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

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## ABSTRACT

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

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

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

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

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

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

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

## 1. INTRODUCTION

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

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

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

Punjab province is highly dependent on irrigation for agriculture. It is one hundred years since the irrigation system was established and the canals and watercourses for the irrigations systems have been decaying, which impedes the efficiency of allocation of water. To strengthen and improve the management and maintenance of the irrigation

system: The project was started in March 2009 to enhance water use efficiency and on-farm productivity. The project applied the results of former JICA support and Japan's 60 years experience for the water user associations named "Land Improvement District" (LID) through the collaboration with JICA's Yen Loan Project "Punjab Irrigation System Improvement Project" (PISIP). The project aims to establish the model of appropriate irrigation management system through verification activities in the pilot areas which in turn contribute to the improvement of the management and maintenance of the irrigation system and increase water use efficiency and on-farm productivity (JICA 2008).

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

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

## 2. POLICY

Challenges of food security

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

Challenges of water security

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

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

(d) Depleting groundwater tables, due to over exploitation

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

How irrigation water allocation system are being effected

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

What strategies are being adopted

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

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

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

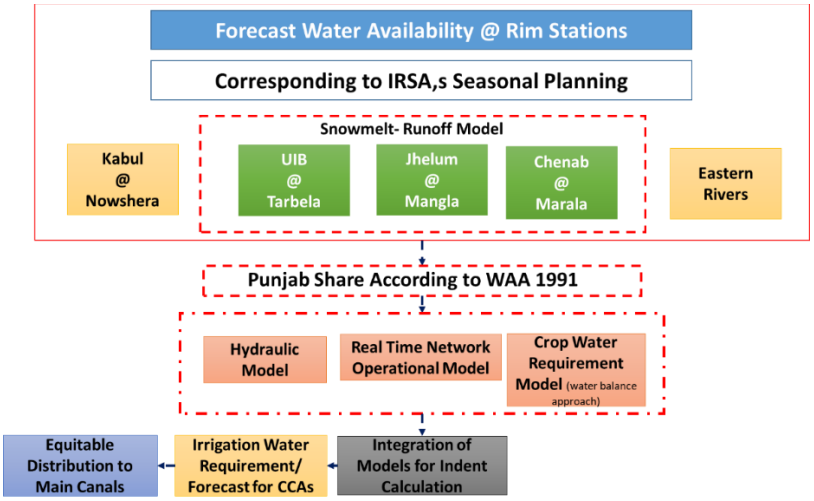


**Figure 1:** Schematic Diagram of Models Integration

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

## 3. APPROACH TO MODERNIZATION

### 3.1 Project Description

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

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

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

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

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

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

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

**Table 1:** Project cost by component and expenditure category

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

**Table 2:** Project Cost by Component and Year

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

Project Information

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

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

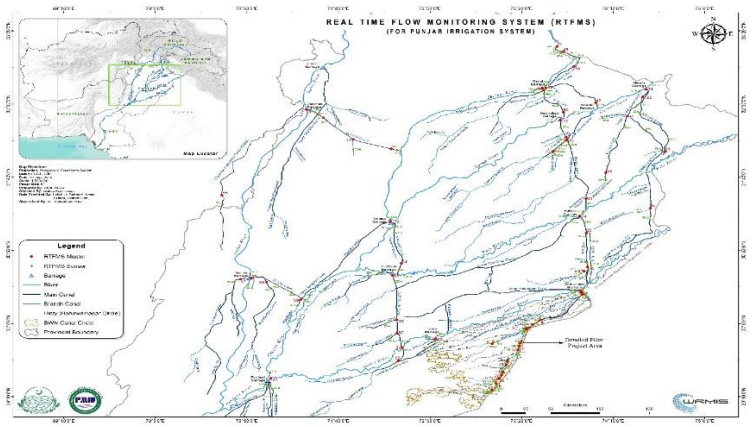


**Figure 2.** Real Time Flow Monitoring System (RTFMS) Installed at Project Area (Eastern Sadiqia Canal)

The complete application would be Water Resources Management Information System (WRMIS) which are facilitating the decesion makers in making informed decesion

regarding water availability and system responce against various management scenarion.


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

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

The system comprised of the following sub-components,

(a) Modern Database (Task-A)

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

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

(d) Management Information System (Task-A)

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

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

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

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

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

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

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

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

Implementation of modernization proposal

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

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

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

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

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

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

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

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

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

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

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

(d) Automation of real time flow data.

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

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

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

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

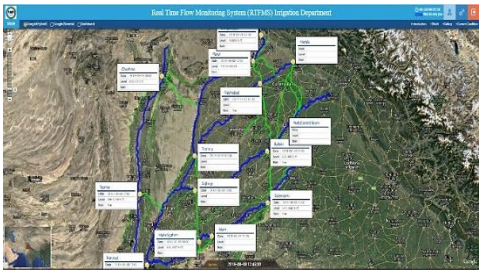

**Figure-5:** RTFMS website screenshot head (ESC Tail)

**Figure-6:** CTD sensor installed at Jalwala

Lessons learnt including benefits from modernization

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

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

(a) Initially, it was decided to install RTFM system at all main canals, off-taking points of distributaries/ minors. The estimated number for all these points was 1548 but to test the working of system, it was decided to install RTFM system at Eastern Sadiqia Canal as Pilot Project with 14 Barrages (Upstream & Down

stream) main canals, link canals offtaking from barrages, tailrace of Mangla Power house, UJC, Bong Escape and LCC Feeder off taking from QB Link Canal.

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

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

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

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

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

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

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

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

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

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

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

main canal level can be minimized through monitoring of violation of Rotational Program on 24/7.

Summary and Conclusions

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

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

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

(a) Projects / Works

(b) Accounts

(c) Assets Management

(d) Mobile Application

(e) Smart Monitoring

**The list of existing modules for which functionalities were improved:**

(a) Daily Operational Data (Web & Android)

(b) Water Theft (Web & Android)

(c) Schedule & Inspections (Web & Android)

(d) Tenders Monitoring (Web & Android)

(e) Water Losses

(f) Flood Operations (Web & Android)

(g) Closure Operations (Web & Android)

(h) Performance Evaluation

(i) Canal Operations Reports

(j) Rotational Programs

(k) Entitlements & Deliveries

(l) Content Management of Public Website.

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

(a) Irrigation Network

(b) User Administration

**New modules which are added as follows:**

(a) Auctions

(b) Effluent & Canal Water Charges

(c) Small Dams

(d) Flood Bund Gauges Data

(e) Flood Early Warning System (FEWS)

(f) Seasonal Planning & Snow Run-off Modeling

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

(a) Modules are fully integrated.

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

(c) Standardization of data throughout the application

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

(e) Implementation of notifications.

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

(g) Android Application Interface where applicable.

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

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

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

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