surface
Meters


CR-4 range in hydrant pressures
Full flow
Zero Flow
Natural surface
Junc 28,
Pressure
23.81
Meters

BERNAM RIVER WATER BALANCE MANAGEMENT SYSTEM, MALAYSIA

A Case Study on Paddy Irrigation Efficiency at the Pasir Panjang Irrigation Block of the Barat Laut Selangor Irrigation Scheme (BLSIS), Bernam River Basin, Malaysia

by

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1 Abstract

In 2017, the Department of Irrigation and Drainage Malaysia has launched the National Water Balance Management System (NAWABS) study for the Bernam River Basin. The objective of the study is to develop a comprehensive water balance study and water resources modelling utilising the forecasted rainfall to form a water resources decision management support system (DMSS) for the Bernam River Basin. The fourth largest and highest yield granary area in Malaysia, the Barat Laut Selangor Irrigation Scheme (BLSIS) (previously known as the Tanjong Karang Scheme) is one of the major components of the NAWABS study for the Bernam River Basin.

This case study examines the irrigation distribution efficiency of a paddy field parcel, namely the Pasir Panjang Irrigation Block of the BLSIS. The irrigation distribution efficiency which were computed using actual field data were found to be 0.70 and 0.55 for scenarios without and with effective rainfall respectively for the main planting season (1st September to 30th November 2015) and; 0.74 and 0.58 respectively for that of the off season (1st March to 31st May 2015).

2 Introduction

Efficiency of an irrigation scheme can be defined as the ratio of the amount of actual water required for land preparation and crop growth to the amount of water supplied via the scheme. For a paddy scheme with no losses in the irrigation water delivery system, the irrigation efficiency will be close to 1.0. The higher the losses, the lower is the irrigation efficiency.

In the computation of the irrigation water demand for paddy, the irrigation efficiency plays an important role. Higher irrigation water than the actual required by the paddy will need to be supplied to cater for the losses in the delivery system due to low efficiency.

The irrigation efficiency of an irrigation scheme consists of the conveyance efficiency of the main conveyance system and the distribution efficiency in the secondary and tertiary canal system. In addition to this, application efficiency in the farm lots should also be taken into account.

Conveyance efficiency is the efficiency of canal and conduit networks channelling water from the supply source such as pumping station, river diversion or reservoir to the offtakes. Distribution efficiency refers to the on-farm system used to store and distribute water to the various fields. The time frame for calculating the water balance of the distribution system can range from a single water delivery to the water delivered over a season or year. To obtain reasonable efficiency, the distribution network should be well designed and be operated as intended. Field application

efficiency in paddy fields is the ratio of the amount of water supplied to the paddy roots to the amount of water supplied to the field.

The most prominent study carried out on the irrigation water demand and system of the BLSIS was by the Japan International Cooperation Agency (JICA) in 1987 titled “Feasibility Study on the Tanjong Karang Irrigation Development and Management Project”. In arriving at the unit irrigation demand of the paddy, quoted as 2.320 l/s/ha for pre-saturation demand and 1.304 l/s/ha for normal demand, the study adopted 0.9 for the conveyance efficiency and 0.75 for the distribution efficiency. Both conveyance and distribution efficiencies by JICA have been adopted since then to date in determining the unit irrigation demand of the BLSIS. The overall irrigation efficiency was calculated as 0.67, not inclusive of application efficiency which was adopted only for the vegetable crop located within the compound of the granary area.

In the 2011 National Water Resources Study (NWRS), overall irrigation efficiency ranges from 0.50 to 0.75 was adopted in the computation of the projected irrigation demand with the assumption that the irrigation efficiency will increase in the near future for the granary areas in Malaysia. However, no detailed description was provided for such irrigation efficiency to be adopted.

The objective of this study is to examine the irrigation efficiency of the BLSIS using one of the BLSIS irrigation blocks namely the Pasir Panjang Irrigation Block. The availability of field data collected at the constant head orifices (CHOs) of the Pasir Panjang Irrigation Block allows this study to be carried out in determining the actual distribution efficiency of the BLSIS in comparison to that adopted by JICA. Two scenarios were examined in this study: distribution efficiency without and with the contribution of effective rainfall. Study on conveyance efficiency of the BLSIS was not conducted due to the lack of data.

3 The BLSIS

The BLSIS comprises 9 irrigation blocks as illustrated in **Figure 1** below with a total area of about 19,000 ha. The main source of irrigation water for the BLSIS is the Bernam River where the irrigation water supply of the scheme is extracted at two places: the Bernam River Headworks (BRH) and the Bagan Terap Pump House.

Main Conveyance System

The main conveyance system of the BLSIS includes the BRH, the Feeder Canal, the Tengi River and the Main Canal with 3 regulators: Sg. Burong, Sg. Leman and Sg. Hj. Dorani. The BRH consists of a barrage across the Bernam River and an intake structure which diverts the river water into the Feeder Canal. The intake structure is 30 m wide and has three radial gates, each 9.1 m wide. The 14.5 km Feeder Canal joins the Tengi River before reaching the Sg. Tengi Spillway. The Sg. Tengi Spillway is used to control the water level in the Main Canal by discharging excess water through its spillway. The regulators are used to maintain the command levels along the Main Canal up to the required full supply level (FSL). Water control in the Main Canal is made through the cross regulators. CHOs are provided as offtakes and end control structures both in the secondary and tertiary canals and these function as control structures. The Irrigation End Control (IEC) acts as a control gate as well as to regulate the water at the Main Canal. The Main Canal conveys water to all irrigation blocks except the pumping areas of

approximately 1,500 ha (part of Bagan Terap Irrigation Block and the entire Sungai Panjang Irrigation Block).

Distribution System

The distribution system comprises secondary and tertiary canals. There are only three irrigation blocks, namely Bagan Terap, Sungai Panjang and Pancang Bedana that are equipped with secondary canals while the remaining blocks receive water directly from the tertiary canals connected to the Main Canal. The remaining blocks are Sawah Sempadan, Sungai Burung, Sekinchan, Sungai Leman, Pasir Panjang and Sungai Nipah. The tertiary canals are spaced at approximately 400 m apart.

In this paper, the distribution efficiency for the Pasir Panjang Irrigation Block was computed using the ratio of the actual paddy water demand to the amount of irrigation water supplied through the CHOs of the distribution system. The amount of irrigation water arrived at the CHOs is estimated based on the records of flow measured at the CHOs.

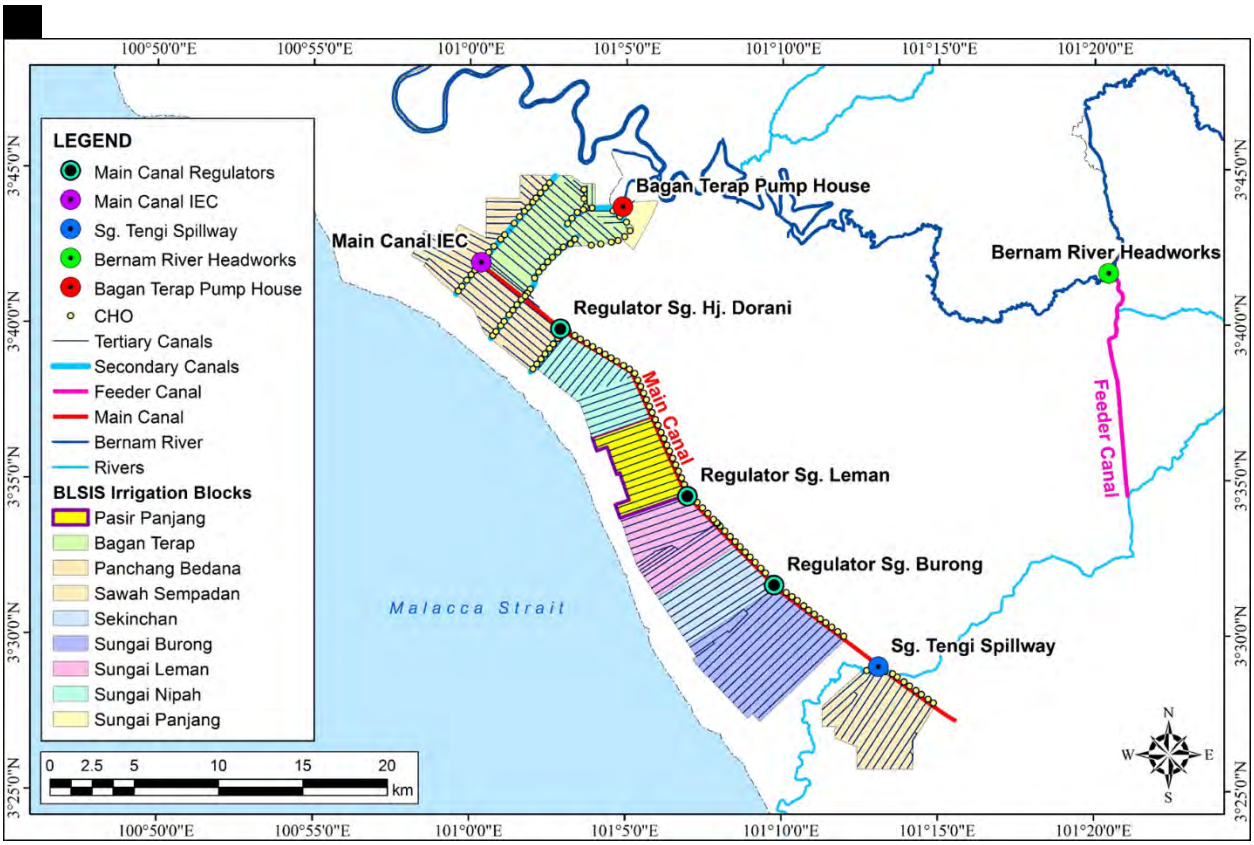

Figure 1: The Barat Laut Selangor Irrigation Scheme (BLSIS).

The BLSIS is divided into four irrigation service areas (ISA): I, II, III and IV. The planting schedule for the ISAs is as follows:

ISA	Main Season Planting Start Date	Off Season Planting Start Date
I	1st July	1st January
II	1st August	1st February

III	1st September	1st March
IV	1st October	1st April

The irrigation cycle of each planting season composes of 30 days pre-saturation supply and 60 days normal supply.

4 The Pasir Panjang Irrigation Block

The Pasir Panjang Irrigation Block is part of ISA III where the Main Season commences from September to November and the Off Season from March to May.

At the Pasir Panjang Irrigation Block water is distributed to the paddy field via 12 tertiary canals each controlled by a CHO at the intake head. The commanding irrigation area of each of the tertiary canals is summarised in **Table 1**. **Figure 2** shows the arrangement of the twelve tertiary canals within the paddy field. The water by common practice of the farmers is transferred from the tertiary canals to the field via risers and syphons.

Table 1: Irrigation commanding area of the tertiary canals.

Tertiary Canal / CHO	Irrigation Area (ha)
TAPP1	176
TAPP2	156
TAPP3	136
TAPP4	134
TAPP5	135
TAPP6	134
TAPP7	140
TAPP8	138
TAPP9	136
TAPP10	134
TAPP11	159
TAPP12	159
Total	**1,737**

Figure 2: Tertiary canals of the Pasir Panjang Irrigation Block.

5 Field Data

The flow measured at the CHOs indicates the amount of irrigation water delivered from the BRH via the Main Canal to the tertiary canals of the irrigation blocks. The flow has been measured and recorded by the BLSIS operators on a daily basis. The records of flow measured at the CHOs of the Pasir Panjang Irrigation Block tertiary canals for the Main and Off Season of a relatively wet year, 2015, were gap filled and analysed. The graph below (**Figure 3**) shows the total flow in MCM delivered to the paddy field via the tertiary canals. In total 21.42 MCM was supplied to the field during the Main Season (from 1st September 2015 to 30th November) and 20.32 MCM during the Off Season from (1st March 3015 to 31st May 2015).

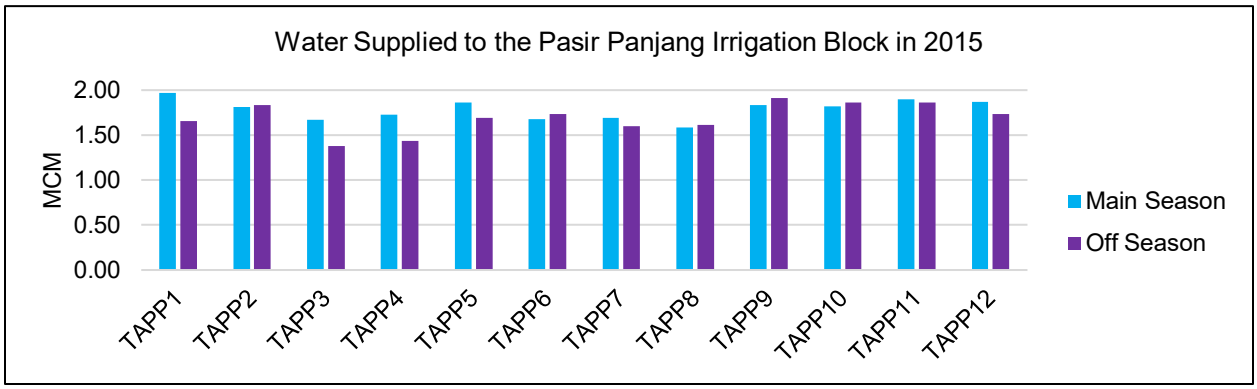

Figure 3: Water supplied to the Pasir Panjang Irrigation Block via the tertiary canals in 2015.

6 Unit Paddy Water Demand

It is important to distinguish the unit paddy water demand from the unit irrigation demand where the latter has been factored by conveyance and distribution efficiencies. The unit paddy demand was used to compute the actual amount of water needed by the crop. The unit paddy water demand (in l/s/ha) computed in the JICA 1987 Study was adopted to compute the paddy water demand for this study. The irrigation schedule and mechanism of the BLSIS has been designed and operated based on the unit paddy demand suggested by JICA since then. The adopted values are:

i. Pre-saturation demand: 1.566 l/s/ha
ii. Normal supply demand: 0.880 l/s/ha

Figure 4 shows the total paddy water demand of each of the commanding irrigation areas of the Pasir Panjang Irrigation Block tertiary canals, which is the same for both the Main and Off Season. A total of 14.97 MCM of water is required per season.

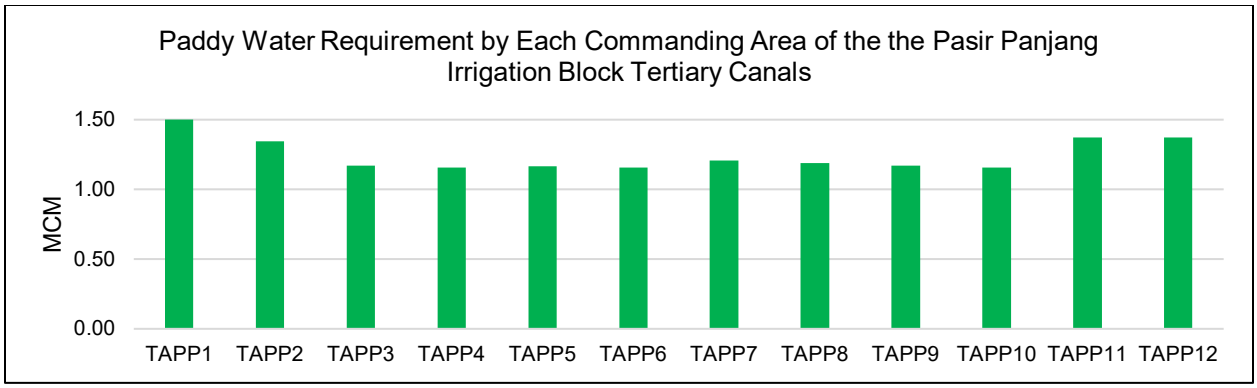

Figure 4: Paddy water requirement by each commanding area of the tertiary canals.

7 Effective Rainfall

In accounting for effective rainfall (ER), the daily total rainfall recorded at the nearest rainfall station to the Pasir Panjang Irrigation Block (Station ID No. 3511002, TA 9 Pasir Panjang at Selangor) was analysed. The effective rainfall according to FAO (2008) can be computed using the formulae as follows:

ER = 0.8 RF - 25 if RF > 75 mm/month
ER = 0.6 RF - 10 if RF < 75 mm/month

The effective rainfall determined for the Main and Off Season is as summarised in the following **Table 2**.

Table 2: Effective rainfall of the Main and Off Season.

Season	Month	Monthly Total Rainfall (mm)	Monthly Total ER (mm)	
Off	March	275	0.8 RF - 25 =	195.0
	April	186.5	0.8 RF - 25 =	124.2
	May	29.5	0.6 RF - 10 =	7.7
Main	September	164.5	0.8 RF - 25 =	106.6
	October	248.5	0.8 RF - 25 =	173.8
	November	82.5	0.8 RF - 25 =	41.0

Figure 5 shows the total effective rainfall in MCM for each of the commanding irrigation areas of the tertiary canals. A total of 5.58 MCM effective rainfall contributed to the irrigation supply of the Pasir Panjang Irrigation Block during the Main Season and 5.68 MCM during the Off Season.

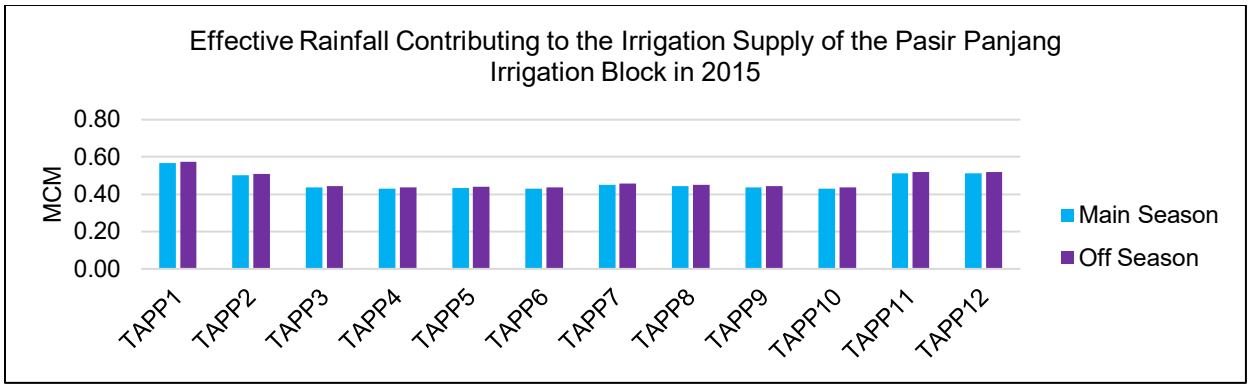

Figure 5: Effective rainfall contribution to the irrigation supply of the Pasir Panjang Irrigation Block in 2015.

8 The Distribution Efficiency

Having to acquire the irrigation water supplied to the Pasir Panjang Irrigation Block from the records of flow measured at the CHOs, the paddy water demand and the effective rainfall, the distribution efficiency of the irrigation block can now be computed. The efficiency for both with and without the effective rainfall can be obtained using the following equations:

$$\text{Distribution Efficiency without Effective Rainfall, } C_D = \frac{\text{Paddy Water Demand}}{\text{Water Supplied}}$$

$$\text{Distribution Efficiency with Effective Rainfall, } C_{DE} = \frac{\text{Paddy Water Demand}}{\text{Water Supplied + Effective Rainfall}}$$

9 Results & Discussion

Table 3 shows the paddy water demand, irrigation water supplied and effective rainfall for each of the tertiary canals of the Pasir Panjang Irrigation Block along with the distribution efficiencies computed from this information. The average distribution efficiency of the 12 tertiary canals is 0.70 without effective rainfall and 0.55 with effective rainfall for the Main Season, the efficiencies are 0.74 and 0.58 respectively for the Off Season.

The distribution efficiencies without effective rainfall are similar to that adopted in the JICA 1987 Study of 0.75 where the effective rain was also not considered. Nonetheless, it also implies there is room for improvement to further increase the efficiency with better water distribution practice within the paddy field. The results also show that with the presence of effective rainfall the required irrigation water supply can be reduced up to 26% (5.58 out of 21.42 MCM) and 28% (5.68 out of 20.32 MCM) for the Main and Off Season respectively as compared to the supply required without effective rainfall.

Table 3: Distribution efficiency of the Pasir Panjang Irrigation Block.

Tertiary Canal (TAPP-)	1	2	3	4	5	6	7	8	9	10	11	12	Total	Aver-age
	Main Season (September to November 2015)													
Paddy Water Require-ment (MCM)	1.52	1.34	1.17	1.16	1.16	1.16	1.21	1.19	1.17	1.16	1.37	1.37	14.97	1.25
Water Supplied (MCM)	1.97	1.81	1.67	1.73	1.86	1.68	1.69	1.58	1.83	1.82	1.90	1.87	21.42	1.78
ER (MCM)	0.57	0.50	0.44	0.43	0.43	0.43	0.45	0.44	0.44	0.43	0.51	0.51	5.58	0.94
Water Supplied + ER (MCM)	3.11	2.82	2.55	2.60	2.74	2.55	2.60	2.48	2.72	2.69	2.93	2.90	32.68	2.72
*C_D	0.77	0.74	0.70	0.67	0.62	0.69	0.71	0.75	0.64	0.63	0.72	0.73		**0.70**
*C_{DE}	0.60	0.58	0.56	0.53	0.51	0.55	0.56	0.59	0.52	0.51	0.57	0.58		**0.55**
	Off Season (March to May 2015)													
Paddy Water Require-ment (MCM)	1.52	1.34	1.17	1.16	1.16	1.16	1.21	1.19	1.17	1.16	1.37	1.37	14.97	1.25
Water Supplied (MCM)	1.66	1.83	1.38	1.43	1.69	1.73	1.60	1.61	1.92	1.86	1.86	1.74	20.32	1.69
ER (MCM)	0.58	0.51	0.44	0.44	0.44	0.44	0.46	0.45	0.44	0.44	0.52	0.52	5.68	0.47
Water Supplied + ER (MCM)	2.23	2.34	1.83	1.87	2.13	2.17	2.06	2.06	2.36	2.30	2.38	2.26	26.00	2.17
*C_D	0.92	0.73	0.85	0.81	0.69	0.67	0.75	0.74	0.61	0.62	0.73	0.79		**0.74**
*C_{DE}	0.68	0.57	0.64	0.62	0.55	0.53	0.59	0.58	0.50	0.50	0.57	0.61		**0.58**

C_D: Distribution Efficiency without Effective Rainfall; C_{DE}: Distribution Efficiency with Effective Rainfall.

10 Conclusions and Recommendations to Improve the Irrigation Efficiency

Based on the analysis of the CHOs flow data, rainfall data and the paddy water demand, the distribution efficiencies of the Pasir Panjang Irrigation Block were determined to be 0.70 and 0.55 for scenarios without and with effective rainfall respectively for the Main Season (September to November 2015) and; 0.74 and 0.58 respectively for Off Season (March to May 2015). The findings on the distribution efficiency of 0.70 to 0.74 without effective rainfall shows consistency with the JICA 1987 Study value of 0.75. Owing to the rather uniform rainfall between the Main and Off Season, the irrigation efficiencies computed are similar between the two seasons.

The significant difference between the efficiency without and with effective rainfall demonstrates the importance of taking effective rainfall into account during the operation of the irrigation system. With higher rainfall, the irrigation water supply can be reduced and thus the irrigation efficiency will increase.

A distribution efficiency within the range of 0.7 shows that there are improvements that can be made to the current irrigation practice at the field.

A study on the irrigation efficiency has been carried out by the Ministry of Agriculture and Food Industry (MAFI) namely the 'Study on the Performance of Tertiary Canal for the IADA Barat Laut Selangor' (Kajian Keberkesanan Taliair Tersier Di Seluruh Kawasan IADA Barat Laut Selangor) in year 2018 (IADA 2018). The Study has applied the Rapid Appraisal Procedure (RAP) developed by the Food and Agriculture Organization of the United Nations in 1999 (FAO) to assess the irrigation system performance for the overall IADA scheme. The RAP assessment indicators are categorised into internal and external. The internal performance indicators comprise efficiency, reliability, adequacy, equity, flexibility while the external indicators cover the water use, production and financial as the performance indicators.

The Study shows relatively low RAP rates of internal indicators for the IADA scheme. The RAP external indicator indicted comparatively good output per unit area, but indicators relating water use, such as output per unit irrigation supply, relative water supply, relative irrigation supply, main canal capacity and irrigation efficiency area all far below the expectation. The RAP findings for the overall IADA scheme are generally consistent with the findings for the Pasir Panjang Block which implies there is room for improvement to further increase the efficiency for the irrigation scheme.

It was pointed out in the Study that low RAP of internal indicators for the IADA scheme generally observed to be due to the problems of high fluctuation in water level, long travelling time, lack of proper flow measurement, lack of maintenance, lack of remote spill monitoring, leakages and uncontrolled field off-takes flow, ineffective ordering and water delivery procedure, and low flow rate capacity of off-takes at tertiary canals. There is also lack of farmers' participation and contribution in management, operation and maintenance of the scheme.

The Study findings show that there are a lot of rooms for improvement in the irrigation supply mode to reduce the water losses and increase the irrigation efficiency through better water management practices. It can be achieved through better control and regular adjustment of off-

takes, monitoring of spilling from the field bunds, capturing of rainfall in paddy fields and control of management loss through regular monitoring of end spills, followed by adjustment of wate diversion from the main canal.

Faster pre-saturation that has been conducted as pilot project in the Study showed a great potential of meeting the objective of improving water delivery management in tertiary canal for modern commercial rice cultivation, managed by individual farmer. Faster pre-saturation delivery to individual field was achieved with the newly developed high-water delivery capacity structure of flexible field off-takes. Faster pre-saturation must be supported with efficient orderly mechanization for land preparation commenced immediately after achieving pre-saturation. The saving comes from the reduction of daily losses in paddy fields due to seepage, percolation losses combined with the evaporation losses.

To improve the irrigation efficiency, upgrading and repairing of the tertiary canal conduits, off takes and regulating structures have been proposed to reduce the losses due to the leakages. The rehabilitation of the existing SCADA system for flow measurement, water level and rainfall monitoring have also been recommended for better irrigation water management and consideration of the effective rainfall during the operation of the irrigation system.

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Towards enhanced capacity of farmers and institutions in irrigation and drainage as key contributors to sustainable food production and poverty alleviation in the Philippines

Mona Liza F. Delos Reyes[1] and Bart Schultz [2]

ABSTRACT

The Philippine population is projected to increase from almost 110 million at present to more than 125 and 142 million in 2030 and 2050, respectively. This implies that the country will face the challenge of increasing food production and/or imports to meet the food requirements of its growing and wealthier population. However, efforts to increase food production are confronted with declining availability of water and land resources as use of these resources by other sectors increases, awareness of the need to preserve the environment grows, and water supply is expected to become more variable due to climate change. Meanwhile, irrigation, which accounts for about 98% of abstracted water used by agriculture, has been a key strategy of the Government to attain food self-sufficiency and alleviate poverty.

This paper examines the level of benefits attained from irrigation development in terms of production, cropping intensity and economic situation of farmers. It identifies options for improvements and expansion of irrigation systems based on initiatives of farmers and system personnel on system operation and water management and make a case for more attention to improvement of drainage systems. It presents an historical overview of laws enacted and institutions and policies created in support of farmers involvement in irrigation development. Capacity enhancement programs for farmers on improved system operation, water management, and decision making on appropriate irrigation technology are also identified.

INTRODUCTION

Prior to the Spanish colonial era (1565-1898), it was estimated that an aggregate of about 25,000 ha in the country was served by mainly very small canal irrigation systems, which were built, operated and maintained by farmers (National Irrigation Administration (NIA), 1990). David (2003) remarked that an interesting feature of these systems was their built-in stability because of crop cultural practices, cropping patterns and soil and water conservation and management practices being interwoven in their design, operation and maintenance. The famed irrigated Banaue rice terraces carved into the Cordillera mountains located in the northern region of the country are testaments to the Filipino ancestors' ingenuity in sustainable irrigation development.

Irrigation development in the country has progressed significantly in terms of area coverage, infrastructures and institutions since then. The National Irrigation Administration (NIA), the agency mandated to develop and maintain irrigation systems in the country, has built 247 small- to large-scale national irrigation systems (NIS) irrigating a total area of about 933,008 ha. Together with other irrigation systems, the total irrigation service area in the

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country has reached about 2.006 million ha (NIA, 2020). Also, the role of indigenous farmer-irrigators has been institutionalized by several instruments, the last of which was by the Agriculture and Fishery Modernization Act of 1997.

While significant progress in expanding the irrigation service areas has been made, the full benefit from irrigation development remains to be realized. Many irrigation systems irrigate less than their developed service areas (David et al, 2012a; Tabios and David, 2014; Delos Reyes et al., 2015; Clemente et al, 2019). The actual rice yield and economic rate of returns in many irrigation systems are less than the projected values (David and Innocencio, 2014).

The urgency to improve the irrigation performance is appreciated more in the context of the required increase in food production to meet the food demand of the growing population, diminishing water supply for agriculture and the need to conserve water ecosystem and alleviate poverty in rural areas. The bulk of the required increase in rice, the staple food of most Filipinos, is expected to come from irrigated lands. To help meet this expectation, irrigation and drainage systems must be upgraded, operated and managed in the most effective and efficient way. Such system improvement requires not only strong commitment of the National Irrigation Agency, but also active participation of farmers-irrigators. Also, enabling policy environment and institutions are necessary.

This paper presents an overview of the level of attained benefits of irrigated agriculture in terms of food production and the country's food sufficiency, contribution to the economy and poverty alleviation, state of irrigation and drainage development, and farmers' involvement and institutions throughout the history of irrigation development. It cites notable management initiatives of irrigators associations in some NIS. It posits strategic areas for improving the institutional and financial situation of farmers and the performance of irrigation and drainage systems. It recommends some improvements that would be required to enable productive involvement of farmers in increasing food production and alleviating poverty.

FOOD PRODUCTION AND SUFFICIENCY

Rice production and sufficiency

Irrigation has been a key component of government's program to attain the goals of food security and poverty alleviation. Publicly funded irrigation systems mainly irrigate rice, the staple food of Filipinos. Based on the Philippine Statistics Authority (PSA) data, the country has a total of about 2.3 million ha of irrigated and rainfed rice lands and produced an average of 18.6 million metric ton (MT) of rice during the period 2015-2019. The average irrigated rice production accounted for about 76% of the total harvest and 70% of the total rice area. The irrigated and rainfed rice yields averaged 4.4 and 3.1 ton/ha per year, respectively. The average yield is among the lowest in neighbouring Asian countries (Food and Agriculture Organization of the United Nations (FAO), 2020). The country's rice production consistently falls short of its rice demand. Its average rice self-sufficiency from 2008-2018 was about 90%. The government imports rice to cover the deficit in rice supply requirement of the country. The country was among the top rice importers with an average import of more than 1.3 MT during the period 2008-2018.

The country's growing population is the main driver of its increasing rice demand. It is predicted to increase from about 101.6 million (M) in 2015 to 125.3 M and 142.1 M by 2030 and 2045, respectively (Philippine Statistics Authority (PSA), 2016). The rice consumption is projected to be about 16.5 MT by 2028, a 2.4 MT increase from its 2016-2018 average level (Organization for Economic Co-operation and Development (OECD) and FAO, 2019). On the

other hand, production is predicted to increase by 2.5 MT from its 12.4 MT level over the same period. The rice importation forecast for the country for 2028 is about 1.5 MT with 116 kg/per capita per year consumption. While importation can help address issues of rice production shortfall, it would not be sustainable in the long run as rice exporting countries domestic need for their own consumption also increases with population increase. Also, heavy dependence on rice imports renders the country susceptible to any disruption on global rice supply and demand.

Sufficiency in other major agricultural commodities

The Government monitors the volume of production and domestic consumption of 35 major food commodities, including rice. It estimates the sufficiency of the country in each of these food items as a ratio of the domestic production to the demand of the population, also called as the self-sufficiency ratio (SSR). Seven of the 34 non-rice food items registered an average SSR below 80% during the period 2014-2018. The food items that had the most inadequate productions to meet the demand was garlic (13% SSR), followed by peanut (27% SSR), coffee (42% SSR) then by mungbeans (51% SSR). Consequently, the country relied on importation to cover the production shortfalls on these food items.

AGRICULTURE, ECONOMY AND POVERTY

The Philippine economy grew at an average rate of 6.4% over the period 2016-2019. It was mainly driven by the services and industry sectors. The agriculture sector had either contraction or minimal gain. It accounted for only about 10% of the Gross Domestic Product (GDP) but employed about 25% of the total labour force of the country (PSA, 2018). This means low labour productivity in agriculture. For the past 10-year period (2009-2019), the growth rates of the agricultural sector averaged at only 2%. The mediocre economic growth in the agriculture sector translated to poverty in the rural areas where agriculture is the main economic activity. Poverty has become a rural phenomenon in the country with about 72% of the poor residing in rural areas.

In 2018, the poverty incidence (PI) in the country, or the proportion of poor Filipinos whose per capita income was insufficient to meet their basic food and non-food needs was estimated at 16.7% (PSA, 2020). This translated to about 17.7 million Filipinos living in poverty. The highest and lowest poverty levels both in terms of incidence and magnitude were observed in the formerly called Autonomous Region of Muslim Mindanao (ARMM) and in the Metro National Capital Region (NCR), respectively. The poorest provinces were mostly provinces in the Mindanao Island. Meanwhile the subsistence incidence (SI) among the population, or the proportion of poor Filipinos whose per capita income was insufficient to meet their basic food needs in 2018 was 5.2%. This meant around 5.5 million food-poor Filipinos. The highest subsistence incidence was estimated for the ARMM and for mostly provinces of Mindanao Island.

Farmers, fisher folks, and residents of rural areas had the topmost poverty incidences among the basic sectors at 31.6, 26.2, and 24.5%, respectively. In terms of magnitude, the topmost sectors with the highest number of poor were the individuals residing in the rural areas (12.6 million), children (9.3 million), and women (8.7 million). The agriculture sector is crucial for inclusive growth as agriculture and other agriculture-related employments remain the major source of income in rural areas where most of the country's poor live.

IRRIGATION STATE AND INITIATIVES

Level of irrigation development and irrigation performance

Irrigation has been considered as engine of growth of agriculture. The Government through NIA continues to construct and improve irrigation systems in the country. About 64% of the 3.13 million ha estimated irrigable areas of the country (NIA, 2020) has irrigation facilities. Of this irrigation service area, 47, 36 and 17% are served by NIS, communal irrigation systems (CIS), and private and other government-assisted irrigation systems, respectively. The irrigable areas are rainfed rice and corn areas with up to 3% slope.

Despite rehabilitation and restoration efforts, there remains a consistent gap between the irrigation service area and the actual area irrigated. On the national average, the actual area irrigated by NIS for the period 2015-2020 ranged from 66-83% of the operation and maintenance (O&M) service area. It did not differ significantly between the cropping seasons, with 74% and 75% during wet and dry seasons, respectively. The performance of CIS in terms of actual area served was lower than NIS for the same period. It fluctuates between 55-68% of the O&M service area, with an average value of 63% during wet season and 59% and dry season.

The underperformance of irrigation systems has been attributed to the shortcomings either in the design, technology, O&M, system management, policy, hydrological extremes, or a combination of these factors (David, 2003). Many national irrigation systems are negatively impacted by highly variable and less reliable water supply due to hydrologic extremes and lower priority water allocation to agriculture. Cases of damaged and inadequate canals and dams; and non-functional, missing, insufficient number, or inappropriate flow control structures have been documented by a number of studies (David et al, 2012b; Moya, 2014; Delos Reyes et al, 2017). Their causes were commonly attributed to old-age wear and tear, insufficient maintenance due to budget constraints, vandalisms, and force majeure, among others.

Irrigation interventions

The NIA has been addressing these problems through its system improvement projects such as the National Irrigation System Rehabilitation and Improvement Project (NISRIP), Small River Impounding Project (SRIP), and Climate Change Adaptation Works (CCAW), among others. At the system level, several promising interventions of NIA and irrigator associations (IA) were observed during the field visits to some NIS, which included Balanac RIS, Sta. Maria RIS, Mainit RIS, Tago RIS, Lower Chico RIS, and Angat-Maasim RIS. At the system level, intervention initiatives included the following.

*Water reuse and c*onjunctive use. The NIA has been constructing check gates to capture drainage water from upstream farms and divert it to downstream farms, usually at the request of IAs (Balanac RIS, Sta. Maria RIS, Tago RIS). Also, many individual farmers have invested in tubewells and pumping units to tap groundwater and nearby creeks for supplemental irrigation (Mainit RIS, Tago RIS, Lower Chico RIS, Agos RIS). Shallow tubewell irrigation has been particulary popular among farmers because of higher reliability of irrigation supply and flexibility in farming schedules. In recent years, the Department of Agriculture and the NIA implemented solar-powered irrigation systems (SPIS) to augment irrigation water supply in selected CIS and NIS, respectively.

Minor irrigation schemes. Construction of secondary, small diversion dams or check structures to tap supplemental water from nearby minor rivers or creeks has been done in Sta. Maria RIS and Tago RIS. Similarly, concrete boxes were constructed to contain or store spring water and augment the available water for irrigation in Sta. Maria RIS. Also, the feasibility of

constructing a secondary dam or installation of pumping units farther downstream of the main dam is being carried for Tago RIS to increase water diversion and facilitate water delivery in downstream farms.

Alternate wetting and drying (AWD). The NIA field-demonstrated the AWD technique to convince rice farmers that continuous irrigation and soil submergence are not necessary because reducing water application to soil water content between field and saturation capacities does not reduce rice yield. Adoption of AWD will reduce upstream water diversion and improve the water availability for downstream farms, hence, increase the actual irrigation coverage. While the IA of Balanac RIS recognized the benefits of AWD and have started practicing it, its adoption is relatively low. One of the reasons is that many of the systems do not have the appropriate flow control structures to successfully operationalize it.

Segmental cropping, rotational irrigation, and proactive shifting of cropping calendar. System-wide segmental cropping and rotational irrigation schedules by management unit called turnout services areas (TSA) are practiced in many irrigation systems. In collaboration with the NIA and advisory with agriculture and weather agencies, many IAs have been strategically adjusting their cropping calendar to avoid or minimize crops exposure to expected flood and drought events. In Sta. Maria RIS, wet season cropping is started early at the flood-prone areas when a La Niña event is expected so that rice plants sown in these areas would have been in their most resilient stage to intermittent flooding when the monsoon period comes. Similarly, early dry cropping season starting at downstream areas is implemented when El Nino is expected so as to avoid competition with upstream farms. Consequently, water delivery starts from downstream-to-upstream farms.

Crop diversification and micro-irrigation. Planting of vegetables and other less-water-loving crops such as corn and mungbean has been a coping strategy of most rice farmers to water scarcity in downstream areas of Angat-Maasim, Lower Chico, Tago and Mainit irrigation systems during the dry cropping season, especially when a drought episode is expected to occur. In recent years, the NIA has implemented drip irrigation projects for vegetables and other high-value crops in tail-end areas of selected NIS.

FARMERS AND INSTITUTIONS IN IRRIGATION DEVELOPMENT

The existence of local farmers who collectively constructed and managed communal irrigation systems to irrigate their farms in prehistoric Philippines is widely recognized. The earliest written records of indigenous, communal, self-governing irrigation societies called Zanjeras were by Spanish friars in 1630. The Zanjeras were mostly found in the Ilocos region, a northwestern part of the Philippines.

Irrigation organizations and institutional circumstances of local farmer-irrigators' organizations varied throughout the history of irrigation development in the country (Table 1). David (2003) noted that the Irrigation Act of 1912 was significant because it attempted to integrate the planning, design, construction and operation and maintenance (O&M) of irrigation systems under one institution. However, he opined that it also paved the way for the centralization of irrigation development and set in motion a process of viewing irrigation development projects mainly from technical and engineering perspective, with focus on physical infrastructure. He stated that the establishment of the Irrigation Service Unit in 1949 is significant because it placed under one institution the planning and implementation of certain irrigation development activities and the delivery of essential irrigation support services and functions. Also, it gave individual farmers access to an easy-to-operate irrigation system and, hence, greater control over its O&M.

Table 1. Key developments in irrigation-related institutions

	Event/Mandate
1908	Establishment of Irrigation Division of the Bureau of Public Works. To construct and repair irrigation facilities
1912	Passage of Irrigation Act. To regulate the appropriation of public waters, prescribe rules on water rights, and provide for the investigation, construction, operation and maintenance of irrigation systems and payments thereof. Transferred control of irrigation facilities from Bureau of Lands to the Irrigation Division
1949	Establishment of Irrigation Pump Administration (IRPA) under the Department of Agriculture and Natural Resources. To purchase pump irrigation equipment and supervision of their installation, operation and maintenance
1952	Reorganization of IRPA as the Irrigation Service Unit (ISU)
1962	National Economic Council and the United States Agency for International Development (NEC-USAID) agreement to establish a planning program for the water resources development in seven major river basins in the country
1963	Passage of law creating the NIA (Republic Act No. 3601). Primary responsible for irrigation development
1966 – 1967	Commissioning the US Bureau of Reclamation (USBR) to plan and conduct feasibility studies of large-scale irrigation projects in major river basins
1974	Launch of a 10-year accelerated irrigation development program Presidential Decree 552 Amendments on the NIA Charter. To give NIA power to delegate the partial or full management of NIS to duly organized farmers organizations
1975	Creation of the Farm Systems Development Corporation (FSDC). To promote organization and assist IAs; to develop small low-lift pump irrigation schemes. Abolished in 1987
1976	Conduct of a pilot project transferring the responsibility, ownership, and management of small-scale irrigation systems to farmers groups
1980	Implementation of Participatory Approach Program of the NIA; adoption of farmer participation in all communal irrigation systems and, subsequently, in NIS
1987	The creation of the Bureau of Soils and Water Management (BSWM). To develop small water impounding irrigation systems
1991	Enactment into law (Republic Act 7607) of the Magna Carta of Small Farmers
1992	Transfer of NIA to the Department of Agriculture (DA); launch of the DA shallow tubewell irrigation project
1997	Passage of Agriculture and Fisheries Modernization Act (AFMA). To accelerate and complete the turnover of O&M and management of secondary canals and on-farm structures of NIS to the IA. Start of implementation of Irrigation Management Transfer (IMT) program
2014	Transfer of the NIA to the Office of the President
2018	Passage of the Free Irrigation Service Act

The NIA was created by a law (Republic Act No. 3601) in 1963 in response to the need to construct more irrigation systems. All functions of the abolished Irrigation Division and the Irrigation Unit of the Bureau of Lands and the Friars Lands Irrigation Systems were transferred to the NIA. The NIA has become a public corporation primarily responsible for irrigation development. In early 1960s, the focus of irrigation development shifted towards large-scale multipurpose development projects. A rapid expansion of rice area with irrigation facilities occurred between 1966 and 1988.

The 1974 amendments on the NIA Charter allowed the NIA to delegate the partial or full management of national irrigation systems to duly organized farmers organizations. Another government entity, the FSDC was created in 1975 to promote organization of farmers and

assisting farmers associations. The NIA contracted it to undertake organization of communal associations and a pilot project aimed at transferring the responsibility, ownership, and management of small-scale irrigation systems to farmers groups was initiated in 1976. It started its Participatory Approach Program in 1980 in communal irrigation systems and, subsequently adopted farmers participation in NIS in its Management Turnover Program. The NIA has been organizing farmer-beneficiaries NIS into irrigators associations (IA) and developing them to be self-governing and self-reliant partners in irrigation system planning and management since then. Under its Institutional Development Program, it has been providing capacity-building and training activities for IA to make them capable of managing the O&M of tertiary systems up to the main system and governing their respective organizations.

While FSDC was abolished in 1987, the BSWM was created in the same year with mandate of developing small water impounding irrigation systems. In 1991, the Magna Carta of Small Farmers, which recognized the right of small farmers to participate in the planning, organization, management and implementation of agricultural programs and projects, was enacted into law (Republic Act 7607).

The transfer of NIA to the DA in 1992 was deemed as an appropriate step to have a better coordination of irrigation development activities with the delivery of essential irrigated agriculture support services. The launching of the DA shallow tubewell (STW) irrigation project in 1992 was viewed as a big step towards increasing farmers' participation in irrigation development and their control over irrigation facilities. The Philippine Congress passed the AFMA in 1997, which mandated the acceleration and complete the turnover of the O&M of secondary canals and on-farm structures of the NIS to the management and O&M by irrigators associations (IA).

Also, in the late 1990s, irrigation management transfer (IMT), a participatory-based irrigation management contract between the NIA and irrigators associations was developed and the IMT program was started in 1997 on a World Bank-funded project. It emerged from a confluence of interest to decentralize irrigation management and reduce government expenses for operation and maintenance of irrigation systems (Bandyopadhyay, 2010;). In the IMT program, the NIA and an IA enter one of the four models of the IMT contract based on the IA capabilities to assume management of system O&M responsibilities (NIA, 2017). Recently, these IMT models were replaced by one uniform contract called the modified IMT contract following the signing into law of the Free Irrigation Service Act in 2018. Under the modified contract the NIA will manage the main facilities such as dams, reservoirs, pumping stations, main canals and large lateral canals while the IA will manage the secondary facilities starting from medium-sized laterals, subsequent smaller canals, turnouts, farm drains down to the terminal structures. As of December 2019, about 81% (1.29 million hectare) of the total NIS and CIS irrigation service areas and about 7,795 (88%) of registered IAs in the country are covered by an IMT contract (NIA, 2020).

KEY AREAS FOR INCREASING FOOD PRODUCTION AND FARMERS' INCOME THROUGH IRRIGATION AND DRAINAGE

Additional food can come from increasing rice yield from 4.4 ton/ha to project development targets of 6-8% and cropping intensity from the national average of 145%. Yield is influenced by key production constraints such as seeds and seedling management, fertilizer and soil management, weeds, insects pests and diseases management, and water management. There is a considerable margin for yield improvement in irrigated areas associated with proper management of these interrelated production constraints. Cropping intensity is more related to provision and management water and can be achieved by the following interventions.

Irrigation expansion. There are about 920,000 hectare of rainfed rice areas, about 40% of which are not planted during the dry season (PSA, 2020). The NIA estimated that there remains about 1.14 million ha of irrigable area for development. Forty seven percent and 46% of this remaining area with potential for irrigation development are in Mindanao and Luzon islands, respectively. Provision of irrigation facilities in these areas will enable cultivation at least twice a year, hence, increase food production.

Irrigation system improvement/modernization. Lack of control of flows along the canal network due to non-functional, damaged and inappropriate flow control structures results in over irrigation in upstream farms and water shortage in downstream farms even with sufficient water supply at the dam. This was seen in the case of Balanac RIS where most flow control structures were damaged and ungated and in Sta. Maria RIS where most gates were functional. Despite the fact that the irrigation water supply of the former was clearly abundant compared to that of the latter, the respective actual irrigated areas of the systems were practically the same. Similarly, damaged and non-operational sluice gates and main intake gates of the headworks resulted in uncontrolled high volume of flows and sediment entering the canal network in times of sudden heavy downpours, causing erosion of canal banks and heavy silt deposit. Also, more than 80% of NIS have intake barrel structure and run-off-the-river diversion dams whose reliability to feed main canals with water have been greatly reduced due to lower low flows associated with the changing climate and rainfall pattern. Like in Sta. Maria RIS, Lower Chico RIS, and Agos RIS, many of these NIS have portions of their service area not planted due to low water supply, especially during the dry season. Cropping intensity in irrigated areas can be increased through upgrading to appropriate irrigation technology to increase reliability of water supply and facilitate efficient control and distribution of water to enable irrigation coverage of the whole service area.

Drainage system. The country's agriculture suffers from floods brought by frequent heavy rains during the Southwest monsoon. The constant gaps between the service areas and actual irrigated areas during the wet season are attributed to the inundation of downstream service areas adjacent to a lake (Balanac RIS, Sta. Maria RIS), overflows from canals and silted rivers and creeks (Tago RIS) and ponding effect within the services areas due to an insufficient drainage network (Lower Chico RIS, Agos RIS, Tago RIS). Dredging of silted creeks and rivers and providing drainage facilities will make cultivation in inundated service areas possible during monsoon months.

Crop diversification. In recent years, the potential of crop diversification for increasing agriculture productivity, farmers' income and improving nutrition has gained the attention of the DA and the NIA, which both implemented programmes to promote it. The DA implemented the High-value Crop Development Programmes while the NIA started constructing solar-powered pump irrigation systems (SPIS) and model family farms equipped with greenhouses and micro-irrigation to support crop diversification in NIS service areas.

CAPACITY ENHANCEMENT FOR FARMERS AND INSTITUTION FOR INCREASED PRODUCTIVITY AND POVERTY ALLEVIATION

The Government through its irrigation and agriculture agencies has a long history of supporting Filipino farmers in the latter's effort to increase their harvest and income – from creating laws, policies, programmes and offices that provide for farmers participation, subsidies on material inputs, farm machineries, irrigation, agricultural support services and capacity enhancement, among others. While these efforts achieved considerable gains, there remain to be desired to sustainably increase food production and farmer's income. Based on the findings of previous studies by the authors (Delos Reyes *et al*., 2015; Delos Reyes, 2017; Delos Reyes and

Schultz, 2018; Delos Reyes and Schultz, 2020), the following training courses for farmers and/or concerned personnel are recommended:

- appreciation course on canal operation at the system level and working principles of flow control structures. The objective is to promote awareness on how gate adjustments and/or presence of specific flow control structure affect water delivery/distribution upstream and downstream of the structure. Many flow control structures such as duckbill weir, proportional weirs, and constant head orifice were vandalized apparently for a notion that they obstruct flow, favour upstream farmers and unnecessary. Clear understanding on the purpose of structures operation or presence would help save structures from vandalism or unauthorized manipulation by farmers;
- course on logical combinations of structures, canal operation objectives and their farming goals. The objective is to address the apparent lack of coherence among desired irrigation scenarios and preferred flow control structures and water distribution methods. Also, the aim is to support the standing farmer's choice policy in planning for irrigation improvement projects by enabling farmers to make the right choice;
- development planning for irrigation modernization. The objective is to promote awareness of the goal and process of irrigation system modernization and the importance of crafting vision and plans in unison with all stakeholders;
- training and field demonstration on diversified cropping and HVC production. This is to address farmers' apprehension to diversify into HVC due to their unfamiliarity to the necessary farming practices and knowledge for successful production;
- training on postharvest handling and food processing. The objective is to equip farmers knowledge on lengthening the shelf life of their produce and/or transform them into food items to avoid produce losses and earn more.

Similarly, some institutional aspects and support services that need strengthening and improvement are:

- synergy among agriculture offices at the national and local government levels and the NIA. The NIA mainly focus on providing irrigation service while the agriculture offices are mostly concern in delivering production support services such seeds, fertilizer/soil management, weeds, disease and pest management, farm machinery and some postharvest facility. Irrigation system personnel and IA follow a cropping calendar after which the irrigation system is closed for maintenance works. However, there were usual cases of delivery of seeds and fertilizers not coinciding with the farming schedules, hence missing on its optimum use and benefits. Collaboration in timely delivery of such support services would result in more efficient use of resources and comprehensive solutions in managing production constraints;
- arrangement with other water right holders to ensure access to water sources based on approved water rights. Use of water for irrigation/agriculture purposes ranks third on priority of use. More IAs are getting worried about the security of irrigation water supply as water diversions for municipal and industrial uses are constructed upstream of irrigation dams and intake sites. An extreme case of dried-up river at dam site was experienced in Cabadbaran-Taguibo River Irrigation System in Region 13, resulting in dried up paddy fields and wilting of recently transplanted rice seedlings;
- institutionalization of IA's role in monitoring and acceptance of completed improvement/modernization works. Farmers have high interest on the performance of irrigation systems, hence, can be expected to be vigilant in guarding the quality of the construction or installation works;
- revisiting of standard O&M budget. Lack of sufficient budget for O&M is one of the most cited system management problems and cause of deterioration of physical structures by system personnel and farmers. IA's effort to supplement their O&M budget by collecting management fees from members is thwarted by unsympathizing farmers by referring to the recently implemented Free Irrigation Service Act;
- access to market and postharvest/processing facility. Uncertainty in prospective buyers,

transport to market, timely sale of highly perishable, high-value crops such as vegetables discourage farmers in venturing to HVC production. Linking farmers associations to assured market or postharvest/processing facilities will encourage them to grow crops. The volume of imports for several non-rice food items represents a volume of unmet domestic demand, hence, potential market.

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Monitoring and detection of soil elements for the sustainable management of irrigation of agricultural resistance by an intelligent system

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Abstract

The provision of data-driven innovations, also known as "agri-food precision" or "smart culture," identifies and supports the rationalization of problems related to monetary, natural and societal problems. As the world's population grows exponentially, it is essential to review current crop practices to meet food security needs. Smart sensor systems provide more information on water and crop requirements. This information can be used to mechanize the water supply system and prepare farmers to optimize their irrigation system. The information acquired from the first step is transferred to the cloud. Uncategorized Outstanding preparation for distributed power generation, which is a very important measure of information, which the manufacturer of a mobile phone application can use. This article proposes and evaluates the concept of remote sensing device.

Keywords: Intelligent System, Monitoring, Detection, Soil, Sustainable, Irrigation, Agricultural

1. Introduction

Soil quality is often related to a function expressed by humans. Thus, the expected quality of soil for infrastructure is different from that for agricultural production, and the indicators to be measured are therefore different. For this reason, scientific groups and research institutes, as well as industry, are racing to offer more and more Internet of Things products to the players in the agricultural sector, and are laying the groundwork for a clear role for the Internet to become a dominant technology [1]. At the same time, the already popular internet and big data provide sufficient resources and solutions to maintain, store and analyze the huge amounts of data generated by internet-connected devices. The management and analysis of data from the Internet of Things can be used to automate processes, predict situations and improve many activities, even in real time. Indeed, the IoT now enables farms to increase operational efficiency by automating and optimizing production lines. IoT also brings undeniable benefits for farm management [2]. Soil monitoring with IoT uses technology to empower farmers and growers to maximize yield, reduce disease and optimize resources. IoT sensors can measure soil temperature, NPK, volumetric water content, photosynthetic radiation, soil water potential and soil oxygen levels. The data from the IoT sensors is then transmitted back to a central location (or the cloud) for analysis, visualization and trending. The resulting data can then be used to optimize farm operations, identify trends and make subtle adjustments to conditions to maximize crop yield and quality [3]. The use of IoT in agriculture is known as smart farming, and IoT is a central component of precision agriculture. Connected objects in agriculture is constantly evolving, and the evolution we will talk about implicitly in this chapter is confrontational agriculture, we will talk about the impact that the Internet of Things has had on this field. The supply of hardware for farmers is diversifying: drones flying over fields to analyze the condition of a soil, robots dispersing pesticides in a targeted manner, tractors performing centimetric soil analysis, precision irrigation equipment, and collars studying the physical condition of livestock [4]. The operation of these tools is based on a digital analysis of data collected by various sensors (thermal, chemical, humidity, etc.). These data are then processed by the robots themselves, but they can also be used by other devices [5]. For example, a tractor will be able to analyze the quality of a soil to accomplish its own task but the extracted data will also be usable for a digital irrigation system. A technological ecosystem is superimposed on the life of the farm, made up of connected objects in "conversation" with each other [6].

2. Materials Techniques and System Structure

2.1.System Structure

The system developed in this research was tested under various soil quality conditions, the result was conclusive according to the first objective of our system [7]. We measured four parameters (pH, Temperature, Humidity and the value of potassium, nitrogen and sodium in the soil) using the conventional method and using our developed system.

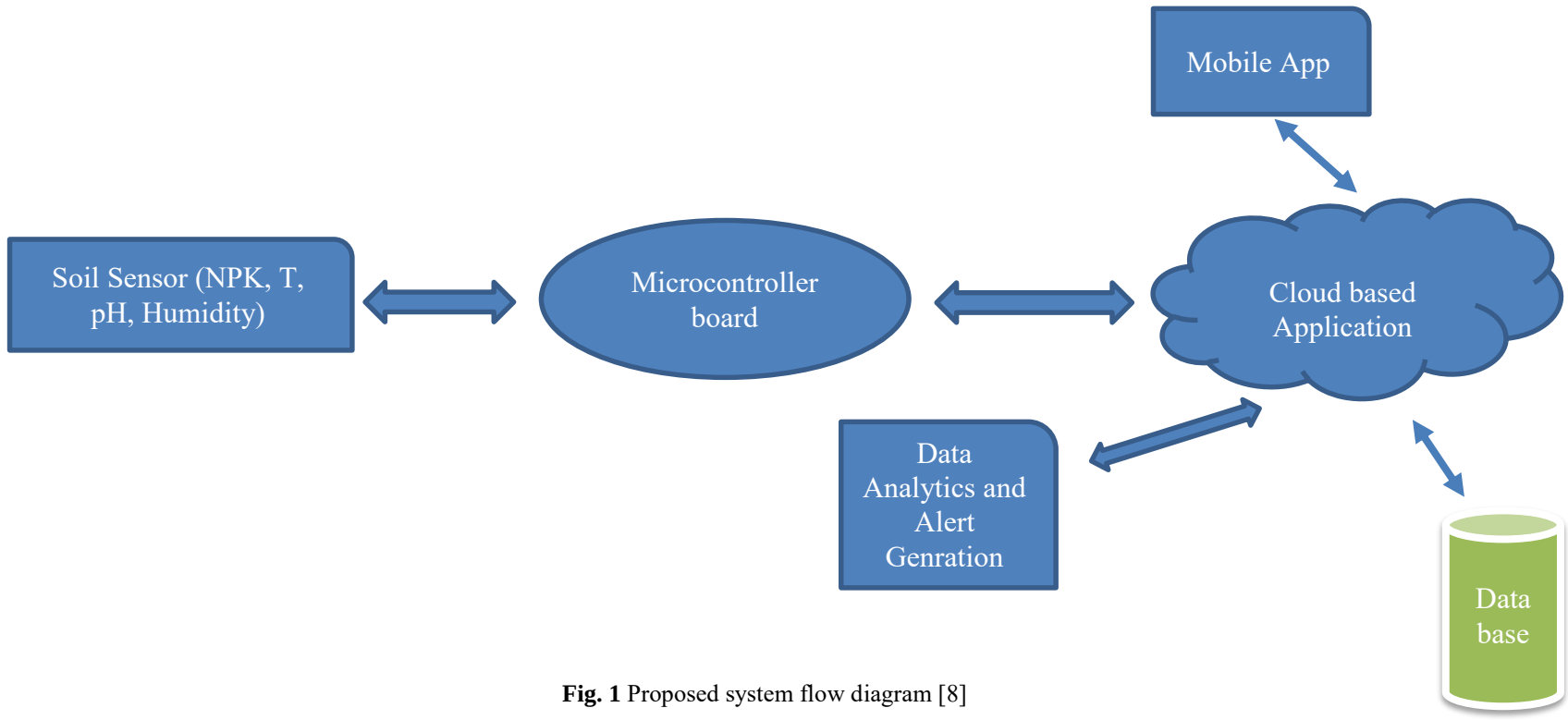


Fig. 1 Proposed system flow diagram [8]

2.2. Microcontroller

Arduino Uno board is a microcontroller board worked around the ATmega328. The card contains everything that is essential for the microcontroller's task (Fig.2). It has small size and low power consumption, and essential in any embedded electronics solution (car, garage door, robots, etc.). In addition, it's the simplest and most economical, and can be programmed with software available with the microcontroller [9]. The board contains all elements that are essential for the microcontroller's task. To implement the microcontroller, we need to associate it with a PC via USB connection, as for the energy sources, it can be powered with an external power supply or batteries [10].

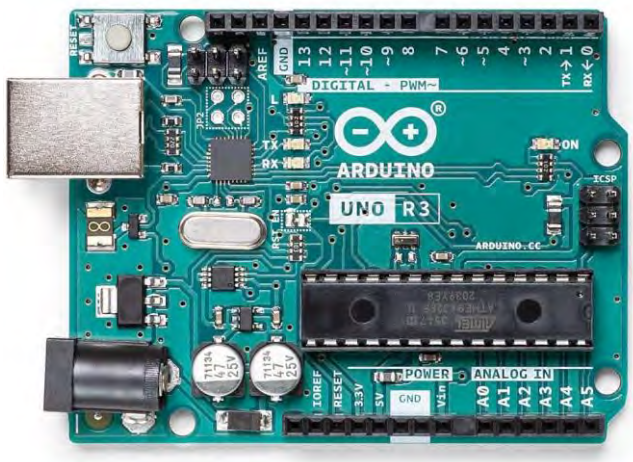
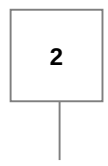


Fig. 2 Arduino cards UNO

2.3.Sensors

To check soil quality, distinctive types of sensors, including optical sensors, hot sensors and attractive sensors, among others, are used.

***pH sensor*:**



It is a measurement that determines the acidity or basicity of the water solution (Fig.3). An acid will release the hydrogen ion (H+) when it dissolves in water, while a base will release the hydroxyl ion (OH-) in water. The pH takes values between 0 and 14 and its measuring temperature is between 0 and 60 °C. Because of the importance of the pH value in determining the acidity or basicity of water, we used a pH meter to detect the pH value of the water being [11].

Fig. 3 pH sensor

Temperature sensor:

The water temperature is a physical property that specifies the thermal energy of the water, it is a considerable parameter to check the water quality (Fig.4). The change in water temperature has several effects on aquatic life. In addition, it has an influence on other [12].

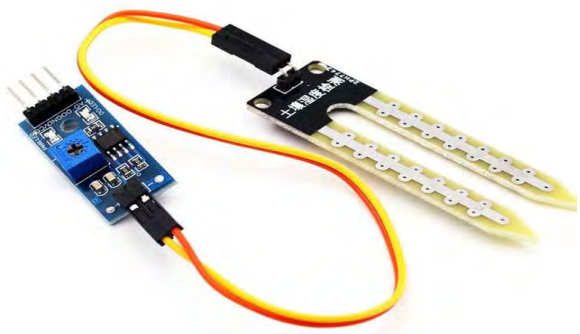


Fig.4.Temperature sensor

Turbidity Sensor:

It is the qualitative characteristic that determines the relative clarity of water (Fig.5). It means the existence of insoluble particles and solid objects in the water that have negative effects on the underwater life in rivers, lakes, seas. It prevents the sunlight from reaching the submerged aquatic plants. As a result, the process of photosynthesis stops and the dissolved oxygen is reduced [13].

Fig.5.Turbidity sensor

NPK soil sensor:

The NPK soil sensor detects the nitrogen, phosphorus and potassium content of the soil (Fig.6). It allows the determination of soil fertility and thus facilitates the systematic evaluation of the soil condition. It is equipped with a high quality probe, which is resistant to rust, electrolysis, salt and alkali corrosion, in order to ensure the long-term operation of the probe part. Therefore, it is suitable for all types of soil. It is suitable for detecting alkaline soils, acid soils, substrate soils, seedbed soils and coconut bran soils. The sensor does not require any chemical reagents. As it has a high measuring accuracy, fast response speed and good interchangeability,

it can be used with any microcontroller. You cannot use the sensor directly with the microcontroller because it has a Modbus communication port. The sensor works on 9-24V and the power consumption is very low [14]. As for the accuracy of the sensor, it is about 2%. The resolution of measurement of nitrogen, phosphorus and potassium is 1mg/kg (mg/l).

Fig.6.NKP soil sensor

2.4. Network tools

In order to transmit the captured values to the local space, we use a Wi-Fi module; which is a tool that allows the Arduino board to communicate the captured values to the access point. Using the Bluetooth module for Arduino, the board can also send the measured parameters to a smart hardware equipped with Bluetooth, such as the smart watch [15]. As well as, for the transfer of captured values, the access point is connected to the Internet. The latter receives the data from the local area and transfers it to the local computer and the remote database [16].

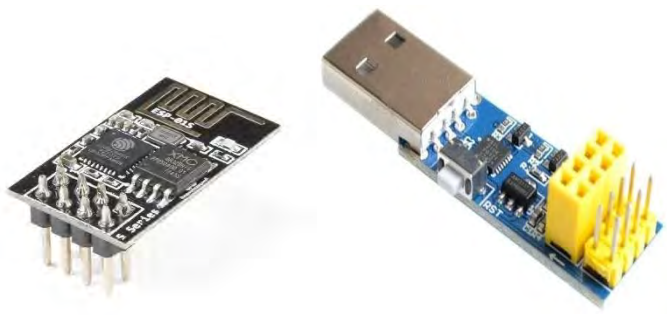


Fig.7. Wi-Fi module: ESP8682

3. Results and Discussion

The right crop for their performance using an Arduino Uno board and some sensors such as pH sensor, humidity sensor and temperature sensor to collect the humidity and temperature information to collect the information from these sensors and send it to the distributed storage to store the estimates. Anyway, this framework cannot anticipate the weather conditions of the previous year. Earlier and will not recommend the best crop to harvest. It neglects to tell with regard to the water system at the necessary time. To examine the quality of the soil, the proposed framework uses a moisture sensor, a temperature sensor and a NPK sensor to get information about the moisture content of the soil, the temperature of the concentration of nitrogen, phosphorus and potassium substance in the dirt [17]. These sensors are associated with the Arduino UNO board. A committed Wi-Fi module is associated with the board that helps to send information to the cloud to process the information gathered by the different sensors. The information gathered is temperature, humidity and NKP values [18].This information from the sensors is stored in the Influx cloud which is a high availability open source distributed storage. The information is refreshed in Influx DB most of the time.

The summary of obtained values is presented in the table below (Table.1.)

Table. 1. Summary of obtained values

Site	Measurements	T (°C)	pH	Humidity	Turbidity (NTU)	P	N	K
P1	conventional method	21,5	7,5	37,6	2	18	6,3	10
	IoT	20,6	7,8	32,5	1,5	15	6,2	12
P 2	conventional method	19	8,5	31,50	1	9	5,3	09
	IoT	20	8,1	31,250	1,2	8	5,5	09
P 3	conventional method	22	8,5	25,40	3	4,2	3,0	14
	IoT	21	8,4	24,82	3,2	4,0	2,8	15

4. Conclusion

In this study, it has been highlighted that technologies have made possible the Internet of Things and the five essential components of IoT. We have outlined the structure of the data processing module, and network communication. In our study, we noticed that all the proposed systems consist of three modules which are: sensing module, processing module and transmission module. The comparison is made on the basis of these three modules. Smart sensor nodes are used to measure soil quality parameters

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