



International Water
Management Institute

Indus Telemetry

Revitalizing Surface Water Accounting in Pakistan

Technical Report

Muhammad Tousif Bhatti, Muhammad Ashraf, Kashif Hussain, Muhammad Azeem Ali Shah,
Muhammad Nawaz, Muhammad Yasir, Khalid Khattak, Nasir Ghafoor Khan, Zahoor Muhammad
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Citation

Bhatti, M. T.; Ashraf, M.; Hussain, K.; Shah, M. A. A.; Nawaz, M.; Yasir, M.; Khattak, K.; Khan, N. G.; Muhammad, Z.; Malik, M. A. 2026. *Indus Telemetry: revitalizing surface water accounting in Pakistan*. Colombo, Sri Lanka: International Water Management Institute (IWMI). 6op. doi: <https://doi.org/10.5337/2025.246>

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Acknowledgements

The authors are grateful for the technical guidance and support provided by the International Water Management Institute (IWMI) office in Pakistan during the journey of Indus Telemetry. Particularly, Dr. Arif Anwar (former Head of Office and Principal Researcher - Irrigation, IWMI, Pakistan), who has been the founding contributor of the Indus Telemetry endeavor. Many colleagues from the Indus River System Authority (IRSA), and provincial irrigation departments are acknowledged for their support to Indus Telemetry.

This work was supported by the CGIAR Policy Innovations Program.

Project

This study on Indus Telemetry was conducted under the: (a) Water Management for Enhanced Productivity (WMfEP) project funded by the United States Agency for International Development (USAID); (b) Informing Change in Indus Basin project funded by the Department for International Development (DFID, now Foreign, Commonwealth & Development Office [FCDO]), UK and; (c) Fostering Trust amongst Pakistan's Water Institutions funded by FCDO, UK.

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Acronyms and Abbreviations

ac	acre
ADCP	Acoustic Doppler Current Profiler
AWS	Automatic Weather Station
BCM	billion cubic meter
CRBC	Chashma Right Bank Canal
cumec	cubic meter per second
cusec	cubic feet per second
FFC	Federal Flood Commission
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

Foreword

The International Water Management Institute (IWMI) is happy to present this report, which documents a transformative journey in Pakistan’s water governance landscape.

At IWMI, we believe that the availability of accurate and reliable data is the key to better water management. The Indus Telemetry initiative exemplifies this principle by demonstrating how modern, automated, and transparent data systems can revolutionize the way water is monitored, accounted for, and governed. What began as a research-for-development initiative has matured into a fully operational, province-wide telemetry system embedded within the institutional framework of the Khyber Pakhtunkhwa Irrigation Department.



This report is more than a technical narrative—it is a story of collaboration, innovation, and institutional trust. It reflects the collective efforts of IWMI, the Pakistan Council of Research in Water Resources (PCRWR), the Government of Khyber Pakhtunkhwa, and our development partner, the USAID. Together, we have demonstrated that, with the right partnerships, even the most complex challenges —such as interprovincial surface water accounting —can be addressed with transparency and scientific rigor.

The successful transfer of Indus Telemetry to the Government of Khyber Pakhtunkhwa marks a significant milestone. It is a testament to the province’s leadership and commitment to evidence-based decision-making. It also sets a precedent for other provinces and national institutions to follow as Pakistan moves toward implementing its National Water Policy.

I extend my sincere appreciation to all the researchers, engineers, government officials, and field staff who contributed to this endeavour. Their dedication has laid the foundation for a more resilient and equitable water future.

Mohsin Hafeez

Strategic Program Director - Water, Food and Ecosystems
International Water Management Institute (IWMI)

It is with great pride and a sense of accomplishment that I present this technical report, "Indus Telemetry: Revitalizing Surface Water Accounting in Pakistan." This document captures a remarkable journey of innovation, collaboration, and institutional transformation in water governance.



The Indus Telemetry initiative represents a pioneering step by the Irrigation Department, Government of Khyber Pakhtunkhwa, towards embracing digital solutions for transparent and accountable water management. In a region where agriculture is the backbone of livelihoods and water is a critical yet finite resource, the ability to monitor, measure, and manage canal flows in near real-time is not just a technological upgrade, it is a governance imperative.

This journey, which began with a single pilot installation, has evolved into a province-wide system covering our major irrigation canals. Through the unwavering support of the International Water Management Institute (IWMI), the technical partnership of the Pakistan Council of Research in Water Resources (PCRWR), and the generous financial assistance of USAID, we have successfully transitioned from outdated manual methods to a robust, automated telemetry system. This system now enables us to generate accurate, timely, and verifiable water accounts, fulfilling the vision set forth in Pakistan's National Water Policy 2018.

The report also highlights the critical role of institutional ownership, stakeholder engagement, and capacity building in ensuring the sustainability of such initiatives. The successful transfer of technology to the Irrigation Department, including the integration of Indus Telemetry into our official systems, is a testament to our commitment to long-term water security and interprovincial trust.

I commend the efforts of all those who contributed to this endeavor, engineers, researchers, field staff, and development partners. Their dedication has laid the foundation for a more transparent, efficient, and equitable water management system in Khyber Pakhtunkhwa.

Let this report serve not only as a technical reference but also as an inspiration for other provinces and institutions to adopt similar innovations in pursuit of sustainable water governance.

Muhammad Ayaz

Secretary

Irrigation Department

Government of Khyber Pakhtunkhwa

The Pakistan Council of Research in Water Resources (PCRWR) is pleased to be a partner in the development and implementation of the Indus Telemetry initiative, a landmark effort to modernize surface water accounting in Pakistan. This report captures the essence of this transformative journey and the critical role that science, technology, and institutional collaboration play in strengthening water governance.



As a national research institution mandated to support evidence-based water management, PCRWR has long advocated for the adoption of reliable, real-time data systems. The Indus Telemetry initiative, led by the International Water Management Institute (IWMI) with our technical support and the strong commitment of the Government of Khyber Pakhtunkhwa, exemplifies how research and innovation can be translated into practical, scalable solutions.

This initiative has not only demonstrated the feasibility of automated flow monitoring in complex irrigation systems but has also addressed long-standing challenges such as the reliability of rating tables and the need for transparent interprovincial surface water accounting. The successful deployment and transfer of this technology to the Khyber Pakhtunkhwa Irrigation Department is a testament to the power of partnerships and the importance of institutional ownership.

PCRWR is proud to have contributed to the design, validation, and quality assurance of the telemetry system. We believe the lessons documented in this report will serve as a valuable reference for future investments in water monitoring infrastructure across the country.

I commend the dedication of all partners involved and reaffirm PCRWR's commitment to supporting innovative, science-based solutions for sustainable water management in Pakistan.

Dr. Hifza Rasheed

Director General

Pakistan Council of Research in Water Resources (PCRWR)

Executive Summary

The Indus Telemetry was initiated in 2017 as a national research-for-development initiative, led by the International Water Management Institute (IWMI) in collaboration with the Pakistan Council of Research in Water Resources (PCRWR) and provincial irrigation departments. The primary objective of the initiative was to inform and guide current and future investments in water management by developing a surface water accounting and audit system based on canal flow data collected via automated sensors.

The initiative aligns with Pakistan's National Water Policy (2018), which mandated the installation of a telemetry system across the entire Indus River System (IRS) by 2021 to enhance transparency and accountability in water distribution. The Indus Basin Irrigation System (IBIS) is one of the world's largest and most complex contiguous irrigation systems. The initial sections of this report provide a comprehensive overview of the IBIS and its operational mechanisms—information that is not readily available in existing literature. The report also outlines the institutional landscape of Pakistan's water sector, highlighting the roles and mandates of key organizations involved in water governance.

Globally, various water accounting frameworks have been developed to support improved water governance. Among these, the Water Accounting Plus (WA+) framework, which employs a water balance approach at the basin scale, is widely adopted. Several countries have also developed national water accounting systems tailored to their specific needs. In Pakistan, the Indus River System Authority (IRSA) is the apex body responsible for maintaining national surface water accounts. It operates within an established framework that defines and monitors provincial water allocations. This report does not propose a new water accounting framework, nor does it seek to replace the existing surface water accounting practices of IRSA and provincial institutions. Instead, it aims to document and elaborate on the current surface water accounting processes in Pakistan and demonstrate how Indus Telemetry can help improve these practices. The intended audience of this report includes, but is not limited to, the development community, water institutions, and research organizations.

Indus Telemetry significantly strengthens the existing surface water accounting system by modernizing traditional flow monitoring methods. It introduces a fully automated, high frequency, near real-time telemetry system, complete with data archiving and reporting capabilities. The Government of Khyber Pakhtunkhwa's Irrigation Department (GoKP-ID) has adopted this system to improve surface water accounting in the province. This system enables the GoKP-ID to share volumetric water accounts with IRSA in a transparent and timely manner. Most importantly, it fulfills a key requirement of the National Water Policy by supporting IRSA in establishing a transparent water accounting system and addressing the issue of unaccounted-for water in the IRS.

The report chronicles the development of the Indus Telemetry in three distinct phases:

Proof-of-Concept Phase: This initial phase involved installing prototype systems in each province. Technical and technological challenges were addressed, resulting in an operational system capable of remotely acquiring, processing, archiving, and disseminating canal flow data. Stakeholder engagement was prioritized through real-time data sharing, validation methods, and capacity-building activities, including workshops and training sessions.

Uptake and Upscaling Phase: Following the successful demonstration of the technology, IWMI and PCRWR were engaged with the Ministry of Water Resources (MoWR) and IRSA to explore opportunities for scaling up. However, to avoid duplication with a national telemetry initiative under consideration by MoWR/IRSA, IWMI focused on the main canals in Khyber Pakhtunkhwa that were not included in the national plan. This phase covered 11 major canals and also introduced velocity sensors to enable discharge calculation without using rating functions. A robust data validation and quality assurance process was also established using an Acoustic Doppler Current Profiler (ADCP). The US Government supported this phase through its "Water Management for Enhanced Productivity" (WMfEP) activity and the continued technical collaboration of GoKP-ID.

Technology Transfer and Sustainability Phase: This final phase commenced with the completion of installations in Khyber Pakhtunkhwa in 2023 and gained momentum following the official inauguration of the Indus Telemetry by the Provincial Minister for Irrigation on June 12, 2024. IWMI presented a comprehensive roadmap for technology transfer and long-term sustainability to GoKP-ID, addressing concerns related to post-project operations and maintenance. The technology transfer was successfully concluded in April 2025, with IWMI reaffirming its commitment to ongoing technical support.

Indus Telemetry: A Journey to Digitalization

The Indus Telemetry represents a collaborative effort of the International Water Management Institute (IWMI) involving the Pakistan Council of Research in Water Resources (PCRWR), the Indus River System Authority (IRSA), and the Provincial Irrigation Departments of Balochistan, Khyber Pakhtunkhwa, Punjab, and Sindh. Designed to modernize canal flow monitoring across the Indus Basin, the initiative supported the transition from manual measurement methods to a digital, real-time telemetry system. This transformation has notably empowered the Khyber Pakhtunkhwa Irrigation Department to systematically monitor, manage, and transparently report its allocated water share from the Indus River System. This report chronicles the digital transformation journey of Indus Telemetry, highlighting the technological decisions made, the challenges encountered, and the key lessons learned throughout its implementation.

Introduction and Background of Indus Telemetry

There is a perception that the provinces of Pakistan have little trust in the monitoring data on water drawn by other provinces from the main canals. How far this perception holds true cannot be judged, as there are no scientific studies or literature available to support or reject this conjecture. A possible cause of mistrust between the provinces is the outdated flow measurement and reporting methods used by provincial irrigation departments. A large part of the existing IBIS was built by British engineers in the early 20th century during the colonial era. After independence in 1947, responsibility for maintenance and operation was entrusted to the provincial irrigation departments. There has been much expansion and modernization of the canals and structures (hardware). Still, very few efforts have been made to modernize management, including the use of current communication and information technology.

It is widely acknowledged that Pakistan needs to improve the mechanism by which it accounts for the water distribution of the Indus River and its tributaries. Recognizing this need, around two decades ago, Pakistan made its first concerted effort to improve the quality of data acquisition and reporting of flows at key locations throughout the IBIS. This effort led to a system that was known amongst water professionals as the “Water and Power Development Authority (WAPDA) Telemetry”. Through this investment of approximately US\$6.0 million in 2004, hardware was procured and installed at key locations of the IBIS, including barrages on the major rivers and irrigation canals. Control rooms were constructed to house equipment and to disseminate data, etc. Unfortunately, this investment did not yield the anticipated dividends. Despite installing state-of-the-art hardware at the time, disputes quickly arose among various agencies about the accuracy and validity of reported data and information. The technology choice in part was constrained by the available technology of the day, which was expensive to maintain – the subscription to satellite services for transmission of data, and the need to provide power mains at every location. There has been a renewed interest in investing in better data and information in the IBIS. Examples of recent/ongoing investments include Punjab Barrages Improvement Project IV, Balochistan Water Resources Project, Water Capacity and Advisory Services and KP Early Flood Warning System. At the federal level, the Ministry of Water Resources (MoWR) has been pushing hard for the agenda of installing a telemetry system. Learning from past experiences, the MoWR was concerned about technological and institutional choices to ensure sustainable investment. More recently (in August 2024), WAPDA awarded Rs 21.534 billion (~US\$76.35 million) project for the ‘Installation of Telemetry System for Real-Time Discharge Monitoring’ at 27 key sites on the IBIS to a consortium of private organizations.

Previously, WAPDA installed an electronic system in 2004 to measure water levels and flows at various key locations along the IBIS and to transmit this data electronically, referred to as the WAPDA Telemetry System. The expectations from the system were very high such as: *“The Telemetry System will develop confidence amongst the provinces and the data will automatically be transmitted to the federal and provincial governments on their monitoring sites without human interference on real time basis simultaneously in parallel”*, stated by the Federal Minister for Water and Power on 1st December 2004, the day the system was officially launched.

Unfortunately, this investment did not meet the IRSA’s acceptance criteria. Similarly, the provinces expressed serious reservations about the quality of the reported data. The Friends of Democratic Pakistan, in a highly influential report

(2012), concluded: “A decade ago, a telemetric system was installed to automate the measurement and reporting process, but it has not worked”.

The late John Briscoe and Usman Qamar, in their seminal work of 2005: “Pakistan’s Water Economy Running Dry”, stated that there can be “...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 authors further describe three key requirements:

- A rigorous, calibrated system for measuring water inflows, storage, and outflows should be put in place
- The measurement system is to be audited by a party that is not only scrupulously independent and impartial but is seen to be so by all parties
- Reporting must be totally transparent and available in real time for all parties to scrutinize.

The obligatory necessity for improved data and information (quality, quantity, and timeliness) was reiterated in Pakistan’s National Water Policy 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 a 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”.

Under the existing institutional setup to manage Pakistan’s water resources, IRSA is primarily responsible for ensuring that surface water is allocated and utilized by all the provinces according to WAA 1991. IRSA allocates provincial water shares based on probabilistic estimates ahead of each cropping season. All four provincial irrigation departments then submit their demand to IRSA, specifying how much water needs to be withdrawn daily into various canal systems i.e., the discharge data at the head of the canals. The volume of water is then aggregated over a 10-day period. IRSA then uses this data for water distribution and accounting for a season. The data acquisition methods by provincial irrigation departments are outdated and occasionally questioned by the lower riparian provinces. Many efforts have been made in the past by IRSA to improve data acquisition methods, such as revisions to discharge rating functions at critical canal locations, spot flow measurements by neutral experts, and the installation of WAPDA Telemetry in 2004. In addition, IRSA and provincial irrigation departments have also invested in improving their surface water monitoring and data acquisition processes. Notably, the Punjab Irrigation Department has installed electronic instruments at a few canal commands. Furthermore, it has established an online reporting system that updates the daily discharge of all canals based on manually entered data. Sindh Irrigation Department has recently invested in the digitalization of flow records in canal systems by using depth monitoring sensors on a few canals.

In this backdrop, IWMI took on the task to showcase a technically feasible and economically viable prototype of a telemetry system that IRSA can scale up to the entire IBIS. The journey of Indus Telemetry can be divided into three phases.

The first phase, “proof-of-concept” focused on stakeholders’ engagement and technology piloting. During this phase, IWMI approached federal and provincial water institutions to convince them to install Indus Telemetry at one canal location in each province. The technology was used to engage stakeholders. IWMI shared real time data, used different methods for data validation, and organized dialogues and training workshops. In this phase, various technical and technological challenges were addressed, and the outcome was an operational telemetry system capable of automatically acquiring electronic data at remote canal locations, processing, archiving and disseminating it in various formats to the stakeholders.

During the proof-of-concept phase, the instruments were commissioned to measure the range from the instrument to the water surface in canals. The range is measured continuously, but averaged and recorded every 15 minutes and then transmitted using mobile phone technology to a remote (cloud) server several times in day. This interval was

user-defined and was selected carefully to conserve power, especially during short overcast winter days. At the server, the data was post processed. The entire process involved certain quality checks and was then integrated with canal section parameters and instrument properties to estimate discharge, delivery performance ratio, and volumes. The data and information were archived on the server and disseminated through digital signage, short-message-services (SMS), and through applications such as Excel, Access, file-transfer-protocol. The technical details to commission these instruments, including calibration checks, validation and verification, programming of instruments, the dashboard, and the procurement of hardware, are discussed in this report with reasonable detail with an aim to inform future investments in hardware and technological choices. This report also covers technical details on the meta-data including sampling interval, data logging periods, data transmission schedule, latency, and data integrity.

A significant amount of time was invested, and efforts were made to build consensus on the relatively modest installation (one in each province). The technology provided an entry point for dialogue and discussions on the larger issue of improved surface water accounting and auditing at national and provincial levels.

Following the successful proof-of-concept, the Indus Telemetry focused on technology uptake and upscaling at the main irrigation canals in Khyber Pakhtunkhwa. There were three main reasons for selecting Khyber Pakhtunkhwa: i) the WAPDA Telemetry (the previous installation as well as the upcoming) considered 27 key locations in the IBIS. These locations are essentially inter-provincial transfer points at the Indus River or the interprovincial canals. But the key locations did not include the main canals of Khyber Pakhtunkhwa, except the Chashma Right Bank Canal (CRBC). Therefore, it was a considerate choice to focus on Khyber Pakhtunkhwa where the main canals did not get attention from public sector investment in a telemetry system. To avoid duplication of efforts, the Indus Telemetry did not include the CRBC canal; ii) active engagement and ownership of the GoKP-ID encouraged IWMI to scale up the Indus Telemetry; iii) the necessary financial and technical resources were made available by USAID through its 'Water Management for Enhanced Productivity' activity implemented by IWMI. The technical support of PCRWR as a federal research institution of the Ministry of Water Resources has been instrumental during the proof-of-concept, uptake, and upscaling phases of the Indus Telemetry.

The technology uptake and upscaling phase started with the installation of instruments already tested in field conditions during the proof-of-concept phase. The installation of instruments at the main canals of Khyber Pakhtunkhwa was completed in close consultation with the water professionals of GoKP-ID. A headline technology upgrade during the uptake and upscaling phase was the retrofitting of velocity sensors. This upgrade solved a big problem in flow measurement, whereby discharge is estimated using 'rating functions' using depth-of-flow as the only regularly measured variable. The rating functions have been a topic of hot debates amongst water professionals in Pakistan and are considered as a root cause of mistrust among provincial stakeholders on water distribution. The velocity sensors enable regular flow velocity measurement, eliminating the need for rating functions and empirical equations. Another significant advancement during the uptake and upscaling phase was the verification/validation process of the Indus Telemetry data. This validation is crucial to ensure data quality and develop confidence in electronic measurements. Based on its accuracy, ease of use, and capability to acquire high-resolution data at canals and rivers, ADCP was used to verify the Telemetry data quality. The output of the uptake and upscaling phase was a larger coverage in Khyber Pakhtunkhwa and an enhanced capability of Indus Telemetry to directly monitor velocity.

The transfer of technology to GoKP-ID was the final phase of this initiative, hereafter referred to as 'Technology Transfer Phase'. The sustainability of development investments is often debated in policy and management discussions. Many such investments could not yield dividends in the past due to a lack of stakeholders' ownership and limited capacity to operate and maintain technological interventions once project-based financial and technical support ended. Therefore, due attention was given to address the sustainability challenges and devise a roadmap for technology transfer to the GoKP-ID to ensure the continuity of its benefits and utility in decision making. IWMI completed technology transfer in April 2025. The key outputs of this phase were developing and enhancing the Indus Telemetry database in open sources PostgreSQL platform, migrating and integrating with the Irrigation Department's official system hosted by Khyber Pakhtunkhwa Information Technology Board, and reprogramming of instruments and handing over of maintenance responsibilities to GoKP-ID.

Understanding Surface Water Accounting in the Indus Basin Irrigation System

The Indus Basin Irrigation System (IBIS)

The land statistics of Pakistan suggest that irrigated agriculture predominantly defines the use of land resources of the country. The land use of various provinces (Table 1) shows that Punjab has two-thirds of its land resources potentially available for agriculture, of which it has brought 90% under cultivation. Other provinces have relatively smaller proportions of potentially agricultural land area, and still, there is a smaller proportion brought under cultivation. For example, in Khyber Pakhtunkhwa, slightly more than half of the potentially available agricultural area is under cultivation. Difficult terrain, irrigation infrastructure, weather conditions, skilled labor, and soil characteristics are the main factors hindering the expansion of agriculture to new areas.

Table 1. Land use statistics of Pakistan

Geographic Units	Total land area (Mha)	Potentially Agricultural Area (%)	Cultivated Land (%)	Forest Area (%)
Pakistan	79.61	38.0	27.6	5.6
Punjab (R)	20.63	67.8	60.7	2.3
Sindh	14.09	45.1	33.6	7.4
Khyber Pakhtunkhwa	10.17	31.6	17.9	11.6
Balochistan	34.72	19.3	8.4	5.2

Source: Pakistan Bureau of Statistics 2022

The largest source of freshwater in Pakistan is the Indus River System, comprising the Indus River and its tributaries (e.g., right-bank tributaries are the Shyok, Gilgit, Kabul, Kurram, and Gomul rivers), and left bank tributaries include Panjnad River (including contributions from Jhelum, Chenab, Ravi and Sutlej) and Soan River, in plains of Punjab. Pakistan and India signed the Indus Waters Treaty in 1960, whereby India got full right of the three eastern (left bank) tributary rivers (Ravi, Sutlej and Bias).

Apart from the Indus River Basin, two other prominent hydrological units in Pakistan are the closed basin of the Kharan Desert and the Makran coastal basin. The Kharan basin is a region in the north-west of Balochistan wherein small mountain streams drain into shallow lakes and ponds. Major streams include the Pishin-Lora, Mashkel, Rakhshan, Tahlab and Buddo rivers. The Makran Coastal Basin is located along the coastal belt of Balochistan, receiving water from streams like Dasht, Shadi, Basol, Hingol, Porali, Winder and Hub. All the streams are flashy and drain in the arid and barani land. Due to a lack of data collection facilities, information on runoff and flooding in these basins is very limited. Surface water from the network of Indus Rivers is diverted mainly to irrigation canals for agriculture. It is estimated that around 93% of the freshwater available in Pakistan is consumed by the agricultural sector (Gul et al., 2024) especially in regions like Sindh province, Pakistan, where shallow groundwater table depths (WTDs). The gigantic IBIS enables freshwater supplies from rivers to farm-gates in irrigated areas (Figure 1).

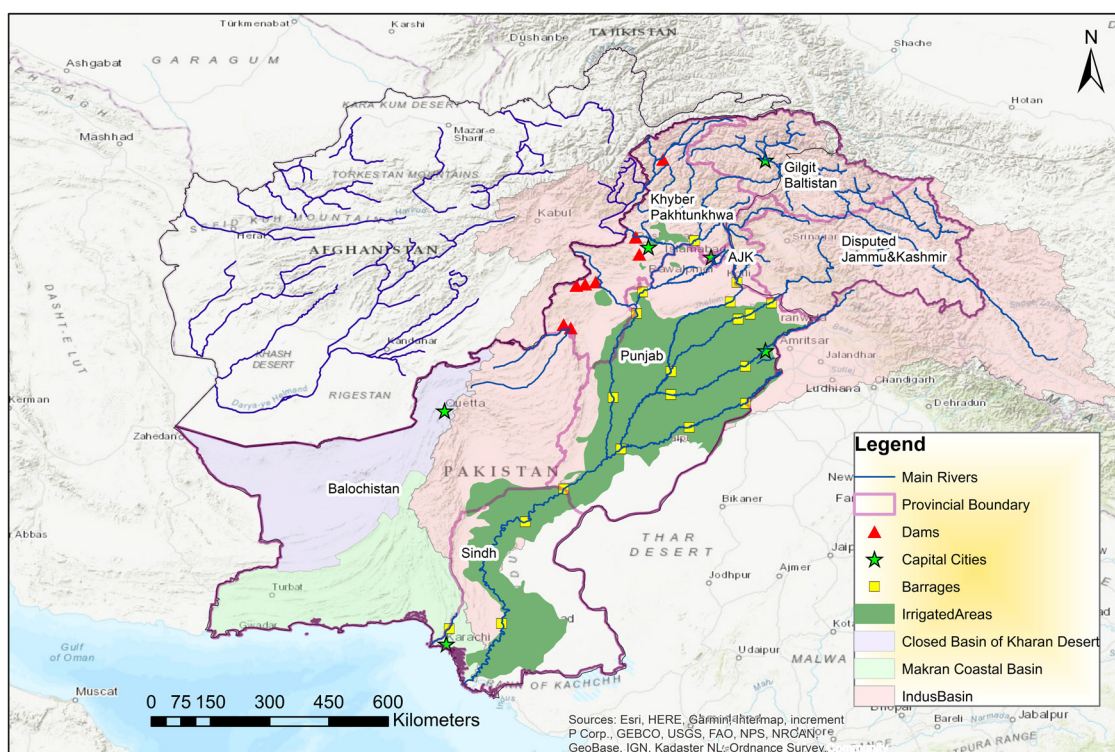


Figure 1. Irrigated landscape of Pakistan

Key infrastructure of the IBIS includes three major reservoirs, 19 barrages and headworks, and 12 inter-river link canals. The gravity-based irrigation canal network of the IBIS consists of a dendritic structure of water channels each having a particular flow carrying capacity. The channels are categorized based on their position on the primary, secondary, and tertiary levels of the canal network, known as main canal, branch canals (distributaries), and minors. The total length of the canals network in the country is around 69,000 km, irrigating an area of about 14.46 million ha of culturable land (Table 2).

Table 2. Characteristics of Canal Network of Indus Basin Irrigation System

	Length of Canal Network (km)	Command Area (ha)
Pakistan	64,936	14.46
Punjab	37,515	8.79
KP	3,912	0.80
<i>Upper IBIS</i>	<i>41,427</i>	<i>9.59</i>
Sindh	22,025	4.52
Balochistan	1,484	0.35
<i>Lower IBIS</i>	<i>23,509</i>	<i>4.87</i>

Source: Development Statistics of Punjab, Provincial Irrigation Department websites

The surface water supplies in the IBIS are shared amongst provinces according to the Water Apportionment Accord (1991). The IRSA implements the WAA and is responsible for interprovincial water distribution and maintaining national water accounts in collaboration with the provincial irrigation departments (PIDs). The PIDs monitor water supplies in their respective irrigation canal networks and share with IRSA on 10-daily bases. The volumes reported by the PIDs make up the yearly national water accounts on surface water withdrawals in two crop seasons i.e., the winter crop season of Rabi (16 Oct to 15 Mar) and the summer crop season Kharif (16 Mar to 14 Sep).

Water Balance in the Indus Basin

The Water Balance approach is sometimes taken in a similar manner to water accounting. Water Balance of a river basin typically considers atmospheric, surface, and groundwater, their interactions, consumptive and non-consumptive use within the basin boundaries, and escape and return of water outside the boundaries. Quantification of these components (and their sub-sets) over time gives a water balanced view of the river basin. The annual water balance of the Indus Basin (part in Pakistan) is presented in Figure 2. Some of the water balance elements are well quantified, while others are poorly assessed or simply overlooked in most resource assessments (Young et al., 2019). The surface water inflows in the Indus and its tributaries are regularly monitored and provide annual inflows with sufficient authenticity. The runoff outside the Indus Basin is often poorly measured. Young et al. (2019) also point out the double counting of groundwater withdrawals, a substantial proportion of which is pumped from shallow subsurface water seeped from canals and watercourses.

A careful assessment of all water resources based on numerous past studies suggests that Pakistan's current total average annual renewable water resources are 229 BCM (186 MAF). Around 96 percent of this water is within the Indus Basin. The inflow to the IRS is averaged at 170 BCM (138 MAF) annually from the Indus, Kabul, Jehlum, and Chenab rivers.

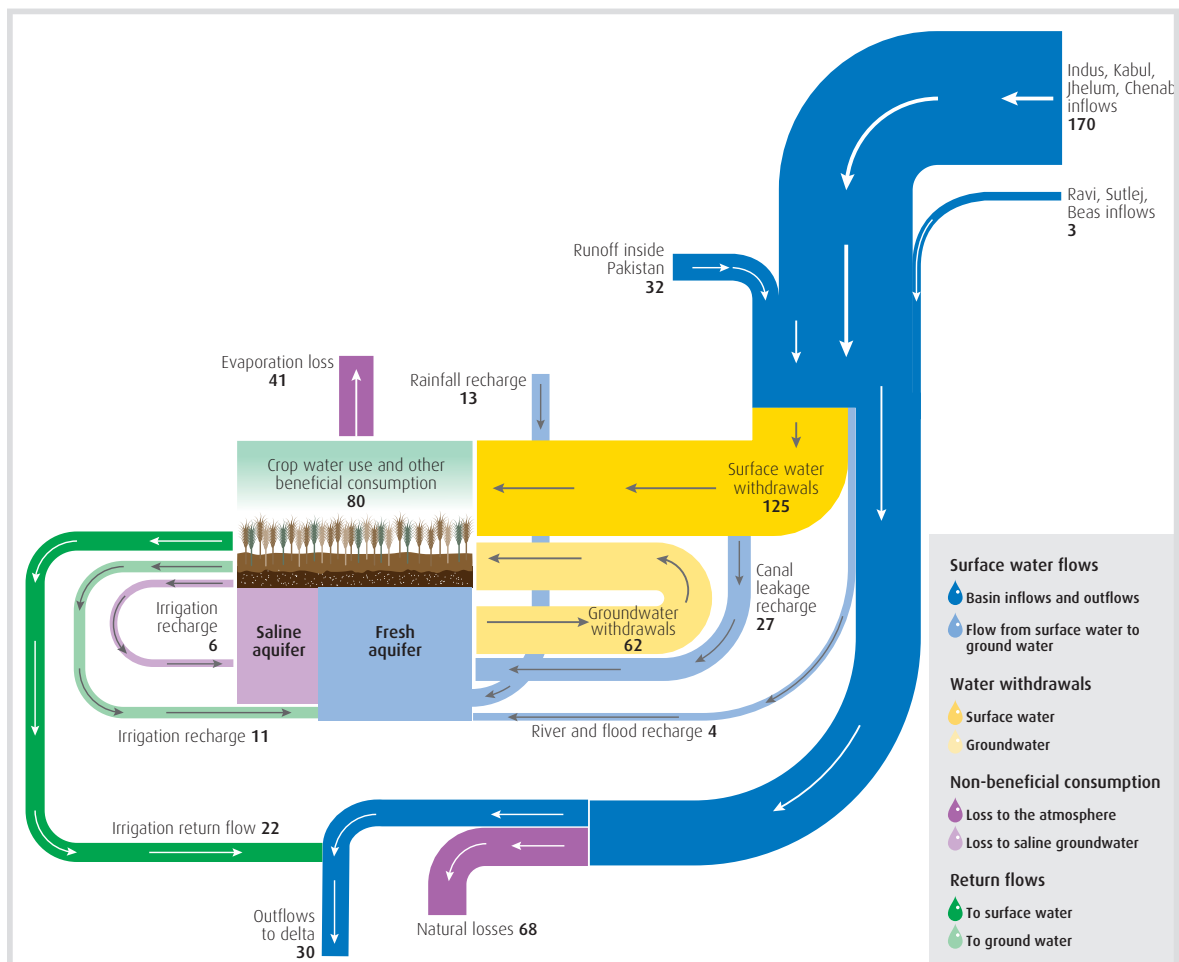


Figure 2. Indus Basin Average Annual Water Balance. Source: Young et al. (2019)

Sources of Water Balance Figures: Ahmad and Rashida 2001; FAO ,2011; Karimi et al., 2013; Laghari et al., 2012; MacDonald et al.,2016; van Steenberg and Gohar, 2005.

Note: Flow in billion cubic meters

There has also been a small but insignificant contribution to inflow from the eastern tributaries of the Indus because of water resources development in India. Figure 3 shows the overall annual system inflow volume from 2015 to 2024. The average annual inflow over this period is 149.58 BCM (121.27 MAF).

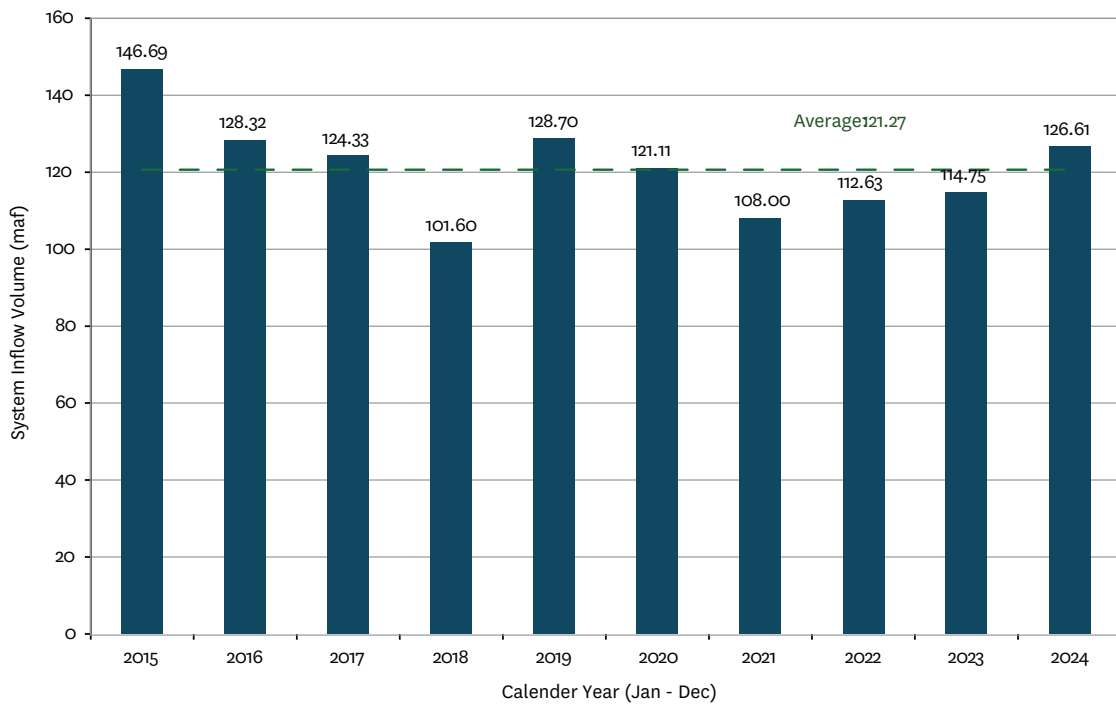


Figure 3. Annual Inflow into the Indus River System

Source: WAPDA (Daily River Discharge 2015-2024)

Figure 4a and 4b highlight interesting insights about the monthly variation of inflows for the Indus and its western tributaries. The first figure exhibits that the Indus and the Chenab rise and recede (at rim stations) almost simultaneously. The River Kabul is rising relatively early and provides much needed flow for agriculture during the late winter months when the other three rivers are in lean flow condition (Figure 4a). This timing is essential because the rivers are interlinked, and water demand is met through releases from reservoirs during winter. The other insight is the relative share of river inflows over the year. The Indus River contributes half of the total system inflows during peak-flow months, while the relative contribution of the Kabul and the Jhelum rivers remains high during Feb-May (Figure 4b).

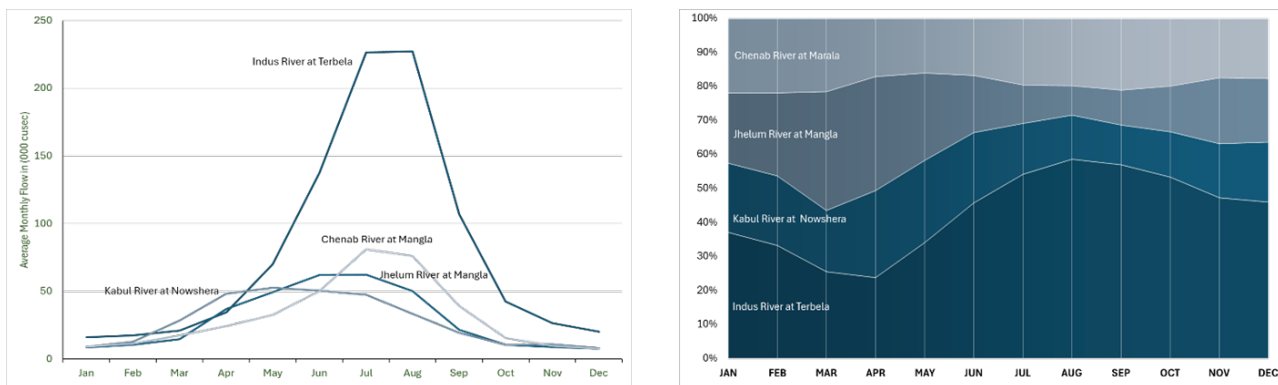


Figure 4. Monthly variation of rivers flow (a); relative percentage of rivers flow to the total (b)

Source: WAPDA (Daily River Discharge 2015-2024)

Stakeholders' Landscape

The preceding section describes the biophysical features of the IBIS, which are substantially large and quite complex in nature. To understand the surface water accounting process, it is imperative to understand the water stakeholders' landscape in Pakistan. In the broader context, the users are the key stakeholders of freshwater resources. Agriculture being the largest consumer makes the farming community at the core of stakeholder's landscape. The governance structure of public institutions in Pakistan defines the relevance of water institutions based on their mandated functions to allocate and distribute water amongst users.

The surface water has the strongest governance structure that includes federal and provincial institutions in public domain. There are several public sector institutions operating at the provincial and national levels. The users of water operate in a private domain. Figure 5 symbolically shows the interactions between water systems at various levels (as shaded blocks) and the relevant governance system in each block. The governance system is vague for groundwater and therefore represented as 'grey area'. Many actors are involved in groundwater management, but no single institution claims to have the leading role.

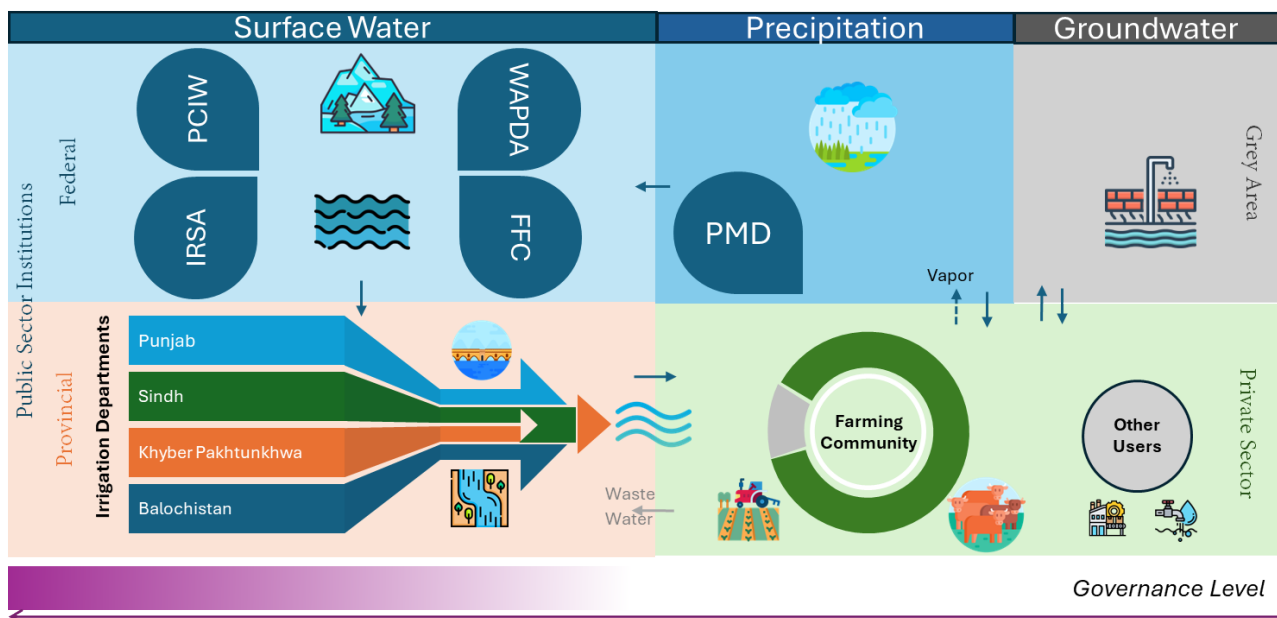


Figure 5. Institutional landscape in Water Resources Management in Pakistan

a) Federal Water Institutions

The Ministry of Water Resources is the umbrella ministry of key water institutions at the federal level. There are other ministries and institutions that contribute to water resources management in a supporting capacity, such as the Ministry of National Food Security & Research, the Ministry of Climate Change and Environmental Coordination, Pakistan Meteorological Department (Ministry of Aviation), Geological Survey of Pakistan (Ministry of Energy), and others. A brief introduction of key federal 'water institutions is provided in Box 1.

b) Provincial Water Institutions

Irrigated agriculture is the primary determinant of Pakistan's economic growth potential. The provincial Irrigation Departments are the key public sector institutions responsible for the operation and upkeep of the irrigation system of the provinces and supply irrigation water from rivers to farm gates through a network of irrigation canals in view of irrigation demands and allocated share. Their responsibilities include operation and maintenance of irrigation and flood protection infrastructure, regulation of flows in canal systems (covering inter-provincial and intra-provincial systems) within their jurisdiction, etc.

c) Private Sector

The water users comprising three main sectors (agriculture including livestock, industry and municipal) function in the private sector. Agriculture, which is the largest sector of the national economy in terms of its contribution to total employment, is almost wholly in the private sector (ADB, 2008). The private sector owns agricultural land and generates primary and value-added agricultural output. Public sector involvement in the agriculture sector is mainly concentrated in providing and maintaining irrigation infrastructure and developing waterways for cultivation, as well as providing agriculture extension services and supporting agriculture research. Similarly, industry and domestic users also operate in the private sector. Public sector involvement in industry (manufacturing and services) is mainly to provide an enabling environment and ease of doing business.

BOX 1. Key federal water institutions in Pakistan

- **The Water and Power Development Authority (WAPDA)** was established through an act of parliament in 1958 for the integrated and rapid development and maintenance of water and power resources of the country. WAPDA looks after reservoir operation, monitoring river flows, coordinating with federal/provincial flood management authorities, and forecasting water availability for distribution among provinces, along with its other roles and responsibilities.
- The Indus basin is shared by several countries. Pakistan receives its water share from the rivers originating in upstream countries. In 1960, Pakistan and India signed the 'Indus Water Treaty' that sets the basis of water sharing from the Indus and its tributaries. The Permanent Indus Commission was established in 1960 after signing the Treaty. **Pakistan Commissioner for Indus Waters (PCIW)** is a part of the Permanent Indus Commission, which is a bilateral commission consisting of officials from India and Pakistan, created to implement and manage the goals and objectives outlined in the Treaty.
- **Indus River System Authority (IRSA)** is a water regulator in Pakistan, established in 1992 through an act of Parliament. The authority was established for regulating and monitoring the distribution of water resources of the Indus River system among the provinces, in accordance with provisions of the water accord. The IRSA oversees the allocation of water based on the seasonally available supplies. It is represented by four provincial and a federal member, who chair the authority on a rotating basis.
- The **Federal Flood Commission (FFC)** was established in 1977 after heavy flood events faced by the country from 1973-76. The FFC is a federal agency responsible for the development and maintenance of nationwide flood protection and control systems. The FFC is headed by a chairman who also serves as Chief Engineering Advisor to the Ministry of Water Resources.
- **Pakistan Council of Research in Water Resources (PCRWR)** is a federal research institution that provides technical support and guidance to other water-related agencies and stakeholders.
- **Pakistan Meteorological Department (PMD)** is an autonomous institution established in 1947. It is both a scientific and a service department, and functions under the Ministry of Aviation. Main objectives are to provide information on weather, climate, and geophysical phenomenon with the aim of traffic safety in air, on land, and sea, early warning for mitigation of disasters, agriculture development based on climatic potential of the country, climate change, impact assessment, future projection of climate, and adaptation options in different sectors. Apart from meteorology, the department is also extending services in the fields of hydrology, seismology, and geomagnetism.

Water Accounting in Broader Context

Water accounting is quite a broad term, and it covers all the components of the water balance. In this report, the term 'water accounting' is used in the sense that is widely understood by the water professionals in Pakistan and refers to the surface water accounts at the national level that the Indus River System Authority is mandated to take care of.

Water accounting and water auditing have been in regular use for more than two decades, often interchangeably. Definitions have been proposed and used but consensus on the definition of these terms has yet to emerge (Batchelor et al., 2016). There are many conceptual frameworks e.g. Australian Bureau of Meteorology’s conceptual framework for water accounting (Water Accounting Standards Board, 2014); United Nation’s conceptual framework is suggested in the System of Environmental-Economic Accounting for Water (SEEA-Water) (United Nations, 2012) approaches, guides and sourcebooks (Batchelor et al., 2016; Vardon et al., 2025); assessment frameworks (Water Accounting Plus (Karimi et al., 2013); System of National Accounts (SNA) (International Monetary Fund, 2009), biophysical information acquisition and management systems, and global programs for data harmonization, generation, and sharing (Wocat ; FAOSTAT , etc.), all contributing to water accounting and auditing. The definitions of water accounting represent the perspective of the defining individuals or institutions. Sometimes specialists from various disciplines have different definitions of the same terms, and these definitions are often contested. In the absence of a universal definition and a broader realm of perspectives and knowledge, it is not worthwhile developing a new definition or framework of water accounting. Rather, getting benefit from existing knowledge is a better way to develop understanding of the water accounting and auditing processes. Although water accounting can be, and often is, carried out in isolation from water auditing, the view taken by Batchelor et al.,(2016) In FAO’s’ Water Accounting and Auditing Sourcebook, ' it is stated that water accounting and auditing are best designed and implemented as mutually supportive processes. Exhibit 1, adopted from FAO’s water accounting and auditing sourcebook, shows typical water accounting and auditing activities. These activities cover various biophysical, societal and environmental indicators within water accounting and extend to governance assessment, laws and regulation enforcement, cost-benefit and even political economy under the water auditing. A somewhat similar view is taken in SEEA-Water of the United Nations (2012) in presenting the scope of water accounting as shown in Figure 6. SEEA-Water has been designed to link economic information with hydrological information to provide users with a tool for integrated analysis. Figure 6 shows the interaction between main flows within the inland water resource system and the economy.

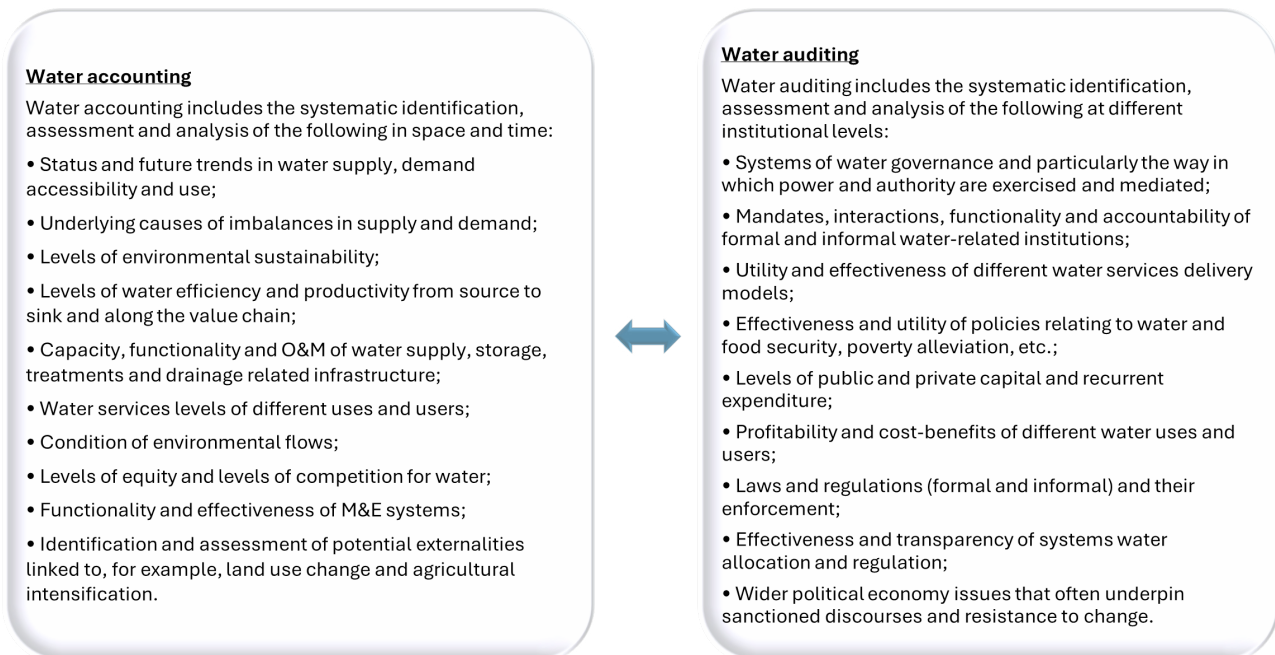


Exhibit 1. Typical Water Accounting and Auditing Activities (Source: Batchelor et al., 2016)

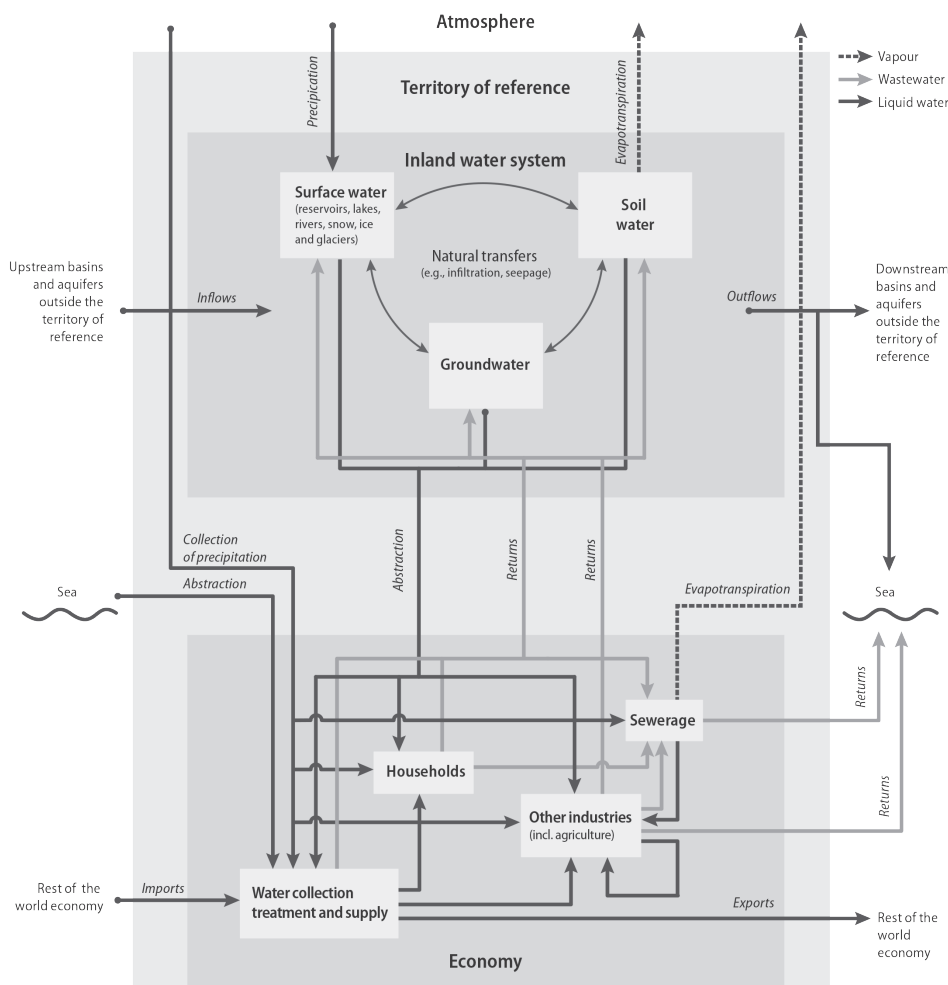


Figure 6. Scope of water accounting
 Source: SEEA Water (United Nations, 2012)

River Inflows and Water Allocation Process in the Indus Basin Irrigation System

WAPDA monitors releases from reservoirs and inflow to the IBIS and at Remote Inflow Measurement (RIM) stations established on the rivers. The RIM stations are established at defined locations at six rivers (Western Rivers: Indus, Kabul, Jhelum, Chenab; and Eastern Rivers: Ravi and Sutlej). Young et al. (2019) report that for hydrologic monitoring, federal authorities operate gauges installed at RIM stations to determine inflows to the IBIS. These are usually defined as the Indus at Kalabagh (which includes the Kabul River), the Jhelum at Mangla, the Chenab at Marala, the Ravi at Balloki, and the Sutlej at Sulemanki. In some instances, the Indus at Tarbela (upstream) and the Kabul at Nowshera are used instead of the Indus at Kalabagh. Several river flow monitoring gauges are also installed at key river locations of the IBIS.

The flow in the Indus River is contributed to by various tributaries along its course (upstream to downstream) in Pakistan, starting from Gilgit Baltistan, Khyber Pakhtunkhwa, Punjab, and Sindh. The Inter-Provincial Water Apportionment Accord (WAA) of 1991 defines the agreed provincial water shares. It is a guiding document for interprovincial water distribution from the Indus River system.

The system inflow is the quantum of water flowing into the Indus River network. The flow monitoring at key locations is converted to volume over 10-daily time steps. Since the system inflow varies over time, the allocation of available water to provinces in accordance with the WAA considers multiple parameters involving calculations and analysis of recent datasets. IRSA undertakes these calculations and defines provincial water shares for summer and winter crop seasons,

locally named as Kharif and Rabi crop seasons, respectively. The Commonwealth Scientific and Industrial Research Organization (CSIRO) (Ahmad et al., 2022) has developed a tool namely '1991 Inter-Provincial Water Apportionment Accord (WAA) Tool' to provide IRSA ease of computing interprovincial water allocations. This tool involves the following 6 steps for calculating interprovincial water share allocations. Step 7, though stated below and included in the schematic (Figure 7), is not included in the tool, as it involves sharing within the provinces, which is a provincial subject.

- Step 1. Forecast 10-daily rim station inflows
- Step 2. Calculate the most recent 5 years of unaccounted-for water (losses and gains in river segments)
- Step 3. Maintain Reservoirs within maximum and minimum 10-daily targets while considering
 - Step 3a. Anticipated targets
 - Step 3b. Safety criteria for dam filling and minimum releases from reservoirs
 - Step 3c. Equity of access to water resources
 - Step 3d. Flows below Kotri
- Step 4. Harmonize the Operation of the Terbel and Mangla reservoirs across 10-daily periods
- Step 5. Balance Resources between Jhelum-Chenab and Indus Systems
- Step 6. Balance and share shortages between provinces across time
- Step 7. Canal Command Sharing within the province (not included in the tool)

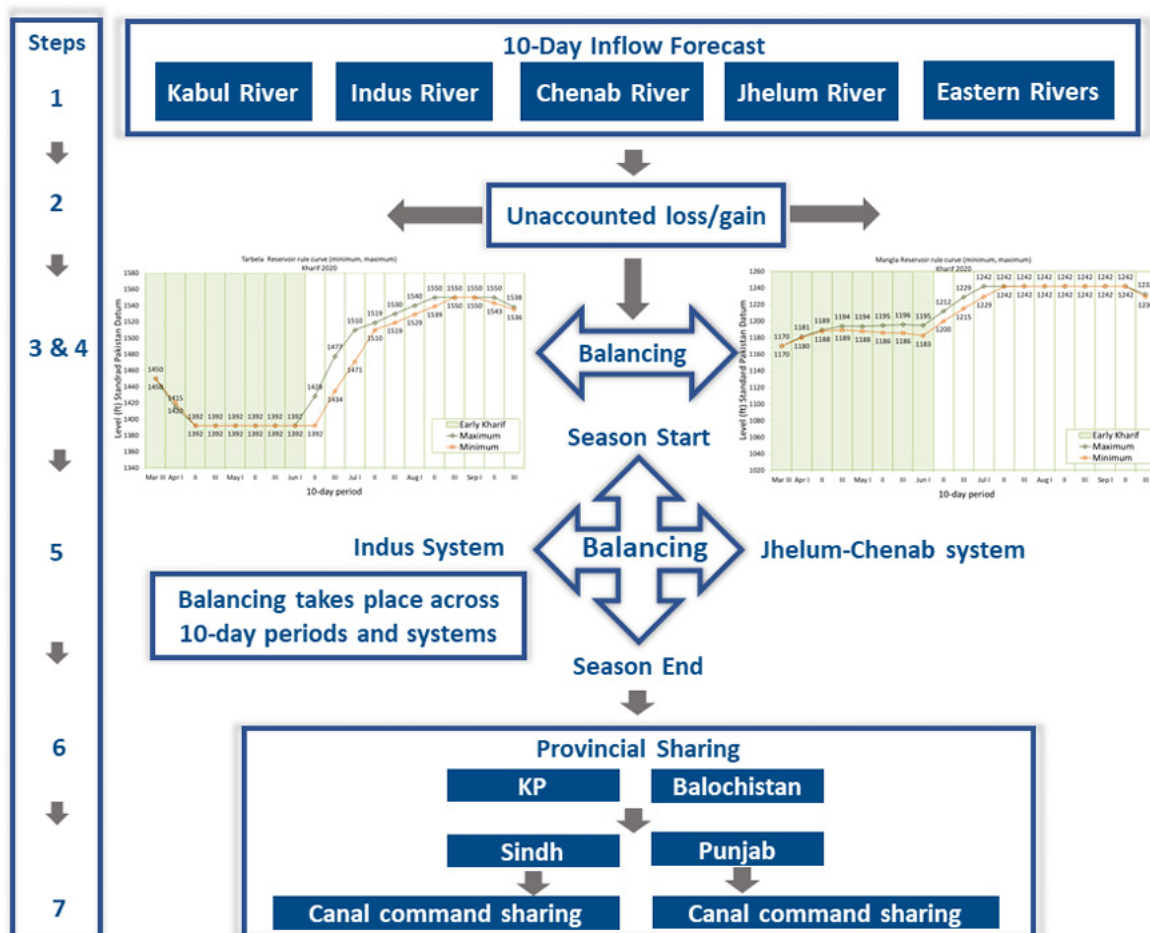


Figure 7. Schematic of Water Allocation Steps
 Source: (Ahmad et al., 2022)

Water Withdrawals and Surface Water Accounting in the IBIS

The provinces withdraw their water share through a network of main canals (also called Tier-1 canals) mostly originating directly from the Indus or its tributaries. In some cases, the provinces withdraw their shares from interprovincial canals. The provincial water is disaggregated in two crop seasons and volumetric reports are prepared on a 10-day time step. The aggregate of volume withdrawn in all the main canals within a province during two crop seasons makes up the withdrawal or the amount utilized out of its defined water share for the year (as explained in the previous section). More details on how WAA is implemented are discussed in detail by Anwar and Bhatti (2018).

The WAA does not restrict provinces from undertaking new projects within their agreed shares (para 8). Outside the provincial shares, the WAA 1991 grants exceptions in para 9 for small projects development (i.e. small schemes not exceeding 2023.42 ha (5000 acres) above elevation of 365.76 (1200 ft); in para 10 for developing irrigation schemes in Kurram/Gomal/Kohat river basins and as long as these irrigation schemes do not adversely affect the existing uses on these rivers; and in para 11 to Balochistan for unrestricted development of water resources of the Indus right bank tributaries flowing through its areas.

Figure 8 provides some key information about the complex river and canal network in the IBIS. The irrigated areas in the IBIS are shaded. There are 48 canal commands shown in Figure 8 as listed in Table 3. IRSA organizes these 48 canal commands in Chanab-Jhelum Zone and Indus Zones as mentioned in Table 3.

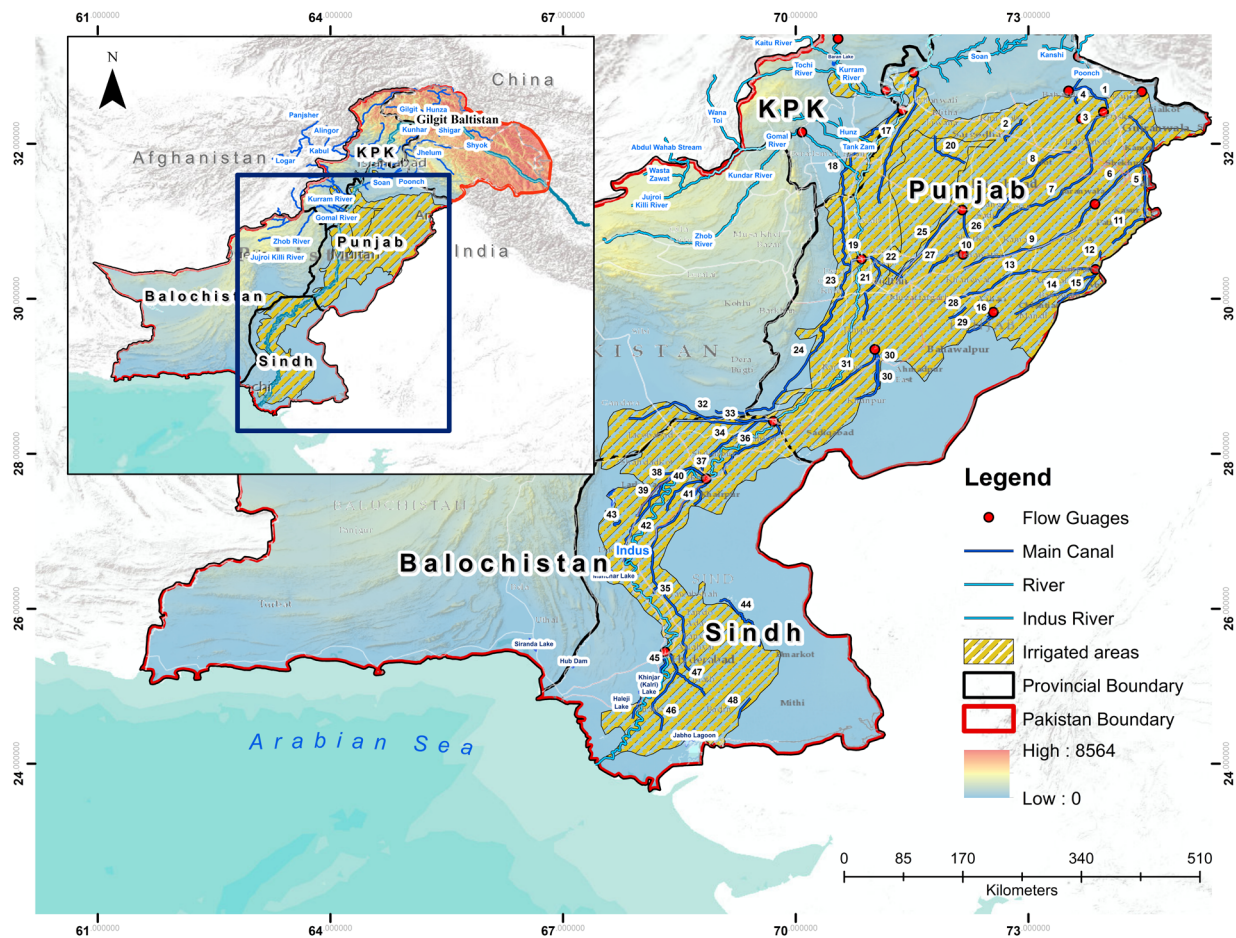


Figure 8. River and Canal networks in the Indus Basin Irrigation System

Note: The lists of 48 canal commands are provided in Tables 3. The key flow gauge locations are provided in Appendix A

Table 3. Canal Commands in Jhelum-Chenab and Indus Zones of the IBIS (as numbered in Figure 8)

Serial Number	Canal Command	Serial Number	Canal Command
Chenab-Jhelum Zone		24	Kachhi Canal
1	Upper Jhelum Canal -Internal (UJC-INT)	25	Rangpur Canal (RC)
2	Lower Jhelum Canal (LJC)	26	Haveli Canal
3	Upper Chenab Canal-Internal (UCC-INT)	27	Sidhnai Canal
4	Marala Ravi Internal (MR-INT)	28	Lower Mailsi Canal & Lower Pakpattan (LM+LPC)
5	Bambanwala-Ravi-Bedian Canal (BRBD) / Raya	29	Bahawal Canal
6	Central Bari Doab Canal (CBDC)	30	Abbassia Canal
7	Gugera Branch (GUG)	31	Panjnad Canal
8	Jhang Branch (JHG)	32	Pat-Feeder Canal (PFC)
9	Lower Bari Doab Canal (LBDC)	33	Desert Canal
10	Karanga Canal	34	Begari Canal
11	Upper Dipalpur Canal (UDC)	35	Rainy Canal (in 2010)
12	Lower Dipalpur Canal (LDC)	36	Ghotki Canal
13	Upper Pakpattan Canal & Upper Mailsi Canal	37	North West Canal (NWC)
14	Fordwah Canal	38	Rice Canal
15	Eastern Sadiqia Canal (ESC)	39	Dadu Canal
16	Upper Bahawal Canal & Qaim Canal (UBC+QC)	40	Khairpur West Canal (KWC)
Indus Zone		41	Khairpur East Canal (KEC)
17	Thal Canal	42	Rohri Canal
18	Chashma Right Bank Canal - KP (CRBC - KP)	43	Upper Nara Canal
19	Chashma Right Bank Canal - P (CRBC - P)	44	Lower Nara Canal
20	Greater Thal Canal (GTC) (in 2010)	45	Kalri Canal
21	Muzaffargarh Canal	46	Pinyari Canal
22	Rangpur Taunsa Panjnad Canal (RTP)	47	Fuleli Canal
23	Dera Ghazi Khan Canal (DGKC)	48	Lined Channel

Table 3 shows that no canal command originating from the Indus right bank tributaries is listed and hence the canal commands in Khyber Pakhtunkhwa are not included in the Jhelum-Chenab and Indus zones.

The provincial water shares are withdrawn by provinces through a network of main canals. Tables 4 to 7 list the main canals in Khyber Pakhtunkhwa, Punjab, Sindh and Balochistan (upstream to downstream), respectively in which flow volume is regularly calculated and reported to IRSA for maintaining water accounts.

There are 14 main canals in Khyber Pakhtunkhwa, mainly organized in four groups (Table 4) that make up the provincial water share. The first three canal groups are named after three main rivers from which they are fed i.e., Swat, Kabul and Indus Rivers, respectively. The fourth group is called other canals, as it includes four canals fed by smaller streams and rivers other than the three main rivers. These four canals draw water from Lora stream (3rd Lora Canal), Kurram River (Marwat Canal), Muqam *Nullah* (stream) and Kohat Toi stream (Tanda Irrigation Main Canal). Table 4 further shows a fifth group, 'Civil Canals', having four canals. These four civil canals are mentioned in the WAA 1991, but their volume is not included in the provincial water share of Khyber Pakhtunkhwa as per the provisions of the accord. However, GoKP-ID reports flow in civil canals to IRSA.

The Irrigation Canals in Punjab are grouped into two zones, namely Indus Zone (Terbela Command) and the Chenab-Jhelum Zone (Mangla Command), as shown in Table 5. Each of the two groups has 13 canals (total 26 canals). The main canals in Sindh province are grouped (Table 6) based on the three barrages from which they originate. These barrages across the Indus River are Guddu, Sukkur and Kotri (upstream to downstream order). A subgroup is also created showing

which side of the river these canals originate at the three barrages. Four canals originate from the Guddu barrage, seven from the Sukkur barrage and four from the Kotri barrage – making a total of 15 main canals in Sindh province. Since the Indus River does not traverse from Balochistan, the province’s only option to withdraw its share of water from the Indus River system is through interprovincial canals. As such, Balochistan withdraws its water share through three canals (Table 7), of which two canals (Pat-Feeder and Kirther Canals) originate in Sindh province, while the third canal (Kachi canal) carries water from Punjab province.

Table 4. Main Canals in Khyber Pakhtunkhwa Province

Serial #	Canal Group		Channel Name
1	Swat Canals	1	Lower Swat Canal
2		2	Upper Swat Canal
3	Kabul River Canals	1	Kabul River Canal
4		2	Warsak Gravity Canal
5		3	Warsak Left Bank Canal
6		4	Warsak Lift Canal
7	Indus River Canals	1	Chashma Right bank canal
8		2	Lower Siran Canal
9		3	Pehur High Level Canal
10		4	Pehur Main Canal
11	Other Canals	1	3rd Lora Canal
12		2	Marwat Canal
13		3	Muqam Nullah Main Canal
14		4	Tanda Irrigation Main Canal
15	Civil Canals	1	Jue Shiekh Canal (from Main Kabul River Canal)
16		2	Jue Zardad Canal (from Budhni Nullah)
17		3	Mian Gujar Canal
18		4	Sangu Branch Canal (from bara River)

Table 5. Main Canals in Punjab Province

Serial #	Canal Group		Channel Name
1	Indus Zone (Tarbela Com-mand)	1	Abbassia Canal
2		2	CRBC-III
3		3	D.G Khan Canal
4		4	Greater Thal Canal
5		5	Haveli Main Line
6		6	Lower Bahawal Canal
7		7	Mailsi Canal
8		8	Muzaffargarh Canal
9		9	Pakpattan Canal Lower
10		10	Punjnad Main Line
11		11	Rangpur canal
12		12	Sidhnai Canal
13		13	Thal Canal Main Line Upper

14	Chenab-Jhelum Zone (Mangla Command)	1	Central Bari Doab Canal
15		2	Eastern Sadiqia Canal
16		3	Fordwah Canal
17		4	Lower Bari Doab Canal
18		5	Lower Chenab Canal
19		6	Lower Depalpur Canal
20		7	Main Line Upper (UCC)
21		8	Main Line, L.J.C.
22		9	MR Link Canal
23		10	Pakpattan Canal Upper
24		11	Upper Bahawal(INT) & Qaim Canal
25		12	Upper Depalpur Canal
26		13	Upper Jhelum Canal

Table 6. Main Canals in Sindh Province

Serial #	Canal Group	Subgroup		Channel Name
1	Guddu Barrage Canals	Left Bank Canals	1	Rainee
2			2	Ghotki Feeder
3		Right Bank Canals	3	Begari Sindh Feeder
4			4	Desert Pat-Feeder
5	Sukkur Barrage Canals	Left Bank Canals	1	Nara Canal
6			2	Khairpur Feeder East
7			3	Rohri Canal
8			4	Khairpur Feeder West
9		Right Bank Canals	5	North West Canal
10			6	Rice Canal
11			7	Dadu Canal
12	Kotri Barrage Canals	Left Bank Canals	1	Akram Wah
13			2	Old Phuleli
14			3	New Phuleli
15		Right Bank Canal	4	Kalri Baghar Feeder

Table 7. Main Canals in Balochistan Province

Serial #	Canal Group	Subgroup		Channel Name
1	Guddu System	from Pat-Feeder Canal	1	Pat-Feeder Canal
2	Sukkur System	from North West Canal	1	Kirther Canal
3	Taunsa System	from Kachhi Canal	1	Kachhi Canal

Indus Telemetry: The Proof-of-Concept Phase

The Introduction section details the process of provincial water allocation and withdrawal. The Indus Telemetry does not cover the provincial allocation, which involves probability analysis of historical flows to estimate provincial water shares ahead of each crop season. Also, it does not cover the regular adjustments to the estimated provincial shares based on flow monitoring in the river system carried out by WAPDA. However, it deals with the provincial water accounts, which are prepared based on withdrawals in main canals in each province as discussed in earlier sections.

The Indus Telemetry is meant for the usage of technology for near real time automatic acquisition of hydrometeorological data from remote locations. The data covers canal flows, weather parameters and groundwater in the IBIS. The data acquisition process involves both hardware installation at remote locations and subsequent post-processing, archiving and dissemination of the derived information. It provides a much more comprehensive solution than merely installing sensors to measure some parameters. Other than the technological part, the Indus Telemetry evolved as a collaborative knowledge partnership between IWMI and the PCRWR, along with other provincial and federal government agencies e.g., the MoWR, IRSA, and all the four PIDs. This knowledge partnership gathered information about the experience of a telemetry system (WAPDA Telemetry) and designed and developed it based on the lessons learned. The key objective was to inform future investments in telemetry in Pakistan. A range of technical issues were encountered during the first phase, included water measurement, electronics, communication, and governance of institutions. The work completed in this phase focused primarily on technological choices and governance questions and hence we refer to this early prototyping phase as ‘Proof-of-Concept Phase’.

Geographical Coverage

Indus Telemetry focuses on the main canals that provinces use to withdraw their water share from the Indus River and its tributaries. The first canal location considered was the Lower Bari Doab Canal in Punjab, where instruments were installed in February 2017. In the next year, IRSA asked IWMI to expand it to the canals in other provinces. Consequently, after consultations with the provincial irrigation departments of Khyber Pakhtunkhwa, Sindh, and Balochistan, one main canal was instrumented in each province. Table 8 provides key features of the four canals so selected for the installation of automatic sensors and instruments.

Table 8. Locations and features of the Indus Telemetry.

Feature	Unit	Lower Bari Doab Canal	Upper Swat Canal	Kirther Canal	Pat-Feeder Canal
River (Barrage/Headworks)		Ravi (Balloki)	Swat (Amandara)	Indus (Sukkur)	Indus (Guddu)
Running distance	km	8.99	5.94	35.35	33.22
Discharge Estimation		Flume	Crump Weir	Rating Curve	Rating Curve
Capacity at head	cumec cusec	263.12 (9292)	101.94 (3600)	67.96 (2400)	189.72 (6700)
Geographic coverage	Province(s)	Punjab	Khyber Pakhtunkhwa	Sindh-Balochistan	Sindh-Balochistan
Proportion of total provincial water share	%	8.8	27.7	22.1 *	49.7 *
Length	km	201	129	84	171
Irrigated area	ha	687,967	111,740	107,647	205,753

Note: *Percentage share of Balochistan Province only

Hardware and Software Technology

Construction of new water infrastructure is often the first solution considered to address water challenges, but decision-makers frequently underestimate the costs of long-term monitoring for effective quantification and management of water resources. Rapidly changing technology, capacity challenges, and operations and maintenance costs are some of the common reasons that result in a costly sequence of events, known as the build-neglect-rebuild cycle (Briscoe and Qamer, 2005).

The foremost issue realized during reconnaissance of the four canals was that the institutional memory about the flow measurement methods had faded. For instance, there were remnants of the fixtures and ancillary equipment used in

WAPDA Telemetry-2004 at the head regulator of Lower Bari Doab Canal (LBDC). The WAPDA telemetry had substantial physical footprints at the site, such as control rooms, a satellite communication system, and power cables laid down for sensors. Under the WAPDA Telemetry-2004, water level sensors were installed in a stilling well located just downstream of the head regulator. However, a dedicated measurement structure (a meter flume) was available approximately 9 km downstream, where an existing stilling well offered a highly convenient location for sensor installation. This setup could allow for the application of the flume equation to accurately calculate discharge. Similarly, in the case of Upper Swat Canal, a dedicated measurement structure (Crump Weir) was available around 6 km downstream of the head regulator, and that was also an ideal location to install sensors and instruments due to its hydraulic stability and structural suitability. Indus Telemetry selected these strategic locations of flume and weir structures at LBDC and USC for the installation of automatic sensors. There were a few small outlets in the 9 km canal segment of LBDC, therefore the flow at the flume structure was not equal to the total inflow into the canal at its head regulator. To calculate flow at the head of the canal, the outflow (a tiny fraction of canal flow) was added to the canal flow at the flume structure.

Flow monitoring at Pat Feeder and Kirther Canals was rather complex. Both canals are interprovincial, i.e. originate in Sindh, run around 35 km to serve irrigated areas in their territory and then enter the Balochistan province. The flow is monitored at the cross-regulators at the provincial transfer points at these canals. The cross-regulator at RD¹ 109 at Pat-Feeder and Garang cross-regulator at RD 112 at Kirther Canal are the two interprovincial transfer points, where Irrigation Departments of Sindh and Balochistan jointly maintain manual gauges to monitor depth of flow and use rating functions² to calculate discharge. However, there is disagreement between the two irrigation departments over the rating functions. Many attempts have been made by the IRSA to resolve this issue, but so far it has remained unsettled. The WAPDA Telemetry-2004 considered both canal locations for automatic monitoring, but they used cross-regulators for discharge calculation. Depth sensors were installed on upstream and downstream cross-regulators and sensors were installed at each gate of the regulator to measure gate opening. A hydraulic equation was then used to calculate discharge. However, at the time of reconnaissance, the sensors were nonexistent, and other equipment was non-functional. In fact, the cross-regulators are not designed as discharge measuring structures and should not be used for discharge monitoring. Their use for discharge measurement requires a greater number of sensors, ancillary requirements, and multiple hydraulic variables thereby increasing complexity of determining discharge.

Based on reconnaissance of the canals, suitable locations were identified prior to the installation of sensors and equipment. Table 8 shows the running distance of selected locations from the origin of each canal. Secondly, it was decided to install sensors at LBDC and USC at locations where dedicated measuring structures were available, namely a meter flume and Crump weir. Thirdly, for the case of Pat-Feeder and Kirther canals, it was decided not to use cross-regulators to install sensors for discharge monitoring. Rather, sensors were installed at a suitable cross-section where depth of flow was monitored electronically using automatic sensors. For the Pat-Feeder canal, the rating equations used by the Sindh Irrigation Department were adopted for discharge calculations. For the Kirther canal, on demand of the Balochistan Irrigation Department, instruments were installed slightly downstream of the interprovincial transfer point where no rating function was available.

Ultrasonic rangefinder sensors were used to monitor water levels and calculate depth of flow in the case of PatFeeder and Kirther canals, and height above flume/ weir crest in the case of LBDC and USC. The ultrasonic rangefinders are non-contact sensors that were installed at a cantilever pointing downwards to the water at a known elevation above datum. The sensor returned range (distance) from the fixed elevation where they were installed to the water surface at a user defined interval. The average bed elevation/crest level above the datum was determined from an elevation survey. The depth of flow and height above the crest were calculated through this set up. The layout of the ancillary and civil works heavily depended on the site conditions.

¹ “Reduced Distance” or RD is the distance along the canal measured from the head as a linear distance. It is normally reported as RD followed by the distance in ft with a + sign as a separator (e.g. RD 19+500)

² A mathematical function usually based on relationship between the stage (height of the water above a datum) and the discharge (volume of water flowing per unit of time). The paired data of stage and discharge is presented as a table called rating table

Figure 9 shows typical hardware installed at remote canal locations during the proof-of-concept phase. Most of the instruments, such as the datalogger, communication device including a GSM SIM, surge suppressor, charge controller, cables, and wires were housed in a secure instrument box. The instrument box was installed on a pole with a cantilever arm. The solar panel and omni antenna were mounted on the pole, while the ultrasonic rangefinder was mounted on a cantilever arm attached to the pole, with the sensor pointing vertically at the surface of the water flowing below.

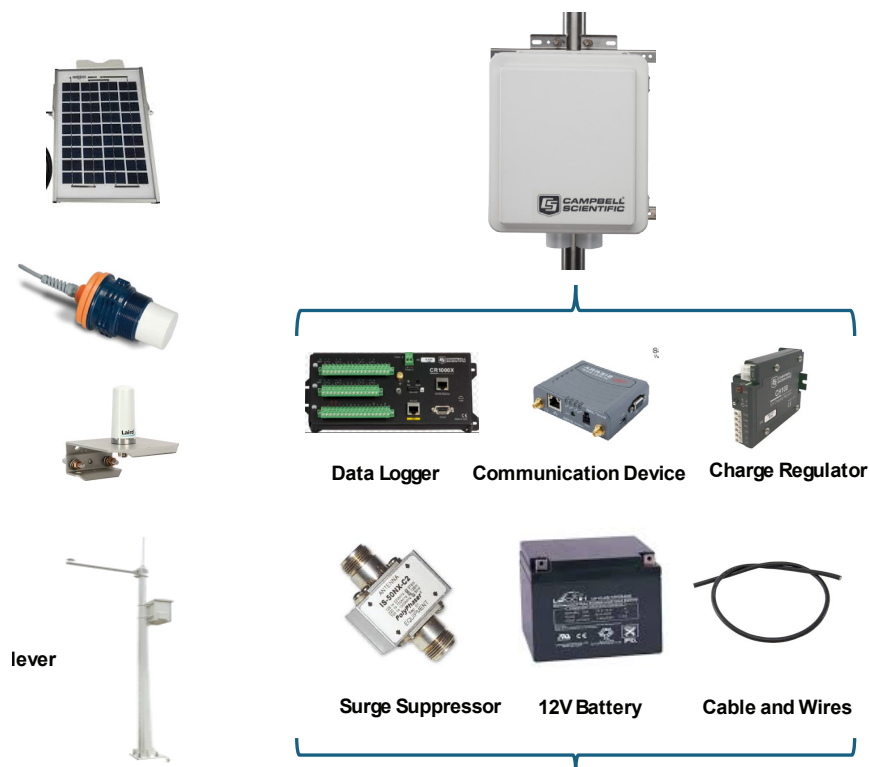


Figure 9. Typical hardware installed at remote canal locations.

The mild steel made manual gauges installed by the Irrigation Departments at these canal locations were found corroded resulting in deteriorated and illegible paint-markings due to submergence in water or highly moist conditions. To address this issue, IWMI developed stainless steel gauges with laser-cut markings, which were installed at the instrumented canal locations (Figure 10). This simple technology was highly appreciated by the field staff due to its durability and laser-cut markings.

The sensor data and dataloggers, while a communication device was used to transmit data periodically to a cloud server using File Transfer Protocol (FTP). A database in MS SQL was developed and hosted on the cloud server. The database was used to store data, process it, design reports by querying processed information. Algorithms were written in C# language (also called SQL Server Integration Services (SSIS) package) to read data files received at the server, store them in database tables and to post-process it automatically. A dashboard was developed in MS Access where users could feed in external parameters such as average bed elevation, datalogger identifier, rating function, etc. The users could visualize data, generate custom-built reports, including volumetric reports (10-daily and seasonal) through this dashboard when required. A web-based reporting service using MS SQL was also provided to the users from various stakeholders.



Figure 10. Stainless Steel Staff Gauge and ordinary painted gauge installed in a stilling well at the Lower Bari Doab Canal. (photo: Muhammad Tousif Bhatti/IWMI)

The stakeholders demanded to share flow information in different ways during proof-of-concept phase. The flow information was disseminated on a daily basis via SMS service and WhatsApp messages. For these services, a SMS server was subscribed to by a local service provider and codes were written to fetch flow data from the server and write it in SMS for automatic sending to users. The most visible forms of data dissemination technology were data screens. IWMI installed a dot-matrix screen that was programmed to fetch data and display on the screen. The screen was installed in PCRWR HQ in Islamabad. One of the limitations in dot-matrix screens was that it could only show discharge values, whereas data could be more appealing if presented in graphical format. It was, therefore, decided to use LED screens to show live data. To enable it, Raspberry Pi devices were attached to LED screens installed in key stakeholder offices, and python scripts were written to fetch data from the server for presenting it in tabular and graphical forms. Figure 11 shows the data flow diagram from the client to users, which lists various data dissemination technologies developed for users.

Different data verification methods were also used to build confidence among stakeholders. These include independent monitoring of depth of flow using cameras and contact sensors (pressure transducers), and then comparing the paired data from independent methods with that measured by ultrasonic rangefinders. Bhatti et al. (2019) storages, and outflows that is trusted by all parties, transparent, and accessible. An earlier attempt for telemetering flows in the IBIS did not deliver. There is now renewed interest in revisiting telemetry in Pakistan's IBIS at both national and provincial scales. These investments are typically approached with an emphasis on hardware procurement contracts. This paper describes the experience from field installations of flow measurement instruments and communication technology to make the case that canal flows can be measured at high frequency and displayed remotely to the stakeholders with minimal loss of data and lag time between measurement and display. The authors advocate rolling out the telemetry system across IBIS as a data as a service (DaaS have discussed the results of such verifications in detail. The authors have proposed a six-step data quality process including definition, assessment, analysis, control, implementation, and improvement. The primary focus of this report is to narrate the evolution and implementation of Indus Telemetry.

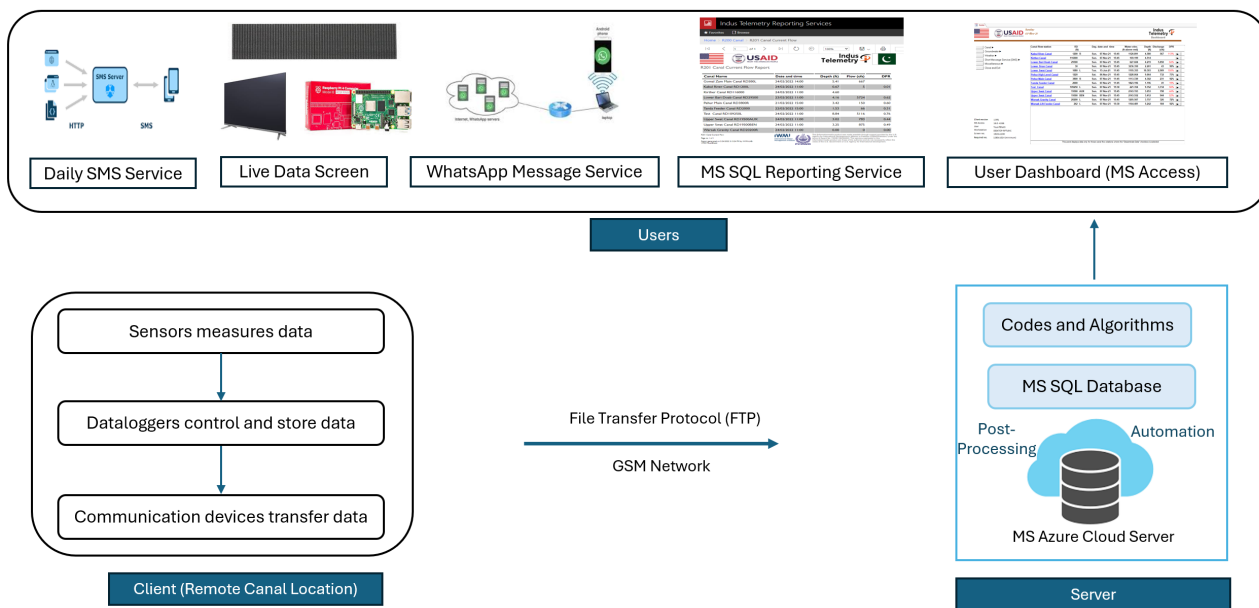


Figure 11. Data flow diagram in a client-server-user architecture

Many technical challenges were faced during this process and most of those were overcome with research and development. It is pertinent and valuable to provide a summary of the challenges and how they were addressed during the proof-of-concept phase and perhaps what worked and what did not.



Data Screen Installed at IRSA HQ in Islamabad. (photo: Riaz Wicky/IWMI)

Table 9. Challenges faced during proof-of-concept phase of Indus Telemetry

Component	Challenge	What Worked	What did not work
Power	Indus Telemetry used 20W solar panels and 24 Ah backup battery to power the system including sensor, datalogger and communication device. The power appeared to drop during cloudy and foggy days.	Communication devices seem to consume more power. Data communication was scheduled only during daytime (3 times) and a threshold of 11V was set below which communication stops without shutting down system. Power challenges due to fog were rectified in subsequent phases by upgrading backup battery, solar panel size and relocating solar panels to a better place.	During long fog spells, the battery used to drain. Also, in some cases the tree canopy hindered sunlight on solar panels.
Communication	Signal strength and timely top up of GSM SIM needed to transfer data.	Testing communication using all mobile operators' SIMs at the canal locations and selecting one with best signal strength. Timely and systematically top up all SIMs.	A closer look at the most recent data file may indicate possible reasons (battery voltage draining, etc.) for data not being received at the server. In some instances, however, it is not possible to judge the underlying reasons by just looking at the previous data trends.
Datalogger internal battery	Datalogger comes with an internal battery to keep its clock running. Weak internal batteries may cause the clock to reset and halt data communication.	The issue arises due to the age of datalogger. The only solution is to replace the datalogger's internal battery.	
Data post-processing	Incomplete data files or cluttered data rows can cause data processing to enter a recursive loop, resulting in generation of duplicate records. This issue often leads to the accumulation of unprocessed data files in the FTP folder.	Regular monitoring of the data and checking for unprocessed file. Delete the file (or incomplete row) and remove duplicate records manually.	
Change in external parameters	Several external parameters used in calculations change over time. The average bed elevation can vary due to sediment deposition/ or bed erosion causing incorrect depth and discharge calculation.	Survey the cross-section and adjust change in external parameters periodically. Ideal time is during canal closure for dredging season.	
Data quality	Any interference with sensor may cause incorrect reading, for example bathing right below the ultrasonic sensor.	Avoid locations for sensor installation used as public recreation and bathing.	

Continued >>>

Continued >>>

Physical Security	Vandalism and theft may happen at locations with no surveillance. Solar panels and backup batteries can be an easy target.	Securing the instrument box by constructing concrete walls around the main pole/ fencing and using razor wires, locking the instrument box. Selecting as secure a location as possible.	During the summer, there were occasional incidents where children engaged in playful behavior that resulted in damage to solar panels, such as throwing stones at them.
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Institutional Engagement

The beneficiaries of Indus Telemetry span a wide spectrum of institutions, from federal entities such as the Ministry of Water Resources, IRSA and PCRWR, to the provincial irrigation departments of Sindh, Punjab, Khyber Pakhtunkhwa, and Balochistan. Meaningful engagement with these stakeholders has been central to the successful adoption of this research-driven technological solution. Throughout the Indus Telemetry journey, strong emphasis was placed on fostering collaboration with key national and provincial agencies to ensure relevance, ownership, and long-term sustainability.

During the proof-of-concept phase, PCRWR served as a trusted government partner, owing to its broad statutory mandate. As per its founding legislation, PCRWR is responsible for “developing and maintaining a national water resources database for use by planning and implementing agencies, as well as the public.” This mandate positioned PCRWR as a natural fit for piloting Indus Telemetry, with its emphasis on data integrity and transparency.

As a research-focused institution, PCRWR values high-quality data and has no operational role in managing the waters of the Indus Basin. This independence ensures that it has no vested interest in influencing water data, allowing it to provide impartial quality assurance and control. Moreover, as a federal entity, PCRWR has the institutional legitimacy to certify data, demonstrated through its recognized role in water quality testing for bottled drinking water across Pakistan.

An important mechanism for engaging key government institutions in the development was the establishment of the Indus Telemetry Advisory Committee. The committee’s Terms of Reference outlined a broad mandate, with a particular focus on providing strategic advice and technical guidance. This included, but was not limited to, input on equipment specifications, sensor calibration, site selection, data acquisition and processing, archiving protocols, dissemination strategies, and the integration of telemetry data into IRSA’s Water Account Reports and related deliberations.

The Advisory Committee was formed through a series of meetings between IWMI/PCRWR and IRSA, the Secretaries of the four provincial irrigation departments, Project Director, Water Sector Capacity Building and Advisory Services Project (WCAP), and the Ministry of Water Resources (MoWR). Table 10 shows a brief history of these meetings and the nominated members of the Committee (Focal Persons) by each institution. All official correspondence in arranging these meetings was made by PCRWR. During the meetings, the provincial secretaries showed keen interest in Indus Telemetry. They provided the necessary permissions to install one instrument at one canal each in Punjab, KP, Sindh and Balochistan. The names of canals are also listed in Table 10.

Table 10. Indus Telemetry Advisory Committee established during proof-of-concept phase

Institution	Dated	Location	Canal	Committee Member/ Focal Person
Irrigation Department Khyber Pakhtunkhwa	13 Apr 2018	Peshawar	Upper Swat Canal	Mr. Zahoor Muhammad Executive Engineer
Irrigation Department Balochistan	18 Apr 2018	Quetta	Kirther Canal	Mr. Abdus Sattar Lakhti Chief Engineer
Irrigation Department Sindh	19 Apr 2018	Karachi	Pat-Feeder Canal	Mr. Zareef Iqbal Khoro Project Director Chotiari Dam
MoWR (WCAP)	27 Apr 2018	Islamabad	-	Mr. Muhammad Ukasha Program Officer
Indus River System Authority (IRSA)	18 May 2018	Islamabad	-	Mr. Khalid Idrees Rana Director Operations
Irrigation Department. Punjab	02 Jul 2018	Lahore	Lower Bari Doab Canal	Mr. Habib Ullah Bodla Chief PMIU



Indus Telemetry Advisory Committee meeting and visit to Upper Swat Canal. (photo: Riaz Wicky/IWMI)



Group Photo of Indus Telemetry Stakeholders' meeting in Lahore. (photo: Riaz Wicky/IWMI)



Group photo of Indus Telemetry Stakeholders' meeting in Peshawar. (photo: Riaz Wicky/IWMI)



Group photo of Indus Telemetry Stakeholders' meeting in Islamabad. (photo: Riaz Wicky/IWMI)

Several meetings and field visits of the advisory committee were organized during the proof-of-concept phase. The advisory committee had been a useful forum to share progress, challenges in technology prototyping and field level issues, and providing directions for future endeavor.

Indus Telemetry: Uptake and Upscaling Phase

The proof-of-concept phase successfully demonstrated the installation of telemetry instruments at one canal site in each of the four provinces. However, a more significant achievement was the active engagement of key federal and provincial institutions, which initiated a broader dialogue on technological solutions for flow monitoring. The formation of the Indus Telemetry Advisory Committee stands as a testament to this institutional collaboration. Technology served not only as a tool for data collection but also as a catalyst for discussions around interprovincial water distribution and measurement. The experiences gained during the Proof-of-Concept and Uptake & Upscaling phases were distinct, shaped by differing objectives, geographical contexts, technological choices, partner institutions, and governance structures. The Proof-of-Concept phase emphasized demonstrating technological feasibility and fostering national-level stakeholder engagement, requiring a consultative and formal approach. By the time the Uptake & Upscaling phase commenced, the technology had already been validated and demonstrated to both federal and provincial stakeholders. This allowed the focus to shift toward addressing specific implementation challenges in Khyber Pakhtunkhwa's main canals. This phase was carried out in close collaboration with the Government of Khyber Pakhtunkhwa Irrigation Department (GoKP-ID), and involved intensive field research to install velocity sensors, develop data validation protocols, and test improved data dissemination methods and system upgrades.

Geographic Coverage

After a successful demonstration of technology, the likely next step was to expand the geographical coverage of the Indus Telemetry. For this, IWMI offered the MoWR to allow IWMI and PCRWR to install some available hardware on other channels. However, the proposal was not accepted by the Ministry as it was considering starting a telemetry project covering the entire IBIS, including the rivers. Therefore, to avoid any duplication, it was decided to focus on Khyber Pakhtunkhwa province. There were several reasons for this decision, other than duplication of effort:

- Most importantly, no main canals in KP province were considered in a WAPDA Telemetry project in 2004 except Chashma Right Bank Canal (CRBC), which is an interprovincial canal supplying water between KP and Punjab provinces.
- There was no plan to include the main canals of KP in future telemetry projects (with the exception to CRBC).
- There are 14 main canals in KP (Table 4). The volume withdrawn in these 14 canals makes up the provincial water share from the Indus River system.
- The GoKP-ID took keen interest in technology and agreed to benefit from the Indus Telemetry.
- Financial resources were available from the USAID to cover the cost associated with R&D, instruments procurement, installation, maintenance and data post-processing, etc.

Therefore, reconnaissance to all fourteen (14) main canals was carried out along with the technical staff of GoKP-ID. After detailed consultations, it was decided to phase out installation at the main canals, excluding CRBC, to avoid duplication. Marwat Canal was also not considered due to the raising of the Baran dam from which it was fed. Muqam Nullah, 3rd Lora Canal, and Warsak Left Bank canals were also not included because of their very small relative size and security concerns. Instead, two additional canals were considered, namely the Gomal Zam Canal due to its large command area and the Khanpur Dam Left Bank Canal, which is interprovincial between KP and Punjab. Neither canal is considered a Tier 1 canal. They do not contribute to KP's provincial water share from the Indus River system and hence are not reported to IRSA. Figure 12 shows the locations of the Indus Telemetry Canals in Khyber Pakhtunkhwa Province, whereas Table 11 provides information about these canal locations referred in Figure 12. These 11 canals irrigate around 0.114 million acres of agricultural land in Khyber Pakhtunkhwa.

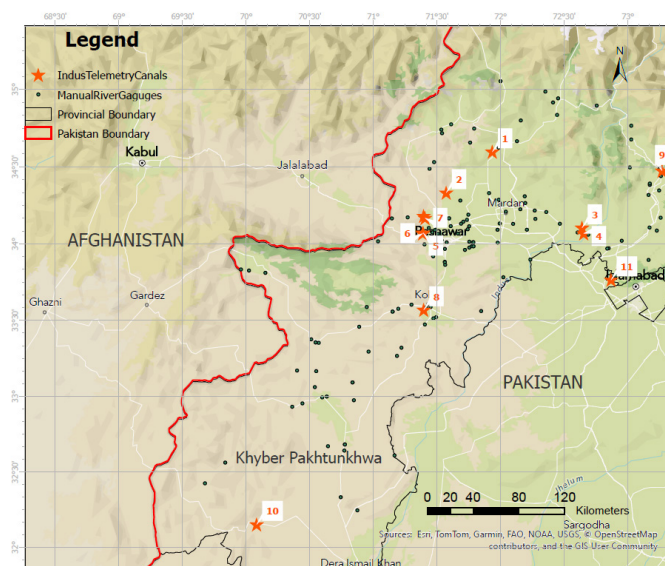


Figure 12. Location map of Indus Telemetry Canal Locations in Khyber Pakhtunkhwa

Table 11. Canal locations considered for Indus Telemetry in Khyber Pakhtunkhwa

Legend Indus Telemetry Canals	Canal Name Long Form Long Form	Canal Name Short Form	Reduced Distance ft	Design Capacity		Culturable Command Area (CCA)		Gross Command Area (GCA)	
				cumec	cusec	ha	ac	ha	ac
1	Upper Swat Canal- Benton Tunnel	USC	19,500	50.4	1,780	129,095	319,000	171,992	425,000
	Upper Swat Canal- Auxiliary Tunnel	USC	19,500	51.0	1,800				
2	Lower Swat Canal	LSC	1,080	54.9	1,940	54,430.3	134,500	59,873	147,950
3	Pehur High Level Canal	PHLC	295	28.3	1,000	1,187.35	2,934	1,384	3,420
4	Pehur Main Canal	PMC	3,800	7.1	250	17,567	43,409	19,338	47,785
5	Warsak Gravity Canal	WGC	20,200	15.6	550	1,5106.1	37,328	19,102	47,201
6	Warsak Lift Feeder Canal	WLFC	2,420	5.7	200	13,186	32,584	18,549	45,836
7	Kabul River Canal	KRC	1,200	12.7	450	9,849	24,338	11,407	28,188
8	Lower Siran Canal	LSiC	50	1.4	48	2,740	6,770	3,297	8,148
9	Tanda Irrigation Main Canal	TIMC	2,900	6.1	215	12,290	30,370	15,176	37,500
10	Gomal Zam Main Canal	GZMC	580	24.0	848	77,335	191,100	109,670	271,000
11	Khanpur Dam Left Bank Canal	KDLBC	26,500	4.2	150	685	1693	992	2451

The Issue of Rating Table

The Indus River and its irrigation network are a complex system. The interprovincial transfer of flow is measured by conventional methods that create mistrust amongst the provinces. It is a purely technical issue, but very quickly escalates to a political level due to the immense importance of water in the agricultural economy of the country. It was learnt through the stakeholders' discussions during Indus Telemetry forums and events that rating tables are the main issues and weakest link in trust building on discharge measurement.

To understand the rating table issue, it is helpful to refresh the understanding of how discharge is measured in open channels. Open channels are the structures (waterways, canals or conduits) 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 through gravity. Flow monitoring is an important measurement for 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 respond promptly to conditions such as flooding or low flow and make decisions to operate canals when control structures are available. Figure 13 shows the flow calculation in an open channel.

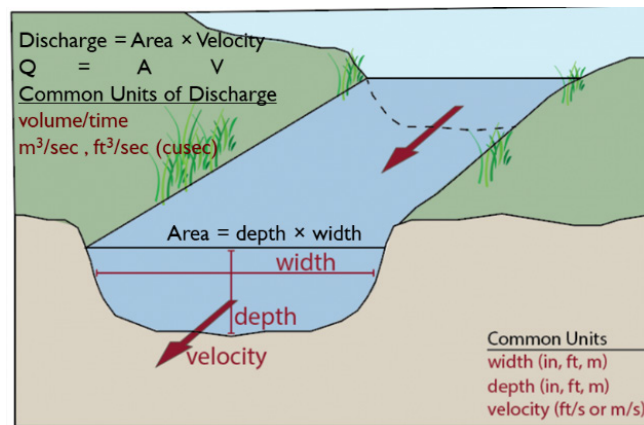


Figure 13. Schematic representation of flow measurement in open channel

The practice to estimate discharge in the IBIS is to assume that the canals behave as wide rectangular channels under uniform flow and hence the discharge rating curve is of the form.

$$Q = CH^{5/3} \quad (1)$$

where Q = discharge; C = rating curve coefficient determined empirically; and H = depth-of-flow. From L'Hopitals Rule and the Manning equation, the coefficient in (1) is given by:

$$C = \frac{BS^{1/2}}{n_c} \quad (2)$$

where B = width of canal; S = bed slope of canal; and, n_c = Manning roughness coefficient. Equation (1) is often generalized to

$$Q = CH^m \quad (3)$$

Where the coefficient C and m in equation (3) are determined from flow meter measurements and an ordinary least squares linear regression of a log transformation of (3).

The most straightforward procedure to develop a rating function as in equation (3) is to measure depth of flow and discharge simultaneously at a cross-section and repeat it for different flow conditions (low to high flow). Plot the paired data time series and apply regression. A mathematical function developed based on the relationship between depth of flow and the discharge (volume of water flowing per unit of time) is referred to as rating function. The paired data of depth of flow and discharge is presented in tabular form called rating table. Measuring cross sectional area and velocity using current meters is a time and resource intensive exercise and not feasible to be performed frequently. Rating tables

address this challenge and make it convenient for monitoring agency only to read depth of flow from manual gauges and get the corresponding discharge from the table.

Despite the utility of the rating table/function, its major shortcoming is its short time validity and limited accuracy particularly when the paired data set is small. Rating functions require regular updating, but specifically when the bed level is changed due to sediment deposition/erosion, or when the cross-section is altered due to remodeling /breach. The issue of the rating table was highlighted in water dialogues organized by IWMI in all the provinces. An exclusive dialogue was also convened by IWMI where specific issue of rating equation was discussed in detail. The provinces of Balochistan and Sindh follow different versions of rating table/function to calculate discharge at Pat-Feeder Canal RD 109. Figure 14a shows the two versions of depth of flow vs discharge relationships plotted simultaneously while Figure 14 b shows the percent difference (%) and Absolute Difference (cusec) between the discharge calculated when two different rating functions are used.

Figure 14b shows that at shallow depth of flow the two rating functions give a smaller absolute difference in discharge and as the depth of flow, increases this absolute difference magnifies. For example, when the depth of flow is 0.5 ft (0.152 m), the absolute difference between the discharge calculated by the two rating equations is 67 cusec (1.9 cumec), which become substantially high as 2295 cusec (65 cumec) at 10 ft (3.028 m) depth. The bar graph in the same Figure shows the percent difference calculated by dividing the absolute difference by the average discharge calculated by the two rating functions. Both indicators give useful information. The absolute difference tells how much larger or smaller one discharge value is than the other in actual units. The percent difference tells what percentage of the average value the difference represents. In some situations, the absolute difference is more meaningful. For example, if comparing the number of people in two cities, the absolute difference in population might be more relevant than the percent difference. In other situations, the percent difference is more useful. For example, if comparing the performance of two investment portfolios, the percent difference in returns is a better indicator of relative performance. Moreover, the percent difference is less sensitive to the scale of the values being compared. A significant absolute difference might represent a small percent difference if the average value is also large. This is the case represented in Figure 14b where a large absolute difference in discharge corresponds to more minor percent difference as the average value of the two discharges becomes large with increase in depth of flow. From this discussion, it can be inferred that the absolute difference is a better indicator when comparing the performance of the two rating functions.

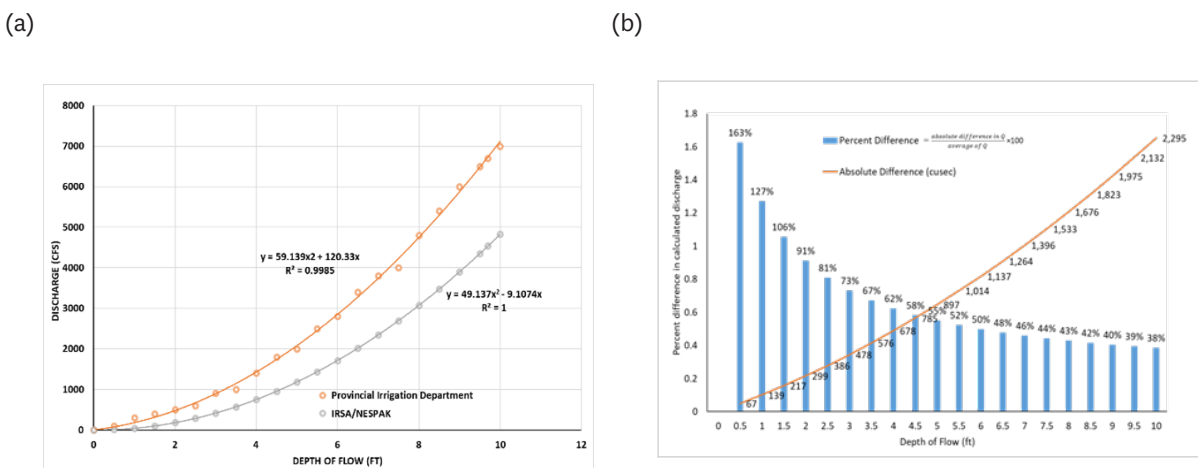


Figure 14. (a) two versions of rating functions at Pat-Feeder Canal RD 109; (b) difference in discharge calculation by using both rating functions

It does not mean that the rating table issue is specific to Sindh and Balochistan provinces. During the field visits to main canals in KP, it was found that the rating functions at most of the canals were outdated and never updated since a long time. In some cases, they were completely missing and the field staff used to report discharge based on their judgement.

In this backdrop, it was imperative to find a solution to the problem of rating functions. Two potential pathways were considered: (i) developing new rating functions for each canal equipped with Indus Telemetry, or (ii) identifying a substitute method that could bypass the need for rating functions altogether. The first option was deemed impractical by stakeholders due to its time-intensive nature and the risk of non-adoption, as previously experienced with the Pat-Feeder Canal.

It was therefore decided to find an alternative solution to this problem. After some research, two options were found to be practiced in advanced countries. First was a horizontal ADCP, which can be deployed in open channels for long-term monitoring. It works on the same principle as a vertical ADCP (which is mounted on a boat and used for spot flow measurement), but fixed on the side wall and looks horizontally while in water. However, the range of horizontal ADCP depends on the channel's water depth. In shallow channels and streams, the acoustic waves can cover smaller distances due to the propagation angle from the sensor. Moreover, the horizontal ADCP are expensive and need to keep deployed in water and require additional maintenance.

The second option, i.e., non-contact surface velocity sensors, emerged as a more feasible solution. These sensors could be retrofitted alongside existing ultrasonic rangefinders to estimate discharge without relying on rating functions. However, a key limitation was that they measure only surface velocity, whereas discharge calculations require the average velocity across the entire cross-section. To address this, field experiments were conducted across multiple canal sites to establish a reliable relationship between surface and average velocity. Vertical ADCP³ was deployed to capture high-resolution velocity profiles at the same cross-sections where non-contact sensors were installed. This enabled the development of a mathematical model correlating surface velocity with average cross-sectional velocity. The process also validated the accuracy of surface velocity measurements from non-contact sensors, which showed strong agreement with ADCP-derived data at the surface layer.

Technology Upgrade

In the initial phase of the Indus Telemetry, only ultrasonic sensors were deployed at instrumented canal locations. However, specific challenges emerged at sites such as the Warsak Lift Feeder and Pehur Main canals, where reliance on depth measurements alone proved insufficient for accurate discharge estimation.

The Warsak Lift Feeder receives water from the Warsak Gravity Canal, which is collected in a sump at the pumping station situated at 1,245 ft (379.5 m) above mean sea level. From there, five large centrifugal electric pumps (each with a capacity of 50 cusec (1.42 cumec)) lift water to the Warsak Lift Canal, aligned at an elevation of 1,400 ft. During pump shutdowns—whether due to power outages or reduced demand—water in the feeder canal becomes stagnant.

In such conditions, depth reading alone cannot reliably indicate flow, as velocity approaches zero. A similar situation occurs in the Pehur Main Canal, where pumps are installed shortly downstream of the canal inlet. When inactive, these pumps cause water to accumulate upstream, resulting in ponding and elevated water levels without corresponding flow. To address these challenges, velocity sensors were introduced. These sensors can detect low flow velocities and even identify reverse flow conditions. When integrated into the continuity equation, they enable accurate discharge calculations, even in stagnant or low-flow scenarios. This technological enhancement significantly improved the reliability of flow monitoring in complex hydraulic conditions.

With a feasible solution identified to address the limitations of rating functions and challenges posed by ponding in canal segments, a plan was developed to source and retrofit velocity sensors into existing Indus Telemetry installations. The first step was to prioritize canal sites where accurate flow monitoring was not possible without velocity measurements.





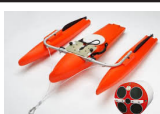

³ An Acoustic Doppler Current Profiler (ADCP) is a type of sonar that measures and records water current velocities over a range of depths. Teledyne RD Instruments actually designed and delivered the industry's first ADCP in 1982. The ADCP is now considered an essential tool for oceanography, estuary, river, and stream flow current measurement worldwide.

The Pat-Feeder Canal was selected as the initial site, and a velocity sensor was successfully installed in November 2020, followed by deployment at the Warsak Lift Feeder Canal. The performance of these sensors was monitored over an extended period, during which spot flow measurements using ADCP were conducted for validation. The comparison between discharge calculated through Indus Telemetry (using ultrasonic and velocity sensors) and ADCP measurements showed strong agreement, confirming the reliability of the new approach. These findings were presented to the GoKP-ID during consultation workshops. Impressed by the demonstrated accuracy and performance, GoKP-ID formally requested the installation of velocity sensors at all canal locations equipped with Indus Telemetry.

In response to the partner department's request, IWMI arranged for velocity sensors at all instrumented canal sites, except for the Upper Swat Canal (USC). This exception was due to the presence of a Crump Weir (a dedicated discharge measuring structure) at USC, which does not require velocity measurements. Accurate discharge readings at weirs can be obtained by measuring the head above the crest. Therefore, at USC, two ultrasonic depth sensors were installed to monitor water levels above the weir crests in the Benton and Auxiliary tunnels separately, enabling individual flow measurements for each tunnel. Technology upgrade during the uptake and upscaling phase was not limited to retrofitting velocity sensors.




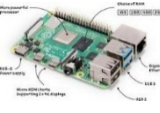
The technology upgrades introduced during the Uptake and Upscaling phase extended beyond the retrofitting of velocity sensors. Several additional sensor types were installed and tested to enhance the system's functionality, as detailed in Table 12.

Table 12. Instrument upgradation for Indus Telemetry during Uptake and Upscaling Phase

Sensor/Instrument	Brands/ Model	Specifications	
Velocity Sensor	Geolux RSS-2-300W Surface Velocity Radar	https://www.geolux-radars.com/rss2300w 	
Velocity Sensor	OTT SVR 100 Surface Velocity Radar	https://www.ott.com/products/water-flow-3/ott-svr-100-2406/ 	
Suspended Sediment	Campbell Scientific OBS 501 Suspended Sediment Sensor	https://www.campbellsci.com/obs501 	
Acoustic Doppler Current Profiler (ADCP)	Teledyne Stream Pro ADCP	https://www.teledynemarine.com/brands/rdi/streampro 	
ADCP	Teledyne River Pro ADCP	https://www.teledynemarine.com/brands/rdi/riverpro-adcp 	
Groundwater/ Surface Water Depth Temperature Electrical Conductivity	CTD Diver	https://www.vanessen.com/products/data-loggers/ctd-diver/ 	

Continued >>>

Continued >>>

Sensor/Instrument	Brands/ Model	Specifications	
Automatic Weather Station (AWS)	Campbell Scientific AWS is equipped with sensors for temperature, relative humidity, solar irradiance, wind speed and direction, atmospheric pressure, and rainfall.	https://www.campbellsci.com/automated-weather-stations	
Snow Depth	Snow Water Equivalent/Snow Depth Sensors / SnowVue 10	https://www.campbellsci.com/snowvue10	
Display	Commercial LED screens/ LED TV of various brands		
Single Chip Computer	Raspberry Pi RPI 3 RPI 4B	https://www.raspberrypi.com/	

As part of the broader technology upgrade during the Uptake and Upscaling phase, additional sensors were deployed beyond the velocity retrofits. These included surface water quality and sediment sensors at the Gomal Zam Canal, weather stations at seven strategic locations across all four provinces, and groundwater monitoring sensors in Punjab. All data generated from these sensors was integrated into the Indus Telemetry database for centralized storage and processing.

This section provides a brief overview of the components of sediment and surface water quality monitoring. Details related to the piloting of weather and groundwater monitoring are intentionally excluded to maintain focus on canal flow monitoring, which remains the primary objective of this report.

Surface water quality and suspended sediment monitoring

Sediment inflow into the Gomal Zam Canal has been a persistent concern for the Government of Khyber Pakhtunkhwa Irrigation Department (GoKP-ID). The canal is fed by releases from the Gomal Zam Dam, and a 37-kilometer stretch of the Gomal River downstream of the dam receives sediment from two primary sources: flushed sediments discharged through the dam's low-level outlet and runoff from the sub-catchment area, particularly following rainfall events. These conditions result in substantial sediment loads entering the canal system. Bhatti et al. (2021) examined this issue in detail and proposed potential management strategies.

Before the Indus Telemetry initiative, there was no mechanism in place to quantify suspended sediment concentrations in the canal. IWMI addressed this gap by installing automated sensors, likely for the first time in Pakistan, to measure both suspended sediment and dissolved solids (as electrical conductivity) in the Gomal Zam Canal. These sensors were integrated with the existing flow monitoring infrastructure under Indus Telemetry.

The suspended sediment sensor underwent rigorous calibration in both laboratory and field settings. Initial calibration involved testing water samples with varying sediment concentrations using both the sensor and conventional laboratory methods. Following installation, regular water sampling was conducted at the sensor site, and laboratory analyses were used to validate the sensor's readings. The results demonstrated, high level of accuracy and reliability, confirming the sensor's effectiveness in real-time sediment monitoring.

Live data screens

To effectively disseminate information from the Indus Telemetry database to a broader audience, live data screens were identified as the most practical solution. As previously described, the database houses a diverse range of data, including canal flow, weather, groundwater, and weather forecasts, necessitating the design of four distinct live data screens tailored to showcase this information to stakeholders.

LED screens were selected as the preferred display hardware due to their visibility and accessibility. However, since LED screens lack built-in computational capabilities to run scripts or retrieve data directly from the database, an additional hardware solution was required. This challenge was addressed by integrating low-cost, single-board computers known as Raspberry Pi, which operate on Raspberry Pi OS (formerly Raspbian), a Debian-based Linux distribution.

Custom Python scripts were developed to extract data from the Indus Telemetry database and present it in user-friendly formats, including tables, graphs, and maps. These live data screens, particularly those displaying canal flow information, were installed in the offices of key stakeholders, enabling near real-time monitoring and supporting informed decision-making (Figure 15).

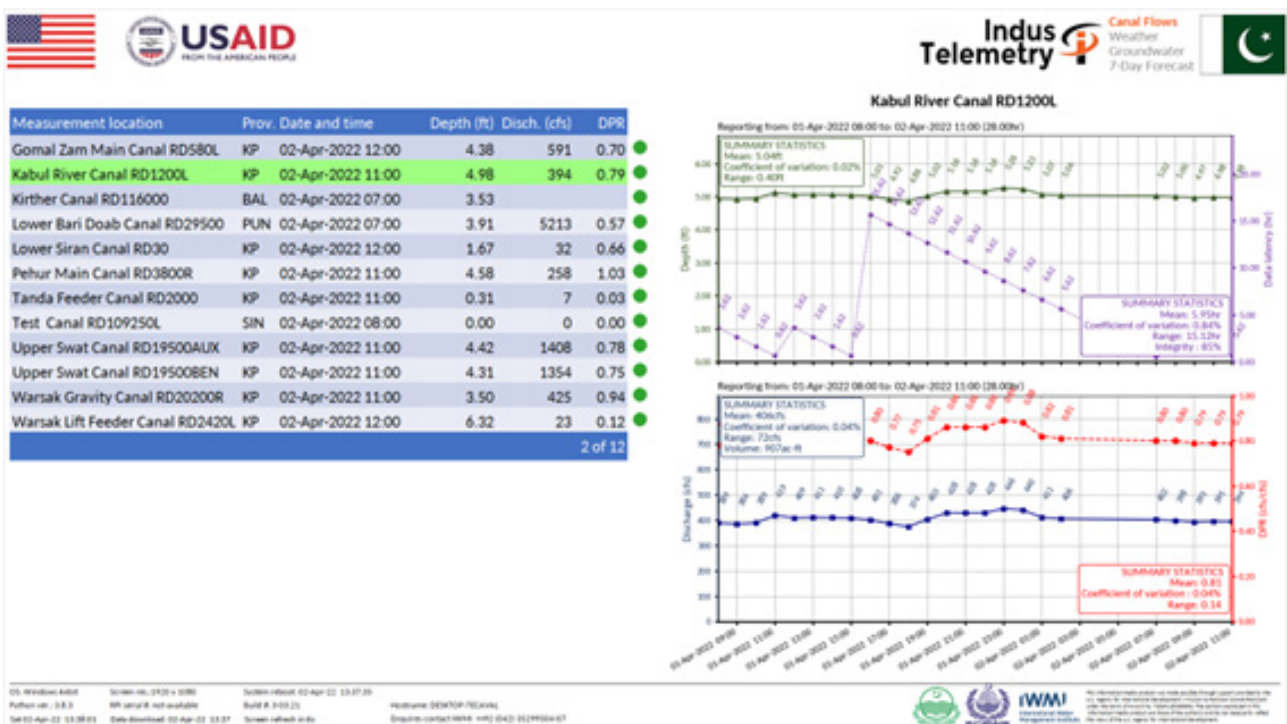


Figure 15. Screenshot of live data screen showing canal flows to showcase Indus Telemetry information

Software and computational resources

A critical component of Indus Telemetry’s infrastructure was its cloud-based computational environment. IWMI subscribed to Microsoft Azure, leveraging its robust cloud services to host the Indus Telemetry database and associated applications. Key software tools included Microsoft SQL Server for database management and RealVNC for secure remote access and system administration. This setup ensured scalable, reliable, and secure data storage and processing, enabling seamless integration of telemetry data from multiple sources.

Retiring technology

Indus Telemetry has served as a dynamic platform for testing innovative data acquisition technologies and information dissemination methods. Over time, a variety of services and tools were developed and piloted, many of which were well-received by stakeholders, while others elicited mixed responses. As the system matured, certain hardware components reached the end of their operational life or were discontinued by manufacturers. Additionally, some services proved resource-intensive, requiring significant time, financial investment, or computational capacity, prompting a strategic decision to focus monitoring efforts on priority areas.

As a result, several technologies and services were retired to streamline operations and ensure sustainability. Table 13 provides examples of these retired components, along with the rationale behind each decision.

Table 13. Retiring Technologies over the Indus Telemetry Journey.

Retiring Technology	Reason
WhatsApp Message Service	No of canals increased causing text to become lengthy WhatsApp group management
SMS service	No of canals increased causing text to become lengthy High cost of bulk SMS service
Groundwater Monitoring	Lack of interest in data sharing by partner organization CTD divers stopped working after passing their useful life
Weather Forecast	Lack of interest among stakeholders. High computational resources requirement Cost of Farmer Advisory Service

Indus Telemetry: Technology Transfer Phase

The Uptake and Upscaling phase of the Indus Telemetry marked significant progress in both technological advancement and institutional governance. The successful adoption of the technology was made possible by the enthusiastic engagement of GoKP-ID, which actively participated in instrumentation, validation processes, and technical consultations. The solutions offered by Indus Telemetry aligned well with the province's broader digitalization agenda. In many cases, the scaling of technology, methods, and reporting exceeded initial targets.

As field installations, validation, and programming neared completion, discussions naturally shifted toward the long-term sustainability of these efforts and the potential for technology transfer to GoKP-ID. These conversations were framed by the understanding that IWMI is a research-for-development organization. Indus Telemetry began as a national-scale research initiative in partnership with PCRWR, but its focus transitioned to Khyber Pakhtunkhwa during the Uptake and Upscaling phase due to strategic and operational considerations (discussed earlier in Geographic Coverage subsection of Uptake and Upscaling Phase), making GoKP-ID the principal partner.

IWMI's work was supported by financial contributions from development partners, notably the USAID, which funded the establishment of Indus Telemetry in KP. As the initiative matured, GoKP-ID raised important governance questions about the future of Indus Telemetry, particularly regarding ownership, operational continuity, and institutional responsibility. The main governance questions were:

- **Sustained support post-project:** IWMI has access to financial resources and technical expertise that enabled the development, establishment, and maintenance of Indus Telemetry. How does IWMI plan to continue supporting the system after the USAID-funded project concludes?
- **Technology ownership and capacity:** Indus Telemetry generates valuable data from key canal sites and weather stations across Khyber Pakhtunkhwa. While GoKP-ID is the primary user of this data, it faces financial and capacity constraints in assuming full responsibility for system management and maintenance. What is IWMI's strategy for transferring ownership and operational responsibility to GoKP-ID?

Both concerns were valid and required careful consideration. IWMI initiated a series of in-depth consultations with GoKP-ID professionals to explore sustainable pathways for technology transfer. The objective was to ensure that GoKP-ID could institutionalize the use of Indus Telemetry data and continue benefiting from the system without compromising its integrity or functionality.

The Indus Telemetry Launch Event

The Uptake and Upscaling phase culminated in a landmark event ‘the official launch of Indus Telemetry’ held on June 12, 2024, in Peshawar. The event celebrated the significant milestones Indus Telemetry achieved in Khyber Pakhtunkhwa and marked a turning point in the province’s journey toward digital water governance. It was proudly announced that Khyber Pakhtunkhwa had become the first province in Pakistan to fulfill a key requirement of the National Water Policy by deploying a state-of-the-art telemetry system across its main canals.

Speaking at the ceremony, the Provincial Minister for Irrigation acknowledged the limitations of traditional flow monitoring methods previously used by the department. He emphasized that the newly adopted technology ensures reliable data collection and supports accurate seasonal and annual water accounting, including audits of water diversions and allocations. Officially launching the Indus Telemetry System, the Minister stated:

“The deployment of the Indus Telemetry System marks a transformative step in our efforts to ensure sustainable water management and equitable distribution. This technology will enhance our capacity to manage water resources efficiently and transparently,”

The event was attended by over 100 water professionals, including representatives from GoKP-ID, USAID, NGOs, international organizations, line departments, and academia. During the ceremony, the Secretary of GoKP-ID unveiled a roadmap for strategic irrigation reforms in the province. He commended IWMI’s technical leadership and acknowledged the financial support provided by USAID in establishing the Indus Telemetry System.



Indus Telemetry Launching Event in Peshawar. (photo: Amjad Jamal/IWMI)

Indus Telemetry Launch Event and Beyond: Road Map

In response to the concerns raised by the beneficiary department, IWMI collaborated closely with GoKP-ID staff to co-develop a roadmap for the sustainable transfer of Indus Telemetry. The roadmap was designed to ensure a phased transition, minimizing financial, technical, and operational burdens associated with system maintenance.

To facilitate a smooth handover, the technology transfer was structured into three distinct components:

- **Hardware** – including sensors, data loggers, and communication devices installed at canal sites.
- **Database** – encompassing the data architecture, storage protocols, and processing systems.
- **Cloud Server** – covering hosting infrastructure, remote access tools, and system administration.

This phased approach allowed GoKP-ID to gradually build capacity and assume ownership of each component, ensuring continuity and long-term sustainability of the Indus Telemetry system (Figure 16)

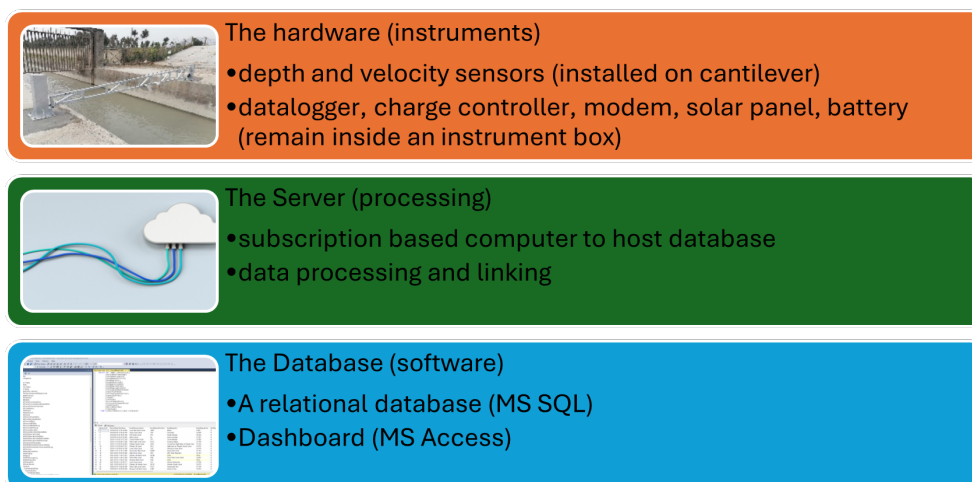


Figure 16. Components of Indus Telemetry

The hardware (instruments)

Telemetry is often considered merely as a piece of hardware comprising sensors and loggers. Hardware is an integral part of telemetry, but it is not the entire system. The first step in technology transfer was to handover hardware to GoKP-ID and shift the responsibility of its maintenance. Physical transfer of the hardware was straightforward as it was already installed at the beneficiary's locations, which are property of the department, therefore no formal transfer was required. However, an inventory for handing over of all the installed instruments was prepared by a joint team of IWMI and GoKP-ID Hydrology Division. During the visit, local field staff of the department also participated, who were oriented to the installed instruments and their working. The instruments are rugged and commercial grade, and they were installed after due process of calibration and stability test. Also, the instruments are powered with renewable solar energy and have very small physical footprint. All these features generally make the instruments maintenance free.

The only recurring maintenance expenditure shifted to GoKP-ID was the top-up cost for GSM data SIMS and periodical replacement of batteries. There have been very few cases where vandalism or damage of solar panel happened since the installation. The instrument box/ poles are secured by fencing with concrete blocks and razor wires. After the system launch event, the signed inventory and the keys of instrument boxes at all locations were handed over to the designated staff of the department.

Validation and quality control

Before the formal transfer of installed hardware, the Government of Khyber Pakhtunkhwa Irrigation Department (GoKP-ID) requested a fresh validation of the Indus Telemetry instruments. IWMI had been consistently validating sensors' data since the inception of the initiative, with particular attention to the newly introduced velocity sensors deployed for the first time in Pakistan for canal flow monitoring. Given the novelty of this technology, stakeholders were keen to assess its performance under local field conditions.

To meet this requirement, a joint validation exercise was conducted in July 2024 by a joint team of IWMI, PCRWR, and GoKP-ID's Hydrology Division. The most reliable portable flow measurement equipment, ADCP, was used to validate the flow data generated by Indus Telemetry. The comparison revealed strong agreement between ADCP measurements and telemetry-derived discharge values, confirming the accuracy and reliability of the installed sensors. A formal validation report was prepared and shared with GoKP-ID for record-keeping.

Table 14 shows validation results at Indus Telemetry sites. The discharge measured with ADCP and Indus Telemetry was statistically compared using Mean Absolute Percent Error (MAPE) as a performance metric. All canals showed small MAPE values except Warsak Lift Feeder Canal. The reason of the high MAPE was investigated and found that the canal bed had damaged at the location of sensors causing a change in average bed elevation. The advantage of ADCP measurement was that a high-resolution data set became available, which helped to update external parameters (usually average bed elevation and coefficient for surface to mean velocity conversion) set in the Indus Telemetry dashboard. These adjustments minimized the MAPE. For other canals, there was little or no need to adjust external parameters.

During the proof-of-concept phase, stakeholders often compared Indus Telemetry data with manually calculated discharge values. However, this comparison was inherently flawed due to differences in data resolution and reliance on rating functions. Manual gauge readings are prone to human error, mainly when transmitted across personnel for calculation. A common assumption was that manual data served as the most reliable reference for statistical evaluation. Indus Telemetry has helped correct this perception by demonstrating that instrument-based readings, when validated against ADCP measurements, offer superior accuracy.

Field demonstrations and training sessions on ADCP usage were instrumental in building stakeholders' confidence. Water professionals from GoKP-ID now recognize ADCP as the gold standard for discharge measurement and validation. In acknowledgment of its importance, IWMI included an ADCP unit in the hardware package handed over to GoKP-ID as part of the technology transfer process.

The server (processing)

A critical component of Indus Telemetry's backend infrastructure is its server environment, which supports data processing, storage, and application hosting. The software architecture includes subscriptions to cloud-based computational resources, operating systems, and essential services such as internet connectivity, applications, and cybersecurity protocols.

The server, essentially the central computer, where Indus Telemetry and its associated applications are hosted, handles all backend data processing. IWMI initially subscribed to Microsoft Azure cloud services, providing secure access to authorized users via the internet. [Microsoft Azure](#) offers a range of pricing plans and service bundles, which are publicly available.

During discussions with GoKP-ID regarding server sustainability, two key constraints emerged: limited budget for IT infrastructure and a shortage of skilled personnel to manage server operations. Given these limitations, it was deemed impractical for GoKP-ID to maintain a dedicated physical server, which would require uninterrupted power supply, reliable internet, air conditioning, and a full-time IT professional to manage system administration and cybersecurity.

Cloud-based solutions were explored, including commercially available options hosted within Pakistan. However, even locally hosted cloud services proved financially unviable for GoKP-ID. The only feasible and sustainable alternative was the government-owned cloud server managed by the Khyber Pakhtunkhwa Information Technology Department. This server, housed at the KP Data Centre, is maintained by professional IT staff and is available to line departments for official computational tasks at no cost to GoKP-ID.

IWMI facilitated the migration of the Indus Telemetry database and all associated applications to the KP Data Centre's Linux-based server platform. This transition resolved the issue of subscription costs and ensured long-term sustainability of the system. Technical expertise and inter-departmental coordination required for the migration were also arranged by IWMI, completing a key milestone in the technology transfer process.

Table 14. Validation of Indus Telemetry Instruments

Serial #	Date	Canal	Location	Measurement Time		Q _{avg1} ADCP		Q _{avg2}		Abs. Percent Diff. between Q _{avg1} and Q _{avg2} (%)
				From	To	cumec	cusec	cumec	cusec	
1	Wednesday, July 24, 2024	Pehur Main Canal	RD 3800	10:20:23	10:54:29	10.46	369.524	9.59	338.75	9.08
2	Wednesday, July 24, 2024	Pehur High Level Canal	RD 1220	12:54:25	13:07:17	19.95	704.528	19.59	691.65	1.86
3	Tuesday, July 23, 2024	Kabul River Canal	RD 1200	10:56:46	11:03:20	9.14	322.895	9.78	345.22	6.47
4	Monday, July 22, 2024	Warsak Gravity Canal	RD 20200	11:17:41	11:29:47	10.77	380.398	10.93	385.95	1.44
5	Monday, July 22, 2024	Warsak Lift Feeder Canal	RD 2420	13:03:18	13:12:10	4.04	142.777	2.15	75.82	88.31
6	Thursday, July 25, 2024	Lower Swat Canal	RD 1200	10:50:39	10:59:20	49.71	1755.522	47.86	1690	3.88
7	Friday, July 26, 2024	Upper Swat Canal	RD 18787	11:11:45	11:25:08	86.98	3071.523	88.85	3137.61	2.11
8	Monday, July 29, 2024	Lower Siran Canal	RD 200	12:28:27	12:42:09	0.65	23.108	0.62	21.95	5.28
9	Tuesday, July 30, 2024	Khan Pur Dam Left Bank Canal	RD 56500	11:26:37	11:33:07	3.59	126.941	3.65	129.05	1.64
10	Wednesday, July 31, 2024	Tanda Irrigation Main Canal	RD 150	10:29:52	10:32:35	1.39	48.964	1.29	45.63	7.31

Note: the validation at Gomal Zam Canal could not be performed due to security situation during the visit.

The database (software)

A common misconception in IT systems is conflating database development with database management. In the case of Indus Telemetry, these are distinct yet interdependent functions. The database was originally developed as a relational structure using Microsoft SQL Server and hosted on Microsoft Azure. Data acquisition from field instruments, processing, and reporting were automated using SSIS packages written in C# and Python. These scripts and algorithms enabled efficient data handling and querying through various user-facing applications—activities that fall under database development.

Database management, on the other hand, involves ensuring the smooth operation of these scripts and algorithms, maintaining data integrity, and performing routine tasks such as record updates, user administration, permission changes, and password management. These tasks were carried out using a custom-built dashboard developed in MS Access, Open Database Connectivity (ODBC), and Microsoft SQL Server Management Studio (SSMS).

Developing and managing a database like Indus Telemetry requires a rare combination of IT expertise and domain knowledge in hydraulics and instrumentation. Recognizing the complexity and specialized skill set required, GoKP-ID expressed reluctance to take over the database due to limited in-house capacity and the high subscription cost of MS SQL Server (see pricing plans at: <https://www.microsoft.com/en-us/sql-server/sql-server-2019-pricing>). Although free and open-source alternatives such as MySQL, PostgreSQL, and MariaDB were available, transitioning to these platforms would require the redevelopment of the entire database and associated applications. Taking a long-term view, IWMI opted to redevelop Indus Telemetry using PostgreSQL, an open-source relational database system. This decision was further justified by the fact that GoKP-ID was already using PostgreSQL for its official “KP-Water” database, which stores manual flow records and reporting data.

It was agreed that Indus Telemetry would be integrated with KP-Water, allowing users to access telemetry data through a unified dashboard. This integration was successfully completed, and all dataloggers at canal sites were reprogrammed to transmit data to the new server address.

This final migration marked the conclusion of the technology transfer phase. Indus Telemetry is now hosted on a Linux-based server managed by the KP Data Centre, using PostgreSQL with no cost implications for GoKP-ID, as all software components are open-source and maintained by government IT professionals.

Wrap up

During the technology transfer phase, no major upgrades were made to the hardware components of Indus Telemetry, except for targeted improvements in physical security and enhancements to power backup systems at select locations. The focus of this phase was primarily on validation and digital infrastructure.

Significant progress was made in rebuilding the server and database architecture. The system transitioned to an improved database structure, incorporating enhanced software and automation techniques. As part of this restructuring, several data dissemination services were discontinued, and two auxiliary databases, i.e. groundwater monitoring and weather forecasting, were retired during the server migration process to streamline operations and reduce resource demands.

Table 15 summarizes the key shifts in digital components of Indus Telemetry during the technology transfer phase, highlighting changes in software, data services, and system architecture.

Table 15. Shift in digital components of Indus Telemetry during the technology transfer phase

Digital Component	Before Server Migration	After Server Migration
Server Services	MS Azure	KPDC
Operating System	Windows	LINUX
Database	MS SQL	PostgreSQL
Dashboard	MS Access	MS Access
Display	RPI + LED Screen	RPI + LED Screen
Programming Languages	C# (SSIS packages)	
Python (Display Screens)	Python (CRON Jobs)	
Python (Display Screens)		
Software for remote access to display screens)	Real VNC	Team Viewer
Web based reporting service	SQL Server Reporting Services	Discontinued
Dail flow SMS service	SMS server	Discontinued
WhatsApp flow message service	WhatsApp	Discontinued
Groundwater Monitoring	MS SQL database	Retired
Weather Forecast	MS SQL database	Retired

Water Accounting and Auditing System

Surface Water Accounting System

The core objective of the Indus Telemetry was to enhance the accuracy and transparency of provincial surface water accounting, specifically by monitoring canal withdrawals from the Indus River System. These withdrawals are aggregated into provincial water accounts, which are then compared with seasonal allocations determined by the IRSA under the Water Apportionment Accord of 1991. Provincial irrigation departments regularly submit flow data from their main canals to IRSA, including 10-daily volumetric reports that contribute to the national water accounting system.

Indus Telemetry has enabled GoKP-ID to automate the acquisition and processing of flow data from its main canals, facilitating the generation of electronic water accounts. A suite of customized reports has been developed for the Hydrology Division of GoKP-ID, accessible through the KP-Water dashboard. This dashboard, built in MS Access for user convenience, enables on-demand report generation.

Figure 17 illustrates a typical volumetric report generated through the KP-Water dashboard, showcasing how Indus Telemetry supports data-driven decision-making in water allocation and auditing.

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-
Canal gauge station (telemetry) (RD) 1200			34.1675 N	71.4056 E
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
Total volume Rabi 2024-25 from 10/1/2024 to 3/31/2025				88,102 ac-f

Figure 17. Volumetric report of Kabul River Canal based on Indus Telemetry data generated by KP-Water dashboard

Surface Water Auditing System

Beyond its role in supporting national water accounting, Indus Telemetry has empowered the Government of Khyber Pakhtunkhwa Irrigation Department (GoKP-ID) to conduct internal water audits with greater precision and efficiency. Several key aspects of water auditing system that are now supported by the Indus Telemetry are:

1. Seasonal water withdrawal audits

Indus Telemetry enables GoKP-ID to aggregate canal withdrawal volumes across the province and compare them against seasonal allocations provided by IRSA under the Water Apportionment Accord of 1991. For example, the volumetric report for Kabul River Canal (Figure 17) shows total withdrawals during the Rabi season 2024-25. Similar reports can be generated for other canals, and when aggregated, they form the basis of the provincial water share. This allows GoKP-ID to audit canal operations and adjust internal quotas based on actual seasonal withdrawals.

2. Water indenting system review

Canal operations in Pakistan are traditionally governed by a demand-supply mechanism known as water indenting, which is ideally based on irrigation requirements in the command area. However, the scientific basis for indenting has eroded over time, and current practices rely on legacy data. Indus Telemetry's high-resolution flow data provides GoKP-ID with the ability to audit canal supplies against indents, helping to assess whether water deliveries align with intended irrigation demands.

3. Water duty assessment

The water duty, in the context of irrigation, refers to the area of land that can be irrigated by a given discharge of water, typically expressed as thousand acres per cubic foot per second (1000 ac/ cusec) in South Asian countries. The water duty essentially quantifies the efficiency of water use for irrigation depending on factors like crop type, soil, climate, and irrigation methods. Indus Telemetry provides flow records into main canals. The area irrigated by main canals is also entered in Indus Telemetry database. An audit of water accounts can inform GoKP-ID about efficiency of water supply in serving the area irrigated by the main canal. This analysis supports improved planning and resource allocation.

4. Delivery Performance Ratio (DPR)

DPR is a quick and effective metric for assessing canal operation efficiency. It is calculated as the ratio of actual discharge to design or target discharge. A DPR close to 1 indicates optimal performance, while deviations suggest inefficiencies. Indus Telemetry calculates DPR in real time and displays it on live data screens in key government offices, enabling timely operational decisions.

5. Volumetric analysis for over/under supply

By comparing volumetric flow data with water duty benchmarks, GoKP-ID can identify over- or under-supply conditions in canal command areas. This insight supports more equitable and efficient water distribution.

To institutionalize these practices, IWMI is committed to co-develop a formal procedure for water auditing with GoKP-ID, using Indus Telemetry data as the foundation. This will ensure that water auditing becomes a routine and data-driven process within the department.

Conclusions and Way Forward

This report highlights the imperative of improving the acquisition of data and its management in the IBIS. This has been reiterated in Pakistan's recently approved National Water Policy and is the subject of numerous development investments (ongoing and past). The report documents the preparatory institutional work and technical details of commissioning automatic instruments to electronically acquire, transmit, post-process, archive and disseminate canal flow data. Details about weather and groundwater data are deliberately not included to keep the readers' attention, to the main theme of the report, that is, canal flow monitoring.

Indus Telemetry began as a national-scale research endeavor led by IWMI, demonstrating viable technological options for flow monitoring. These technologies were successfully upscaled in Khyber Pakhtunkhwa, with strong technical engagement from PCRWR and GoKP-ID. A major breakthrough was the deployment of advanced velocity sensors, which addressed the long-standing challenge of rating functions, often the weakest link in accurate flow estimation. The complete transfer of Indus Telemetry, including hardware and backend systems, to GoKP-ID reflects the growing capacity and commitment of public sector water professionals to manage modern telemetry systems.

This journey of Indus Telemetry illustrates that leveraging recent advances in information and communication technology makes it feasible and cost-effective to implement digital flow monitoring across critical junctures of Pakistan's IBIS. The widespread availability of mobile networks has eliminated the need for costly satellite communication, while solar energy and energy-efficient electronics have enabled off-grid installations. However, the success of such systems depends on informed and judicious technological choices. Equipment must be robust, supported by reliable manufacturers, and evaluated based on lifecycle costs, not just procurement price. Procurement policies focused solely on the lowest cost may undermine long-term system reliability and stakeholders' trust.

Regular validation has emerged as a cornerstone of system credibility. The use of Acoustic Doppler Current Profilers (ADCPs) has proven to be the most accurate method for validating sensor data, challenging the traditional reliance on manual measurements, which are often low-resolution and prone to human error. Field demonstrations and training have helped shift stakeholder perceptions, establishing ADCP as the gold standard for flow validation.

Indus Telemetry has significantly strengthened surface water accounting in Khyber Pakhtunkhwa. The province is now committed to preparing and submitting 10 daily volumetric reports to IRSA using electronically acquired data, improving transparency and reliability. The technological choices, operational procedures, and governance arrangements developed through Indus Telemetry offer a replicable model for national-scale telemetry deployment.

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Appendix A. Location of WAPDA's Key Gauging Stations of the IBIS

River	Country	Location	Latitude	Longitude
Chenab	Pakistan	Khanki Barrage	32.408078	73.969372
Chenab	Pakistan	Marala	32.672244	74.464494
Chenab	Pakistan	Punjnad Barrage	29.345653	71.021358
Chenab	Pakistan	Qadirabad	32.320897	73.6.55561
Chenab	Pakistan	Trimmu Barrage	31.144686	72.146797
Gomal	Pakistan	Kot Murtaza Barrage	32.149421	70.080452
Gomal	Pakistan	Gomal Zam Dam	32.098458	69.881339
Haro	Pakistan	Haro River at Garriala	33.748294	72.260934
Haro	Pakistan	Khan Pur Dam	33.803000	72.929310
Indus	Pakistan	Besham Qila	34.906242	72.866303
Indus	Pakistan	Chashma Barrage (1971)	32.435678	71.379886
Indus	Pakistan	Diamir Bhasha Dam (under construction)	35.541844	73.607217
Indus	Pakistan	Guddu Barrage	28.418767	69.712981
Indus	Pakistan	Jinnah Barrage	32.918561	71.521800
Indus	Pakistan	Kotri barrage	25.442311	68.315833
Indus	Pakistan	Sukkur Barrage	27.677200	68.846278
Indus	Pakistan	Terbela Dam (1976)	34.088228	72.694200
Indus	Pakistan	Taunsa Barrage	30.512883	70.849461
Jhelum	Pakistan	Mangla Reservoir (1968)	33.126378	73.644458
Jhelum	Pakistan	Rasul Barrage	32.631267	73.519272
Kurram	Pakistan	Thal	33.355878	70.546669
Kurram	Pakistan	Daratang	32.609286	71.165599
Ravi	Pakistan	Balloki Barrage	31.221122	73.859908
Ravi	Pakistan	Sidhnai Barrage	30.572306	72.157681
Soan	Pakistan	Chirrah	33.657906	73.305031
Soan	Pakistan	Dhok Pattan	33.130681	72.350772
Soan	Pakistan	Simly	33.720560	73.341940
Soan	Pakistan	Rawal Lake	33.693880	73.122960
Sutlej	Pakistan	Ganda Singh Wala border with India	30.992181	74.554639
Sutlei	Pakistan	Islam Barrage	29.826039	72.549236
Sutlej	Pakistan	Sulemanki Barrage	30.377769	73.866556

Note: This is not an exhaustive list of river gauges maintained by the WAPDA to monitor river flow



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