



International Water  
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# Setting Up Indus Telemetry for Canal Flow Monitoring

## A Learning Experience

### Technical Guide (Manual)

Muhammad Tousif Bhatti, Muhammad Ashraf, Kashif Hussain, Khalid Khattak, Muhammad Yasir  
and Manzoor Ahmad Malik





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Cover photo: Indus Telemetry at Warsak Lift Feeder Canal, Khyber Pakhtunkhwa (photo: Amjad Jamal/IWMI)

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# Acronyms and Abbreviations

ADCP	Acoustic Doppler Current Profiler
FTP	File Transfer Protocol
GoKP-ID	Government of Khyber Pakhtunkhwa-Irrigation Department
ha	hectare
IBIS	Indus Basin Irrigation System
IRSA	Indus River System Authority
IWMI	International Water Management Institute
LBDC	Lower Bari Doab Canal
maf	Million Acre Feet
MoWR	Ministry of Water Resources
NGO	Non-Government Organization
P&D	Planning and Development
PCRWR	Pakistan Council of Research in Water Resources
PDMA	Provincial Disaster Management Authority
PMD	Pakistan Meteorological Department
RD	Reduced Distance
SEEA-Water	System of Environmental-Economic Accounting for Water
SNA	System of National Accounts
SQL	Structured Query Language
USAID	United States Agency for International Development
USC	Upper Swat Canal
USD	United States Dollar
WAA	Water Apportionment Accord
WAPDA	Water and Power Development Authority
WMfEP	Water Management for Enhanced Productivity

## Summary

Indus Telemetry started as research for development endeavor in 2017 in Pakistan, led by International Water Management Institute (IWMI) in partnership with Pakistan Council of Research in Water Resources (PCRWR) and provincial irrigation departments. It was concluded in April 2025 by sustainable transfer of Indus Telemetry to the partner provincial irrigation department. The goal of Indus Telemetry was to inform and guide these ongoing and future investments and develop a surface water accounting and audit system based on the data acquired using automated instruments. Indus Telemetry delivers on Pakistan's National Water Policy 2018 which necessitates water institutions of Pakistan to install a telemetry system across the entire Indus River System by the year 2021.

Indus Telemetry has gone through various phases from its start to completion and sustainable transfer of technology to the government partner. These phases brought many technical challenges and learning opportunities for the water professionals. This manual is an attempt to share some learning experiences in setting up and upgrading Indus Telemetry. Indus Telemetry has been installed at 11 main canals in Khyber Pakhtunkhwa province of Pakistan. The layout of Indus Telemetry at individual canal location may slightly differ but overall, the design, instruments and sensors and data processing principles are identical for a typical telemetry station at a canal location. In this backdrop, it is imperative to document the procedure for setting up a typical telemetry station for canal flow monitoring. This report is therefore formed as a guide or manual and explains various steps involved in this process.

There are various manufacturers of sensors used for flow monitoring, dataloggers and flow measurement equipment, and hence they may have slightly different features and programming methods. The objective of this manual is not to do market research and provide list of sensors/equipment and their features. Rather, its purpose is to document steps adopted in setting up Indus Telemetry that are fairly generic and can be repeated elsewhere for similar applications. Hence the intended audience of this report are irrigation department and private sector and research institutions. The calibration, validation and programming of various instruments used for flow monitoring in main canals can be of interest to researchers and irrigation practitioners. Identical sensors may be used to monitor flow in non-prismatic channels such as natural streams and rivers. However, non-prismatic channels require additional parameters to compute flow that are not discussed in this manual.

## Introduction and Background of Indus Telemetry

Pakistan's water management challenges are deeply intertwined with the complexity and scale of the Indus Basin Irrigation System (IBIS), one of the largest contiguous irrigation systems globally. Amid growing water scarcity, climate variability, and increasing competition among sectors, the demand for transparent, real-time, and reliable water data has become critical. Telemetry systems, which enable automated and remote monitoring of water flows and levels, offer a transformative solution to these challenges.

The IBIS irrigates over 17 million hectares of agricultural land and sustains millions of livelihoods. However, disputes over water distribution, often between provinces and even districts, are common due to the absence of transparent and verifiable data. A telemetry system can provide real-time, tamper-proof data on canal inflows, fostering trust among stakeholders and enhancing transparency in water allocation. By enabling timely adjustments and enforcement of allocations, telemetry systems can promote equitable distribution and improve operational efficiency.

Manual data collection is labor-intensive, prone to errors, and often delayed. In contrast, telemetry facilitates remote monitoring, reduces human error and operational costs, and supports proactive water resources management, especially during droughts and floods. Reliable data is essential for water accounting, planning, and policy formulation. Telemetry systems can feed into decision support systems (DSS), enabling evidence-based governance and long-term sustainability of water resources.

Despite its advantages, implementing telemetry systems presents several challenges. Infrastructure limitations, such as unreliable internet connectivity and security concerns in remote canal areas pose significant barriers. Integrating telemetry data with existing water management platforms and DSS is complicated by inconsistent data formats and a lack of standardization. These issues were particularly evident during the transfer of the Indus Telemetry system to a partner government department in 2025.

In addition to challenges related to physical set up and data processing, there are institutional challenges as well. Lack of ownership and accountability is perhaps the most important one. In Pakistan, past telemetry projects failed partly due to unclear institutional responsibilities. Agencies often lacked the capacity or mandate to maintain and validate the systems. Another aspect is resistance to transparency as real-time data can expose inequities and mismanagement, leading to resistance from stakeholders who benefit from the status quo. This undermines system adoption and sustainability.

Irrigation departments often lack trained personnel to operate, maintain, and interpret telemetry systems. Capacity building is essential but underfunded. This exposes another layer of complexity which is around financial constraints. Telemetry system requires significant upfront investment in hardware, software, and training. Budget constraints in provincial irrigation departments limit scalability. In the case of Indus Telemetry, the initial set up cost and scaling cost is born international development partners. The challenge of software cost is addressed by using open-source database platform (PostgreSQL) and hosting it at government-maintained servers.

It is widely acknowledged that Pakistan needs to improve the mechanism by which it accounts for water distribution of the Indus River and its tributaries. Water management literature in Pakistan often speaks to this effect and seminal reports alluded to the need of a telemetry system e.g. Briscoe and Qamar (2006) stated "...no higher priority for water management in Pakistan than to move aggressively in putting in place a totally transparent, impartial system for implementation of the Accord". The obligatory necessity for improved data and information (quality, quantity, and timeliness) was reiterated in Pakistan's National Water Policy's (2018) with a very ambitious timeline. "Real-time monitoring of river flows by IRSA is to be ensured through inter alia telemetric monitoring to maintain transparent water accounting system and to check the increasing trend of unaccounted-for water in the Indus System of Rivers. This task should be completed before the end of 2021".

While there have been some attempts to establish a national telemetry system in 2004, but it did not yield its intended dividends. The provincial irrigation departments have also invested in automatic flow monitoring, but the technical, capacity and financial challenges explained above diminish the success and utility of the outputs in management. In this backdrop, IWMI took on the task to showcase a technically feasible and economically viable prototype of telemetry system that IRSA can scale up to the entire IBIS. The journey of Indus Telemetry has been reported in detail in a separate technical report.

Briefly, Indus Telemetry started in 2017 and went through different phases and finally completed in 2025 with a formal handing over of the technology to the Government of Khyber Pakhtunkhwa Irrigation Department (GoKP-ID). The Indus Telemetry comprises of instruments (sensor and equipment, and electronics), software, programming codes, algorithms, applications, data and information, and in-field civil work, hardware fixtures, ancillary and security enclosures. Indus Telemetry is operational, and flow is automatically monitored at 11 main canals in Khyber Pakhtunkhwa province of Pakistan. Seven automatic weather stations are also part of Indus Telemetry installed across the four provinces of Pakistan. The locations of Indus Telemetry canal flow monitoring stations and salient features of the canals are provided in Table 1. These canals have variable size and capacity and irrigate 824,026 acres (333,471 ha) of agriculture land in Khyber Pakhtunkhwa province.

**Table 1.** Canal locations considered for Indus Telemetry in Khyber Pakhtunkhwa

Legend	Canal Name	Latitude	Longitude	Canal Name	Reduced	Design	CCA	GCA
Indus	Long Form			Short Form	Distance	Capacity	(ac)	(ac)
Telemetry					(ft)	(cfs)		
Canals								
1	Upper Swat Canal-Benton Tunnel	34.5975	71.93401	USC	19,500	1,780	319,000	425,000
	Upper Swat Canal-Auxiliary Tunnel			USC	19,500	1,800		
2	Lower Swat Canal	34.33209	71.57191	LSC	1,080	1,940	134,500	147,950
3	Pehur High Level Canal	34.06741	72.65235	PHLC	295	1,000	2,934	3,420
4	Pehur Main Canal	34.10407	72.63913	PMC	3,800	250	43,409	47,785
5	Warsak Gravity Canal	34.07214	71.3904	WGC	20,200	550	37,328	47,201
6	Warsak Lift Feeder Canal	34.06696	71.38766	WLFC	2,420	200	32,584	45,836
7	Kabul River Canal	34.1675	71.4056	KRC	1,200	450	24,338	28,188
8	Lower Siran Canal	34.4741	73.2688	LSiC	50	48	6,770	8,148
9	Tanda Irrigation Main Canal	33.5682	71.395	TIMC	2,900	215	30,370	37,500
10	Gomal Zam Main Canal	32.15163	70.08199	GZMC	580	848	191,100	271,000
11	Khanpur Dam Left Bank Canal	33.76490	72.86846	KDLBC	26,500	150	1,693	2,451

## Setting Up a Telemetry Station for Canal Flow Monitoring

### Open Channel Flow

Open channels are the structures (waterway, canal or conduit) in which water flows with a free surface (at standard atmospheric pressure). A vivid example of open channel flow is an irrigation canal in which water flows due to gravity. Flow monitoring is an important task for the organizations that manage rivers and canals. Monitoring flow at critical junctures allows water managers to understand resource availability and usage patterns throughout the year. It is imperative that they react in a timely manner to conditions such as flooding or low flow and make decisions to operate canals where control structures are available.

The canal flow is essentially volume passing through a particular location per unit of time. To calculate flow at a given instance, the cross-sectional area of flow and velocity must be measured. In manual practice, flow depth (as a proxy measure of area because cross-sectional width is fixed) is read using staff gauges which is then used in empirical/hydraulic equations known as rating functions. There are high chances of inaccuracies in this manual system of monitoring flows due to human errors at data acquisition, processing, archiving and dissemination stages. It leads to inaccurate provincial water accounts and gives rise to mistrust amongst stakeholders.

The following sub-sections explain common steps to set up Indus Telemetry for canal flow monitoring using automatic sensors and instruments:




### Step 1. Reconnaissance and Site Selection

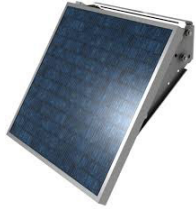



The first step towards automated data acquisition is to collect relevant information about the site where monitoring instruments are to be installed. Such reconnaissance visits to the potential site are indispensable for data acquisition. Selection of suitable locations and suitable instruments also depends on the information gathered during the visits.

## Step 2. Selection of Instruments

After selecting the locations along the designated canals, the next step is to choose appropriate instruments and sensors. Indus Telemetry relied on rugged and commercial grade instruments to avoid high transactions involved in visiting remote canal locations for troubleshooting. It is often argued that locally manufactured sensors and instruments should be installed rather than costly imported sensors. Local technology may be adopted, but its best use is for research and development. The transaction cost can quickly exceed the capital cost if research grade instruments are installed. Indus Telemetry addresses a sensitive technical issue of interprovincial water sharing, where a wrong choice of instrument can result in mistrust in technology and reputational damage. The cost of instruments was therefore not given priority criteria in the selection process for instruments. Table 2 provides a brief description of instruments installed at Indus Telemetry canal flow monitoring locations. The web links in Table 2 provide detailed specifications of these instruments.

**Table 2.** List of components used in Indus Telemetry for canal flow monitoring

Name of component	Purpose	Manufacturer	Specification details	
Ultrasonic Level Sensor	Measures range from instrument to water surface	Automation Product Group (APG), Inc.	<a href="https://www.apgsensors.com/sites/default/files/datasheets/IRU-6429.pdf">https://www.apgsensors.com/sites/default/files/datasheets/IRU-6429.pdf</a>	
Surface Velocity Sensor	Measures Surface Velocity	Geolux RSS-2-300W Surface Velocity Radar	<a href="https://www.geolux-radars.com/rss2300w">https://www.geolux-radars.com/rss2300w</a>	
Datalogger	Configure, control sensors and peripherals and logs data	Campbell Scientific Inc.	<a href="https://www.campbellsci.com/cr800">https://www.campbellsci.com/cr800</a>	
Communication Peripheral/Modem	Data communication	Campbell Scientific Inc.	<a href="https://www.campbellsci.com/cell215">https://www.campbellsci.com/cell215</a>	
Surge Suppressor Kit	Help protect communication device from electrical transients conducted through the antenna cable.	Campbell Scientific Inc.	<a href="https://www.campbellsci.com/31317">https://www.campbellsci.com/31317</a>	
Charge Regulator	To regulate solar voltage	Campbell Scientific Inc.	<a href="https://www.campbellsci.com/ch100">https://www.campbellsci.com/ch100</a>	

Solar Panel (10W)	Solar power supply	Campbell Scientific Inc.	<a href="https://www.campbellsci.com/sp10">https://www.campbellsci.com/sp10</a>	
Omni Cellular Antenna	To enhance GSM network signal	Campbell Scientific Inc.	<a href="https://www.campbellsci.com/31317">https://www.campbellsci.com/31317</a>	
Weather Enclosure	To house datalogger and peripherals	Campbell Scientific Inc.	<a href="https://www.campbellsci.com/standard-enclosures">https://www.campbellsci.com/standard-enclosures</a>	
Backup Battery/ Cables and Accessories	To supply power in the absence of solar power			

An ultrasonic level sensor is the main sensor attached to the datalogger, which senses the variation in water levels from the known elevation where it is mounted, and measures the distance (range) from the mounted location to the water surface electronically. Using additional parameters (parameters not measured by the sensor), the depth of flow in the channel can then be estimated during the post-processing phase. An ultrasonic sensor has the advantage that it is a non-contact sensor (does not touch the water) and therefore is less prone to fouling from debris and/or sediments in the water. It has no moving parts and requires very modest power – an important criterion given the entire instrument is powered by a modest 20-50 W solar panel and a rechargeable battery.

Surface Velocity Sensors measure the velocity of surface layer of the flowing water. Geolux RSS-2-300W radar sensor works on the Doppler shift principle. It transmits radar waves, and the frequency shift of the waves reflected from the moving water surface allows it to determine the flow velocity. The surface velocity is the average velocity measured over the footprint of the radar beam. Flow calculations using continuity equation involve area and mean velocity of the open channels cross-section. Costa et al., (2006) time-consuming, and frequently dangerous. This report evaluates the use of a continuous wave microwave radar, a monostatic UHF Doppler radar, a pulsed Doppler microwave radar, and a ground-penetrating radar to measure river flows continuously over long periods and without touching the water with any instruments. The experiments duplicate the flow records from conventional stream gauging stations on the San Joaquin River in California and the Cowlitz River in Washington. The purpose of the experiments was to directly measure the parameters necessary to compute flow: surface velocity (converted to mean velocity) and cross-sectional area, thereby avoiding the uncertainty, complexity, and cost of maintaining rating curves. They used hydroacoustic instruments (i.e. Acoustic Doppler Current Profiler [ADCP]) to convert surface velocity to mean velocity based on detailed velocity profiles measured by ADCP. Indus Telemetry also used similar approaches to convert surface velocity to mean velocity rather than relying on the typical theoretical relationships available in literature or those suggested by the sensor manufacturer.

A typical datalogger can be connected to a wide variety of sensors simultaneously. Hence at any one site, it is technically possible to include additional sensors to measure, for example, turbidity of the water, temperature of water, salinity of water, etc. as required. Most sensors require very little power, but power becomes an important criterion if instruments are to be powered with solar panel only.

### Step 3. Site Preparation

Site preparation is a detailed process. Once the correct set of instruments are identified and procured, an instrument layout plan is prepared for the specific site, and depending upon the site conditions, ancillary work is required to prepare it for installation of instruments. The factors considered in planning are safety, ease of access to the working area for installation and future maintenance, and hardware footprint. Typical ancillary work includes:

- Poles and cross arm
- Space frame/ trusses
- Mounting plates and cantilever
- Security fence/ box; and
- Civil work

The existing manual gauges (staff gauges) for water level measurement at most of the canals were of poor quality. Generally, these gauges are made of mild steel and marked with ordinary paint. These manual gauges are typically installed on side walls of canals and remain immersed in water. Due to this reason, the manual gauges rust very quickly, and the graduations and numbering become illegible. Faced with this, the gauge readers (field staff of Irrigation Departments) are compelled to take readings based on judgment and hence the accuracy of flow data is compromised. Indus Telemetry overcome this problem by fabricating rust-free stainless-steel gauges. These gauges were laser-cut so that the graduations and digit markings do not degrade with time.

#### Box 1. Physical Security of Instruments/Assets

It is well known among field scientists that leaving equipment in remote areas makes it vulnerable to petty vandalism and theft. Interference of animals such as water buffaloes may also cause damage to delicate instruments and resultant loss of invaluable data. On top of that, it also costs a lot of effort, time and resources to arrange the damaged or lost part to be procured and replaced back.

Primarily, the Indus Telemetry locations are where there is important/critical infrastructure and so these sites persist under surveillance. Chances of vandalism remain high at greenfield sites where surveillance is not possible. More often, theft or damage involves petty items perceived as attractive and valuable, such as solar panels and battery packs. Although these items are of low power capacity which can hardly power light instruments, they have to stay outside the secure enclosures making them more vulnerable to theft and damage. The following are some guidelines which can reduce the risk of damage and vandalism: Installing poles of reasonable height with solar panels mounted at the top. The height should not be too great to allow for easy cleaning.

- Using anti-climb spikes on the poles where possible.
- Locking down the instrument enclosures.
- Placing a friendly warning at the enclosure.
- Sensitizing community and employees of the local institutions about the benefits of the data and seeking their support in protecting the instruments.
- Using mesh wiring fence and razor wires in heavily trafficked installation sites.
- Insuring the instruments/assets particularly for long term deployment.

The choice of material and size of poles, cross-arm, cantilever and spaceframes etc. depended on site conditions and layout plans for the instruments. In some cases, instruments were secured by using fences, enclosure boxes and razor wire. Physical security of the instruments was a matter of concern for the irrigation departments due to the high cost of instruments. Moreover, they were wary of being blamed for incidents of deliberate vandalism or accidental damage. Box 1 summarizes some important points considered to secure the instruments deployed at remote canal locations. In most cases, site preparation required a little civil work, mostly limited to constructing concrete plinths and foundations for the poles/frames to mount sensors, cabling, and other equipment.

A photograph of Indus Telemetry installation at Pehur High Level Canal is shown in Figure 1. The sensors are installed on a truss frame at the middle. The ultrasonic sensor looks downwards while the velocity sensor looks upstream side and is fixed at 45° angle from the horizontal plane. Hinges are provided on one side of the truss frame while on the other side a locking is provided. The instrument enclosures and solar panels are mounted on a pole installed slightly away from the bank. This design enables easy access to the sensors if servicing or troubleshooting is required. A truss structure is suitable to install sensors at canal cross-section with small width where reasonable service road is available at both banks.



**Figure 1.** Indus Telemetry installation at Pehur High Level Canal. (photo: Muhammad Tousif Bhatti/IWMI)

For wide canals, a pole with cantilever is a better option to install sensors and instruments. Figure 2 shows a photograph of Indus Telemetry at Warsak Gravity Canal. The sensors are mounted on the cantilever. The instrument box and solar panels are mounted on the pole that is secured by a brick-walled structure.

There is no standard layout that fits for every canal location. The layout design heavily depends on the ground conditions and factors such as cross-section type, space availability, security material, etc.



**Figure 2.** Indus Telemetry installation at Warsak Gravity Canal. (photo: Kashif Hussain/IWMI)

## Step 4. Instrument Programming and Calibration

### *Programming datalogger*

Dataloggers are suitable devices for deployment in rugged environments for reliable data acquisition. Selection of the appropriate datalogger depends mainly on the type, memory capacity, accuracy level, expansion capability, data sampling rate, operating temperature range, etc. Dataloggers also provide non-volatile data storage, on-board battery-backed clock, initiation of measurement and control functions based on time or event and data processing capabilities. A variety of sensors and external devices can be connected to and controlled by a datalogger such as pumps, motors, alarms, freezers, valves, etc. They require PC-supported software or keyboard/display for programming and operation, and function independently of AC power, computers, and human interaction. The dataloggers consume minimal power from a 12 V source, which typically require rechargeable batteries. They can interface with on-site and telecommunication devices such as telephone modems (including cellular and voice-synthesized), short-haul modems, radio transceivers, satellite transmitters, and Ethernet interfaces, and can operate in temperature range of  $-25^{\circ}$  to  $50^{\circ}\text{C}$ .

The Campbell Scientific dataloggers used in Indus Telemetry installations are programmed using CRBasic, a proprietary programming language developed by Campbell Scientific Inc., USA. Prior to deployment, each datalogger must be programmed to enable measurement acquisition, data storage, and hardware control. LoggerNet software facilitates communication between the datalogger and a computer for programming and data retrieval. Instructional resources, including videos and documentation, are available on the [Campbell Scientific website](#).

### *Configuring ultrasonic level sensors*

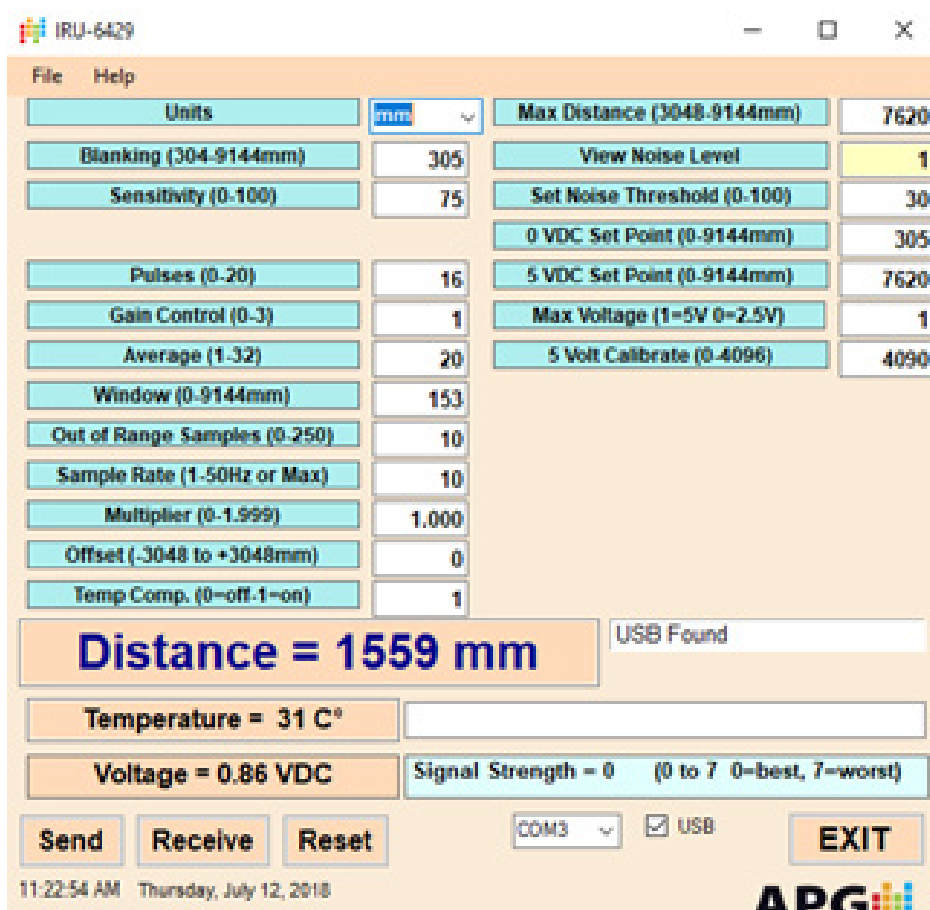
The term ultrasonic refers to sound waves with frequencies above the upper limit of human hearing (typically greater than 20 kHz). Ultrasonic level sensors operate by emitting the high-frequency sound waves that reflect off the target

surface and return to the transmitter, which also serve as receptor. The time delay between the emission of the wave and reception of its echo from target surface is used to determine the distance using its relationship with the time and sound speed. The sensor's microprocessor generates a voltage proportional to this distance.

As the speed of sound varies with temperature, these sensors include integrated thermometers for real-time compensation, maintaining high accuracy, up to 0.25% of the detected range.

The ultrasonic sensors are compact, require low-maintenance, and are easy to install and suitable for both indoor and outdoor environments, with measurement ranges from 100 mm (4 inches) to 8 m (30 feet). They require an unobstructed air column between them and the target. Therefore, physical obstructions, excessive foam, dense vapors, or thick particles may produce errors. To mitigate this, embedded microprocessors allow user-defined filters to identify and discard anomalous readings or outliers.

At Indus Telemetry, these sensors are used to measure the water surface level. These sensors can be configured by using proprietary hardware and software provided by the manufacturer-(see Figure 3), supporting advanced control functions and reliable performance across varied weather conditions. The configuration procedure as explained by the manufacturer is as follows.



**Figure 3.** Automation Product Group (APG) software and calibration in lab.

There are three main settings to adjust:

- Pulse strength and sensitivity
- Filtering and response time
- Output and trip points

### Pulse Strength and sensitivity

Pulse strength fine-tunes the intensity of sound wave bursts for optimal detection based on the application, while the sensitivity setting determines how attentively the sensor listens for returning echoes. The higher is strength of emitted signals, proportionately so is that of returned echoes. However, for longevity of the sensor, pulse strength of emitted waves should be set only as high as needed to obtain a reliable return signal echo. If high pulse strength is required to consistently achieve a valid return signal, it often indicates the sensor is underpowered for the application. Similarly, sensitivity settings govern how the sensor receives and interprets returning echoes. If set too high, the sensor may detect dubious signals, leading to false readings. Continuously requiring high sensitivity often indicates insufficient pulse strength, a target surface that absorbs or diffuses the signal, or use of a sensor with an inadequate measurement range. Ultrasonic level sensors are available in multiple operating ranges and configurations. Table 3 lists several APG models used for monitoring water levels. Mid-range sensors (IRU-2420) and long-range sensors (IRU-3430) have been deployed in the Indus Telemetry system across various canal sites according to site-specific needs.

**Table 3.** Ultrasonic level sensors.

Sensor Type (APG)	Operating Range	Response time	Accuracy	Supply Voltage (V)	Output (mA)	Operating Temp. (C)	Temp. Compensation	Data Logging
Mid-Range Ultrasonic Level Sensor IRU-2420	1-25 ft	Up to 50 Hz, or once every 20 ms	± 0.25%	12-28	4-20	-40-60	internal	No
Long-Range Ultrasonic Level Sensor IRU-3430	1.5 to 50 ft	Up to 50 Hz, or once every 20 ms	± 0.25%	12-28	4-20	-40-60	internal	No
Short-Range Ultrasonic Level Sensor IRU-5000	4-79 inch	Up to 50 Hz, or once every 20 ms	± 0.25%	12-28	4-20	-40-60	internal	No
Mid-Range Ultrasonic Level Sensor with Data Logging IRU-6429	1-30 ft	Up to 50 Hz, or once every 20 ms	± 0.25%	12-28	4-20	-40-60	internal	Yes
High Sensitivity Ultrasonic Level Sensor IRU-9400	0.5-35 ft	Up to 50 Hz, or once every 20 ms	± 0.25%	12-28	4-20	-40-60	internal	No

### Filtering and response time

Filtering out unwanted echoes with an ultrasonic level sensor requires setting maximum and minimum detection distances, the averaging of readings, and the response speed to changing levels. Setting maximum and minimum detection distance causes the sensor to ignore any echoes beyond the set range. The minimum detection distance is controlled by the blanking distance, which is the short undetectable distance adjacent to the sensor face. The maximum distance setting helps to ignore static or mobile objects beyond the intended measurement zone, to avoid false reflections and improve measurement reliability.

Averaging readings is a way to smoothen out rapid level changes owing to turbulence and ripples. The averaging feature is very useful, unless the target is very slow moving, or perfectly still. For any turbulence or uneven movement on the surface, and averaging becomes very valuable. This setting tells the sensor how many samples (singular readings) to include in the calculation of the average observation. The larger the sample size, the greater the smoothing effect.

Controlling the response speed to changing levels is helpful for filtering out noise. This setting is called a window, or a set distance selected in front of and behind the current distance reading. This is a moving window that follows the current accepted reading. Along with the window, a user sets the number of samples the sensor needs to detect out of the window before it validates a new level, essentially forcing the sensor to double check the changes in the level before it reports an output.

Both averaging and the windows settings can speed up and slow down response time. If the application is for a fast-moving target, then these parameters must be adjusted judiciously. Lower averaging and a looser window are required to keep up with rapid changes.

### Calibrating ultrasonic level sensor

The ultrasonic sensors come as factory calibrated and are provided with user's manual to wire them with datalogger and control through programming. However, calibration validation is considered appropriate before deployment. Following is a process that explains the calibration method designed for ultrasonic sensors prior to deployment to the field.

Once the parameters settings are complete as explained before, the programmed sensor will report a voltage. To convert voltage into distance, the function between voltage and distance needs to be developed. This is typically a linear equation, and the parameters (intercept and slope) can be estimated using ordinary least squares regression.

The first step of calibration validation is to test the stability of the sensor. For this purpose, the sensor is programmed and continuously switched on (taking readings every second) facing it against a wall as a fixed target. The voltage by logging datalogger is recorded for several hours without changing the position of the sensor and the target. The Coefficient of Variation (CV) of the collected data is then estimated, and the voltage stability is accepted if the CV falls within the user defined threshold, which we selected as 1%.

The next step is to establish an empirical relationship between sensor voltage and the distance. For this, the sensor is mounted on a movable stand and targeted towards a fixed surface (herein called a setting), with the actual distance between the sensor face and the target surface measured with a digital range finder. At least five (averaged over 2 minutes) readings are taken at each setting. This process is repeated for 20 random settings. The mean voltage at all 20 settings is then again randomized from which 10 data points are used to develop (calibrate) empirical relationship between the voltage and the measured distance.

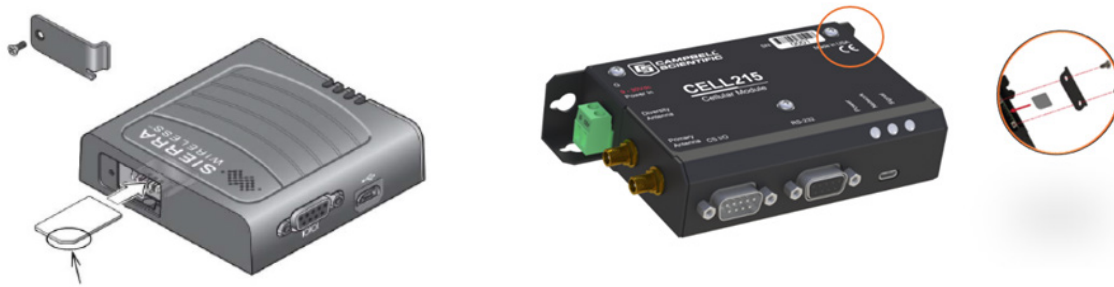
The so developed empirical relationship is then validated using the remaining 10 readings against a Mean Absolute Percent Error (MAPE) of less than 1%. Table 4 provides indicators and their acceptable range for sensor calibration and validation.

**Table 4.** Calibration and validation of ultrasonic sensors.

Test	Indicator	Formula	Acceptance Limit
Voltage Stability	Coefficient of Variance (CV)	$CV (\%) = 100 \times \frac{SD}{Mean}$	CV < 1%
Calibration Validation	Voltage-distance relationship Mean Absolute Percent Error (%)	$MAPE = \frac{\sum_{t=1}^n \left  \frac{M_t - E_t}{E_t} \right }{n}$ <p>Where <math>M_t</math> is measured data at time t and <math>E_t</math> is estimated data</p>	MAPE < 1%

### *Programming communication device (cellular modems)*

Cellular modems manufactured by Sierra Wireless were deployed during the proof-of-concept phase. These cellular modems were retired by the manufacturer and replaced with Campbell Scientific CELL215 during the uptake and upscaling phase. The new modems were connected to an external antenna through a surge suppressor kit and powered from the datalogger via serial port (RS-232). In order to configure the modem, an activated SIM card is required which is inserted in the modem as shown in Figure 4. In the case of CELL215, no configuration is needed, it connects instantly to the mobile network once the SIM is inserted. In case of any issue, a diagnostic is required following the procedure explained at: <https://www.campbellsci.com/blog/easily-diagnose-cell2xx-connection-issues> .



Sierra Wireless LS300 Cellular Modem

Campbell Scientific CELL 215 Cellular Module

**Figure 4.** Modem showing the SIM slot

### *Instrument commissioning*

After programming and calibration, all the instruments are deployed on site. Once all the instruments are installed and duly commissioned on site, data acquisition and transmission to the server starts for post-processing.

### *Data quality attributes*

The data quality attributes are the characteristics and metrics to analyze accuracy and timeliness of data.

### *Data sampling period*

Data sampling period is defined as the time period between samples (measurements). Typically, the data sampling period is small, i.e. samples can be taken at high frequency, but the data sampling period may depend on the “warm-up” time of instruments, as some devices do require a voltage to be applied for a short duration first to allow the circuits to reach normal operating temperatures. For Indus Telemetry, the ultrasonic sensors remain powered up continuously, and the data sampling period is 60 seconds. On the other hand, the surface velocity sensor is not powered continuously rather it is switched on every 15 min and takes a measurement after a delay of 5 second after powering up and then switch off. This arrangement is used to conserve power. The dataloggers come with switch channels where surface velocity sensor can be attached. Otherwise, solid state relays can be used to perform this switching operation.

### *Data-logging period*

The data-logging period is the time interval at which the data is logged (recorded) in the datalogger. Pertinent to note is that the date-time stamp refers to the time the data is logged rather than when it was sampled. Therefore, the data must be interpreted accordingly. Dataloggers store the sampled data after applying aggregation (i.e. average/sum/count etc.). For Indus Telemetry, the data-logging period is set at 15 minutes, meaning that each “logged” observation is the average of 15 sampled measurements.

### Data transmission period

Data transmission period defines the time-period after the logged-data is transmitted using installed system components, and this is typically multiples (including one) of the data-logging period. During the proof-of-concept phase, various data logging periods and transmission periods were tested to find out the optimal combination that consumes minimum power, because the data acquisition and transmission are highly power consuming. Most of the dataloggers have been programmed for data transmission thrice a day at 07.45, 11.45 and 15.45, Pakistan Standard Time (PST). This means all transmissions are scheduled during daylight hours in order to avoid battery voltage dropping below threshold value (i.e. 11V). Further, if the battery voltage falls below critical value (i.e. 9V,) the sensor stops recording data. Although it is tempting to increase data transmission frequently, that is the most power consuming process of an automated data acquisition system. This issue is mitigated using daylight hours when the solar panels are in power generating mode. However, excessively frequent data transmission can drain the battery and lead to system shutdown at night-time or during short overcast winter days. At a few canal locations where ample sunlight is available most of the day, hourly transmission between 0700 and 1600 is also programmed.

### Data transmission and latency

Through Indus Telemetry, the range to the water surface is sampled (measured) every 60 seconds. The data-logging period is set to 15 minutes, and the average is used as the aggregate function. Hence, the datalogger records the average water surface level above a datum (e.g. channel/stilling well bottom, weir crest of known elevation above mean sea level) for the 15 minutes preceding the date-time stamp.

As mentioned before, data transmission is set to thrice daily (07.45, 11.45 and 13.45 PST) for power conservation to sustain functioning overnight and short overcast winter days.

The sampling period is set through appropriate programming of the datalogger which works with the sensor – in this case 60 seconds. Sampled data points are only stored temporarily in a datalogger until an aggregate function is applied to the sampled data. In a data acquisition contract, it would be difficult to specify or validate/verify sampled data. However, when the aggregate function is applied to the data, a count of the sample size that is aggregated can be recorded. The theoretical sample size is given by:

$$N_s = \frac{T_D}{T_S} \dots \dots (Equation C - 1)$$

where  $N_s$  = theoretical sample size aggregated at the data logging period;  $T_D$ = data logging period;  $T_S$  = data sampling period. Therefore, Equation C-1 provides the maximum or upper bound of the sample size (15 in case of parameters we have used) that is aggregated and averaged. Actual sample size may be less than this due to hardware/software failures or other limitations.

Latency is defined as the time that elapses between when a sample is taken and when that data and derived information from post-processing is accessible to a user. Hence in this work, latency is the time that elapses from when the aggregate function is applied to when the data and derived information become accessible to a user. Latency is a function of the data logging period, data transmission period and the data post processing delay, and is given by:

$$\mathcal{L} = \frac{\sum_{i=1}^{\frac{T_T}{T_D}-1} (\Delta + iT_D)}{\left(\frac{T_T}{T_D}\right)} \dots \dots (Equation C - 2)$$

where  $\mathcal{L}$  = latency;  $T_D$  = data logging period;  $T_T$  = data transmission period;  $i$  = index 0,1,2...; and  $\Delta$  = data processing delay. The data transmission period is expressed as any multiple (including one) of the data logging period. The expression in Equation C - 2 determines the lower bound of latency. Observed latency will be equal to or higher than this lower bound if there are hardware or software failures.

## Step 5. Collecting External Parameters and Indus Telemetry Dashboard

### External parameters

In the case of Indus Telemetry, the data logged and reported is the range from the instrument to the water surface, which is post-processed to determine discharge. The post-processing requires elevation data for both the instrument and the canal bed.

The practice in the IBIS is to assume the canals as wide rectangular channels having uniform flow. The goal of developing a rating equation is to fit a mathematical function to the observed data (particularly over the range of flow within which the equation will be used). Indus Telemetry gives the flexibility to the user to choose from a number of rating functions listed in Figure 5. The list also includes the continuity equation (highlighted), wherein sensor measurements are directly incorporated for discharge computation. In this equation, the first part ‘Cross-sectional Area’, is the function of Depth, while the second part ‘Mean Velocity’ is a function of Surface Velocity, both of which are measured by automatic sensors. The discharge calculations also require some additional inputs called external parameters.

The external parameters in Indus Telemetry are those that are not measured by sensors and logged. These parameters are required to process data and calculate discharge by using parameters included in the datafile. The most important external parameters for discharge calculations are the average bed elevation of the canal cross section, elevation of ultrasonic sensor, coefficients used in the functions of depth-area and surface to mean velocity relationships.

The screenshot displays the 'Canal X-Section Parameters' section of the Indus Telemetry Dashboard. It includes a list of parameters and a dropdown menu for selecting a rating equation. The dropdown menu is open, showing several options with their respective coefficients and formulas. The 'Discharge = f(Depth)\*f(Surface vel.): Quadratic \*linear' option is highlighted. Below the dropdown, there are input fields for 'manning roughness n', 'Lacey silt factor f', and 'Polynomial coeff. B0', 'B1', 'B2', and 'B3'. An 'Evaluate Rating Equation' button is visible at the bottom of the parameter list.

Eqn.	Coefficients	Formula
Discharge = f(Depth): Cubic	B0, B1, B2, B3	$B0 + B1 * D + B2 * D^2 + B3 * D^3$
Discharge = f(Depth): Empirical power law	A, C	$A * D^C$
Discharge = f(Depth)*f(Surface vel.): Quadratic *linear	B0, B1, B2, A, C	$(B0 + B1 * D + B2 * D^2) * (A + C * V)$
Discharge = f(Depth): Quadratic	B0, B1, B2	$B0 + B1 * D + B2 * D^2$
Discharge = f(Depth): Weir or flume equation	B, K, C	$B * K * D^C$
Discharge = f(Depth): Wide rectangular channel	K	$K * D^{5/3}$

Polynomial coeff. B0: 0.000  
 Polynomial coeff. B1: 46.750  
 Polynomial coeff. B2: -0.638  
 Polynomial coeff. B3:

Figure 5. Screenshot of Indus Telemetry Dashboard menu for external parameters.

### Data post-processing

Once the data file is received by the server, parameters such as water depth, water surface elevation, discharge, delivery performance ratio, etc. are computed. However, to avoid what is known in computing parlance as a “race condition” whereby data is being transmitted and processed at the same time (a race between two processes which may lead to instability), a deliberate post-processing delay is introduced to allow the data to be transmitted first and then for the data to be post-processed. Therefore, data is transmitted 15 minutes before the hour (07.45, 11.45, 15.45 PST) and post processing is initiated 10 minutes passed every hour. A SQL Server Information Services (SSIS) package runs every hour checking within a particular folder in the File Transfer Protocol (FTP) server if a data file is available. The SSIS package is replaced by CRON job after migration of Indus Telemetry database to a LINUX based server at KPDC. If data files are found, they are processed automatically.

The data file typically consists of one or more header rows and then a series of data rows as partially illustrated in Box 2. The structure and format of this data table is determined by the programming of the datalogger.

**Box 2:** A typical data file (comma separated values) received from a datalogger

```

"TOA5","Khanpur Left Bank Canal","CR1000X","43582","CR1000X.Std.06.00","CPU:KhanpurCanal_incl5Min 20230916.CR1X-
","25124","Canal"

"TIMESTAMP","RECORD","SerNum","Range1_Avg","Range2_Avg","Range3_Avg","Range4_Avg","Range5_Avg","Range6_Avg","-
SensVolt1_Avg","SensVolt2_Avg","SensVolt3_Avg","SensVolt4_Avg","SensVolt5_Avg","SensVolt6_Avg","PTemp_Avg","Batt_Volt_
Min","BackupBatt_Min","FlowDirection","FlowSpeed","FlowSpeed_Min","FlowSpeed_TMn","FlowSpeed_Max","FlowSpeed_TMx-
","FlowSpeed_Avg","Level","Level_Min","Level_TMn","Level_Max","Level_TMx","Level_Avg","TiltAngle_Avg","Q1","Q2","AvgFlow-
Speed","AvgFlowSpeed_Min","AvgFlowSpeed_TMn","AvgFlowSpeed_Max","AvgFlowSpeed_TMx","AvgFlowSpeed_Avg"

"TS","RN","Logger Serial No","mm","mm","mm","mm","mm","mm","mVolt","mVolt","mVolt","mVolt","mVolts","Degree
C","Volts","Volts","mm/s","mm/s","mm/s","mm/s","mm/s","mm/s","mm","mm","mm","mm","mm","mm","mm","Deg","mm/s","m-
m/s","mm/s","mm/s","mm/s"

","Smp","Avg","Avg","Avg","Avg","Avg","Avg","Avg","Avg","Avg","Avg","Avg","Avg","Avg","Min","Min","Smp","Smp","Min","TMn","Max",
"TMx","Avg","Smp","Min","TMn","Max","TMx","Avg","Avg","Smp","Smp","Smp","Min","TMn","Max","TMx","Avg"

"2024-11-16 01:00:00",40451,43582,2731,-187,686.4,-358.4,1490,-242.5,1669,-192.9,651.4,-361.7,1482,-
242.7,17.39,12.63,3.713,1,1005,991,"2024-11-16 00:54:00",1045,"2024-11-16 00:48:30",1000,663,350,"2024-11-16
00:49:00",785,"2024-11-16 00:54:00",616,47,0,0,1019,997,"2024-11-16 00:58:30",1057,"2024-11-16 00:48:30",1014

"2024-11-16 01:15:00",40452,43582,2731,-192.9,685,-358.6,1480,-248,1660,-199.5,648.1,-361.7,1477,-
248.6,17.35,12.63,3.716,1,1051,1005,"2024-11-16 01:00:30",1051,"2024-11-16 01:14:00",1028,333,333,"2024-11-16
01:14:00",856,"2024-11-16 01:03:30",648,47,0,0,1050,989,"2024-11-16 01:03:30",1065,"2024-11-16 01:13:30",1021

```

The script run by the CRON job undertakes a number of checks. It first uses the datalogger serial number to locate the canal and location at which this datalogger is installed. Then it uses the channel to determine the exact sensor where the record was logged. Then it adds this record to a table in the PostgreSQL database and archives the data file in a designated folder on the server. The PostgreSQL server then uses the data in the table and external parameters of the canal location to undertake a series of defined quality control checks to ensure that the estimated water surface elevation is not above or below the user specified thresholds which would indicate erroneous readings. If the water surface elevation is within the user-defined limits, the PostgreSQL server then estimates depth of flow and using the user-defined rating equation estimates discharge, delivery performance ratio and several other statistics (e.g. latency, coefficient of variation of discharge etc.). The PostgreSQL server also provides information for dissemination (described later in this report).

### Indus Telemetry dashboard

For convenience in inputting external parameters, processing data and visualization, a dashboard has been developed in Microsoft Access. The choice of MS Access was simply because many beneficiaries are already using it as a part of MS Office package and therefore did not require additional investment. Furthermore, PostgreSQL integrates with MS Access and is reasonably versatile. This user interface connects to the PostgreSQL server once valid credentials are inserted. The dashboard primarily facilitates the Telemetry Managers for viewing the received data, checking its quality and fetching the information. This dashboard can be considered as a decision support tool to make informed decisions about maintenance and troubleshooting of instruments if needed. The Indus Telemetry dashboard was integrated with the KP-Water dashboard after migration of Indus Telemetry database to the official server for KPDC. A variety of tabulated summaries and reports of flow and weather data can be generated through this dashboard as shown in Figures 6 to 8.

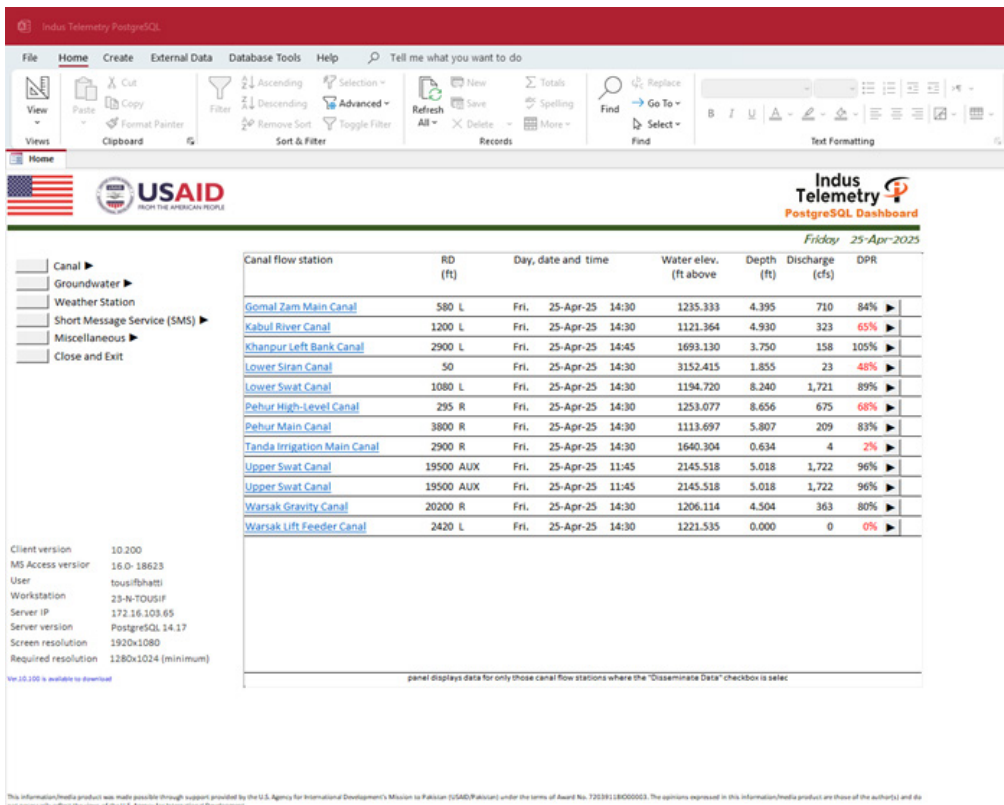


Figure 6. Indus Telemetry dashboard home screen

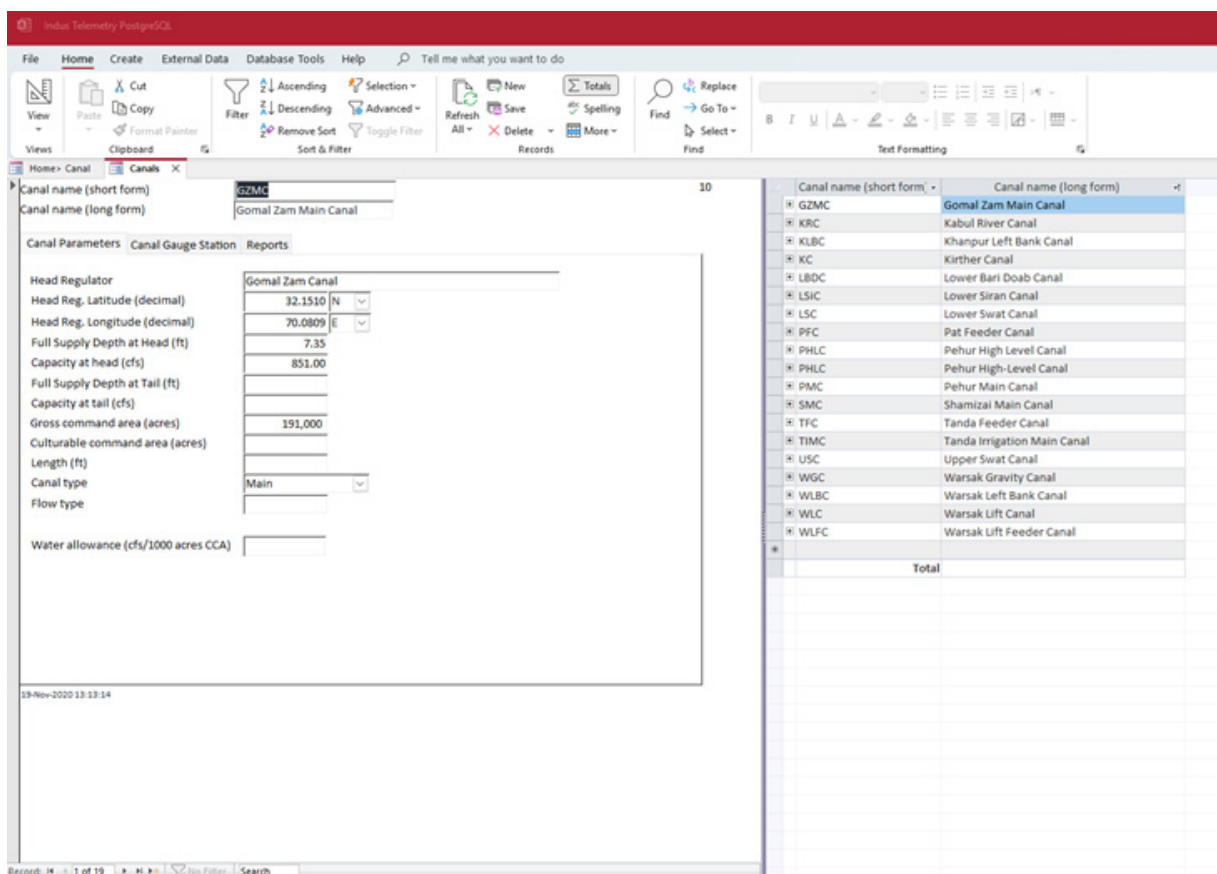


Figure 7. Canal data input form

Measured at RD. (ft)	Measurement date and day	Avg. water elev. (ft above)	Avg. depth (ft)	Avg. discharge (cfs)	Avg. DPR	CV of avg. daily discharge	Avg. susp. sed. conc.	Avg. Temp. (C)	Avg. salinity (mS/cm)	Record count	Avg. latency (hrs)
50	25-Apr-25 Fri	3152.759	2.199	29	60%	6%				30	2.70
50	24-Apr-25 Thu	3152.811	2.251	30	63%	6%				48	5.83
50	23-Apr-25 Wed	3152.690	2.130	28	58%	7%				48	5.83
50	22-Apr-25 Tue	3152.660	2.100	27	57%	4%				48	5.83
50	21-Apr-25 Mon	3152.295	1.735	21	43%	54%				48	5.83
50	20-Apr-25 Sun	3151.456	0.896	5	10%	10%				48	5.83
50	19-Apr-25 Sat	3152.065	1.505	16	33%	86%				45	6.24
50	18-Apr-25 Fri	3152.709	2.149	28	58%	6%				48	6.71
50	17-Apr-25 Thu	3152.329	1.769	20	43%	54%				48	6.71
50	16-Apr-25 Wed	3152.683	2.123	28	58%	42%				48	6.00
50	15-Apr-25 Tue	3152.862	2.302	32	67%	28%				48	6.00
50	14-Apr-25 Mon	3152.969	2.409	34	71%	12%				48	6.00
50	13-Apr-25 Sun	3152.881	2.321	32	66%	10%				48	6.00
50	12-Apr-25 Sat	3152.835	2.275	30	63%	5%				48	6.00
50	11-Apr-25 Fri	3152.798	2.238	30	62%	7%				48	6.00
50	10-Apr-25 Thu	3152.810	2.250	30	63%	7%				48	6.00
50	09-Apr-25 Wed	3152.878	2.318	32	66%	7%				48	6.00
50	08-Apr-25 Tue	3153.001	2.441	35	72%	10%				48	6.00
50	07-Apr-25 Mon	3152.931	2.371	33	69%	9%				48	6.00
50	06-Apr-25 Sun	3152.954	2.394	34	70%	18%				48	6.00
50	05-Apr-25 Sat	3152.732	2.172	29	60%	11%				48	6.00
50	04-Apr-25 Fri	3152.538	1.978	24	49%	5%				48	6.00
50	03-Apr-25 Thu	3152.607	2.047	26	54%	3%				48	6.00
50	02-Apr-25 Wed	3152.650	2.090	27	56%	7%				48	6.00
50	01-Apr-25 Tue	3152.644	2.084	27	56%	7%				48	6.00
50	31-Mar-25 Mon	3152.639	2.079	26	55%	7%				48	6.00
50	30-Mar-25 Sun	3152.537	1.977	24	50%	6%				48	6.00
50	29-Mar-25 Sat	3152.487	1.927	23	47%	7%				48	6.69
50	28-Mar-25 Fri	3151.777	1.217	10	20%	85%				48	6.67
50	27-Mar-25 Thu	3152.577	2.017	25	53%	24%				48	6.00
50	26-Mar-25 Wed	3152.657	2.097	27	56%	5%				48	6.00
50	25-Mar-25 Tue	3152.616	2.056	26	54%	4%				48	6.00

Figure 8. Daily canal flow depth, discharge, DPR and summary statistics

Indus Telemetry system also receives data from weather stations deployed at seven locations in all four provinces. Figure 9 shows the dashboard form for the weather station.

Location: Samana Top-Orakzai

Latitude (decimal): 33.5590 N

Longitude (decimal): 70.9200 E

Elevation above msl (m): 1987.35

Datalogger serial number: 22170

Deployed on: 24-Feb-24

SIM phone number: 0333-XXXXXX

SIM phone company/service provider: Ufone

Location	Latitude (de)	Longitude (c)
PCRWR-Bahawalpur	30.1470	71.4420
PCRWR-Di Khan	31.8130	70.9180
PCRWR-DLR Lahore	31.5580	74.3680
PCRWR-Multan	29.3930	71.7080
PCRWR-Quetta	30.2720	66.9390
PCRWR-SialMore Sargodha	31.9530	73.1130
PCRWR-Tandojam	25.4200	68.5280
Samana Top-Orakzai	33.5590	70.9200

Current Data		GW Observation Well Parameters		Notes
Date of record	25-Apr-2025	Battery voltage min. (V)	13.53	
Time of record	14:00	Panel temp. (deg. C)	26.62	
Avg wind speed (m/s)	1.02	Record count	7,316	
Wind direction (deg.)	348.10	Data file name	22170-730.dat	
Air temp. (deg. C)	22.410	<a href="#">View weather station daily data...</a>		
Relative humidity (%)	23.070			
Solar irradiance (kW/sq.m)	0.21			
Rainfall intensity (mm/hr)	0.00			
Barometric pressure (kPa)	102.024			
Ref. crop ET (mm/hr)	0.20			
Solar radiation (MJ/sq.m)	3.28			
Comp. GW head (m)				

Figure 9. Indus Telemetry dashboard form for weather station

### *Comparison with manually acquired data*

Comparing Indus Telemetry with manual data has very little scope due to shortcomings and unreliability of the latter and therefore is not suggested. For verification, it is highly recommended to use ADCP to take spot measurements of discharge and use it for any adjustment required in external parameters of Indus Telemetry such as change in canal bed elevation, etc.

### *Use of ADCP for validation*

Acoustic Doppler Current Profiler (ADCP) is the most reliable flow measurement instrument available so far. It works on the principle of doppler shift effect. The instrument comes with an acoustic sensor installed on a specially designed float such that it looks downward in the water. To carry out flow measurement, it is towed on the water surface (Figure 10) from one bank of stream to the other (termed as transect). Over the transect, it captures high resolution data including complete profile of the channel cross section, velocity in individual small sections (called ensembles) along the transect and in small grid cells (termed as bins) in each ensemble along with many other parameters. Statistical and graphical indicators reflected in the measurement carried out in each transect, or combination thereof, highlight whether, or not the measurement is acceptable for consideration. The ADCP measurements therefore help in validating Telemetry data. The Indus Telemetry dashboard has a form where a summary of ADCP measurement can be inserted and archived. The measurement is also helpful to:

- Observe any change in canal cross section
- Develop surface to mean velocity relationship
- Develop depth-area relationship
- Track and update any change in external parameters.



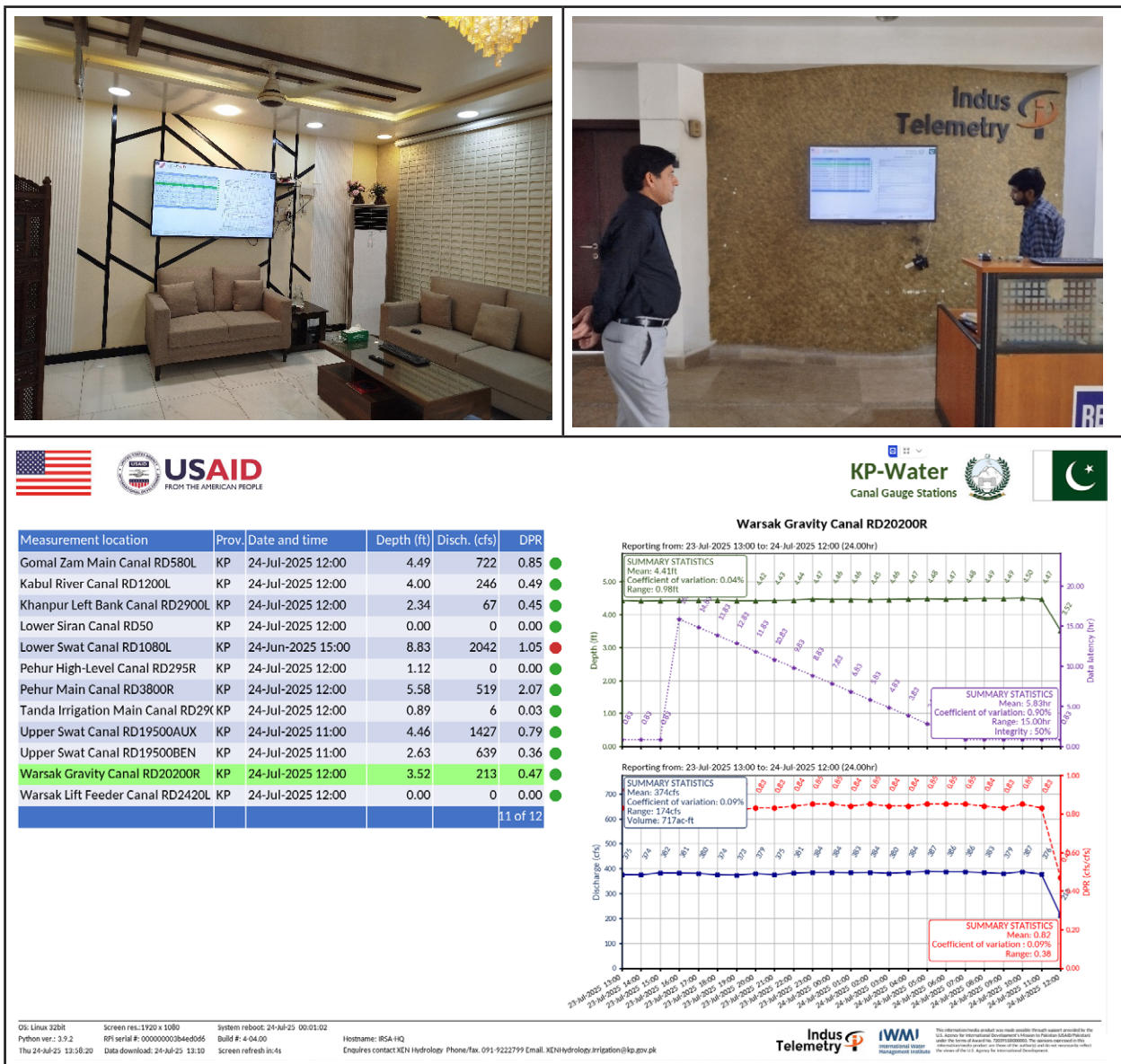
**Figure 10.** ADCP measurement at Warsak Gravity Canal. (photo: Muhammad Tousif Bhatti/IWMI)

### *Information dissemination*

The information (processed data) from Indus Telemetry is disseminated to the interested stakeholders in a variety of ways keeping in view the need of the recipient.

## Display screens

Dot Matrix (now retired) and LED display screens can show information in tabular, scrolling, or graphical form if they are configured and connected via internet to the FTP server through an external Raspberry Pi (RPI) hardware. RPI is a low cost, small size computer that comes with peripheral ports and connects with a monitor/LED TV. RPI supports several operating systems but the commonly used is Raspberry Pi OS (previously called Raspbian) that is Linux based. Once configured, RPI can run scripts at user defined schedule to automatically fetch information from the server. Indus Telemetry display screens show canal flow data in tabular and graphical formats generated by a python script running on RPI connected to them. A total of 14 data screens (3 weather and 11 canal monitoring) have been installed in key stakeholder offices. Figure 11 shows two data display screens installed in key stakeholder offices. These display screens have been very useful in showcasing the technology and get the attention of visitors to the key offices.



**Figure 11.** Indus Telemetry data display screens: Secretary GoKP-ID Office in Peshawar (top left); IRSA HQ Islamabad (top right), close up view (bottom).

### SMS alert service (now retired)

Indus Telemetry can be used to disseminate flow information directly to the cell phones of registered users through daily scheduled Short Message Service (SMS) broadcast via an SMS server (external service provider). The process of SMS Alert service includes (i) writing the information into the text body of SMS, and (ii) writing application program interface (API) routines for SMS server in Java Script Object Notation (JSON) programming language.

A SSIS package automatically writes a text message to broadcast to multiple recipients at any specified time (in our case at 0805 hours every morning). The text body contains canal names, the RD where measurements are taken, depth of flow in feet and discharge in cusec. The recipients can unsubscribe at any time by calling the number given in the SMS. Figure 12 shows the typical SMS alerts.

These SMS alerts were initiated at the request of stakeholders in the beginning of Indus Telemetry endeavor. At that time, a small number of canals were covered by Indus Telemetry. As the coverage expanded, the SMS characters limit became insufficient to send flow information of all canals. Therefore, this SMS alert service was discontinued.

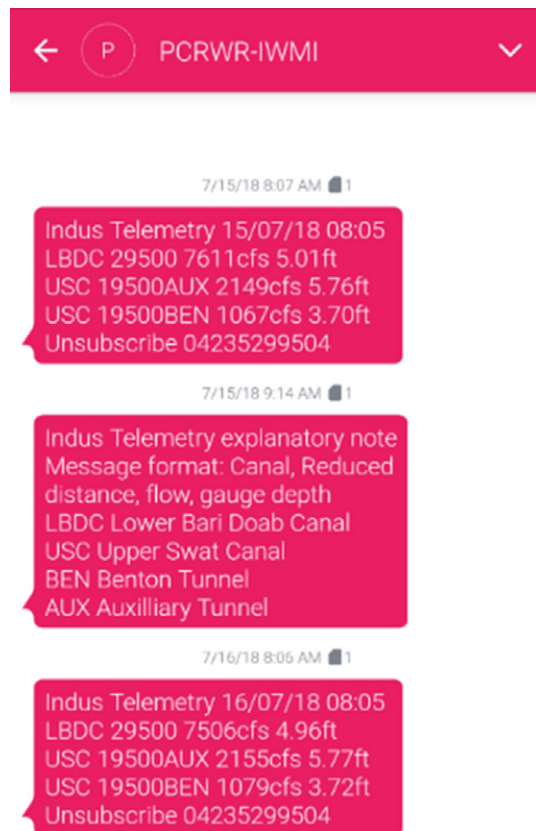




Figure 12. Typical SMS alert

## Volumetric reports

The volumetric reports available in Indus Telemetry are designed keeping in view the reporting requirements of irrigation departments to Indus River System Authority (IRSA) i.e. the accumulated volume withdrawal on a 10-daily interval. The volumetric report for each cropping season disaggregated into 10-daily volumes can be generated with click of an icon on the dashboard. Figure 13 shows a volumetric report of Kabul River Canal withdrawal during Rabi season 2024-25 (from October 1, 2024 to March 31, 2025).

**R150 10-Day Volume** **KP-Water**  

Canal name (long form) **Kabul River Canal**  
 Canal name (short form) **KRC**  
 Reporting period **Rabi 2024-25 from 10/1/2024 to 3/31/2025**

Yea	Mont	10-day period	Avg discharge	10 day volume (ac-
<b>Canal gauge station (telemetry) (RD) 1200 L</b>			<b>34.1675 N</b>	<b>71.4056 E</b>
2024	October	I	311.102	6,163
2024	October	II	299.087	5,931
2024	October	III	325.305	7,101
Sub-total volume Oct 2024				19,195 ac-f
2024	November	I	330.627	6,554
2024	November	II	311.145	6,211
2024	November	III	304.435	6,030
Sub-total volume Nov 2024				18,795 ac-f
2024	December	I	303.224	6,010
2024	December	II	304.484	6,041
2024	December	III	302.571	6,602
Sub-total volume Dec 2024				18,653 ac-f
2025	January	I	304.506	6,039
2025	January	II	97.484	2,186
2025	January	III	37.892	837
Sub-total volume Jan 2025				9,062 ac-f
2025	February	I	27.366	557
2025	February	II	56.631	878
2025	February	III	238.290	3,809
Sub-total volume Feb 2025				5,244 ac-f
2025	March	I	244.513	4,835
2025	March	II	288.031	5,649
2025	March	III	304.636	6,671
Sub-total volume Mar 2025				17,155 ac-f
<b>Total volume Rabi 2024-25 from 10/1/2024 to 3/31/2025</b>				<b>88,102 ac-f</b>

**Figure 13.** Indus Telemetry volumetric report for Lower Siran Canal withdrawals during Rabi 2023-24

## Summary and Conclusions

In the case of Indus Telemetry, setting up a telemetry station for canal monitoring followed a five-step procedure. Reconnaissance to select suitable canal locations is the first and foremost important step. This step lays a strong foundation for the subsequent steps as the information collected in this step effects data integrity, timeliness, security, instrument layout plan, ancillary and civil work requirements with cost implications. Selection of instruments is the next step in which instruments features, nature of application, manufacturer, cost, and market access define the final selection of instrument and procurement. Site preparation in the next step involves implementation of instruments lay out plan, undertaking civil work and erecting ancillary structure as required. In the subsequent step, all instruments and calibrated sensors are programmed, configured and commissioned in the field. In the last step external parameters such as elevation of instruments, canal cross-section, and ADCP measurement are collected, which are feed in the database using a custom-built dashboard. Various reports are designed and made available on dashboards that conform with the reporting requirements to the governing agencies. There can be several ways and formats of data dissemination that primarily depend on the partners' needs. Live data display screens have shown good response in case of Indus Telemetry. These display screens show flow data in tabular and graphical formats through python scripts run on Raspberry Pi devices connected to them.

Documenting and sharing the experience of implementing a technological endeavor like a telemetry system is crucial for several reasons, especially in water management and research contexts. The first reason is to preserve institutional memory so that future teams can learn from past implementations, avoiding the need to reinvent the wheel. This documentation of Indus Telemetry endeavor is formatted as a manual that will serve as a learning resource for skill development and continuous improvement. The manual takes a process approach and identifies challenges and solutions at different steps in setting up a telemetry station for canal flow monitoring. We relate the generic steps with the case of Indus Telemetry set up in Khyber Pakhtunkhwa province of Pakistan. The readers may find the technological choices used in Indus Telemetry interesting and adapt them to similar projects. This manual also documents what worked and what did not that would help refine the telemetry system. It would also enable replication in other regions where researchers can adopt or adapt the system based on documented experiences and build on our work to create new tools or methodologies.

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