FINAL REPORT: WMO HydroHub Innovation Call in Latin America and the Caribbean

"RIVeR-LAC"

Funded by the Inter-American Development Bank

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Date: April 14th 2025

CONTENT

1. Executive Summary

1.1. Purpose and Context of the Project

The RIVeR-LAC Project aims to advance hydrometric monitoring in Latin America and the Caribbean through the development and implementation of image-based techniques, with a focus on Large-Scale Particle Image Velocimetry (LSPIV). Supported by the Inter-American Development Bank (IDB) under the WMO HydroHub Innovation Call, the project promotes more accessible, efficient, and non-intrusive streamflow measurement practices across the region.

The initiative was designed to strengthen technical capacity, enhance data quality, and promote innovation in water resources monitoring. Its integrated approach combines open-source software development, the production of regionally adapted guidelines, and the validation of techniques in diverse field conditions. Emphasis was placed on fostering regional collaboration, accessibility for non-experts, and long-term sustainability through training and community engagement.

1.2. Major Achievements

- Successful development of the new RIVeR software, featuring a modern, user-friendly interface with basic and advanced modes, multilingual support (English, Spanish and French), and automated workflows.
- Completion of the Best Practice Guidelines, which provide step-by-step instructions for fieldwork, desk work, and data analysis. The guidelines are complemented by high-quality 3D-modeled visuals and hosted in a public GitHub repository for continuous improvement and accessibility.
- Installation of fixed LSPIV stations in Buenos Aires and Córdoba, demonstrating the adaptability of the technology to diverse environments.
- Extensive dissemination efforts, including webinars, conferences, and active engagement with stakeholders through social media and institutional networks.
- Targeted regional and global accessibility: A regional webinar was conducted for National Meteorological and Hydrological Services (NMHSs) in Latin America and the Caribbean. The multilingual nature of the software (English, Spanish, French) and the bilingual guidelines (Spanish and English) ensure usability across most countries in the region and support broader international adoption.

1.3. Key Challenges and Solutions

- Modernizing legacy software: The transition of RIVeR from its original MATLAB-based version to a modern, open-source environment posed several key challenges. These included a complete restructuring of the workflow, the design of a user-centered interface, and the optimization of image processing routines to ensure efficient performance. These challenges were addressed through iterative development, modular architecture, and continuous testing—with active participation from INA in the testing and validation phases to ensure alignment with operational needs.

- Promoting adoption of new practices across diverse institutions: Encouraging the uptake of the Best Practice Guidelines among NMHSs with varying levels of technical and institutional capacity required careful design choices. These included a bilingual, accessible format, user-centered structure, and a regional webinar to provide practical training
- Handling operational measurement limitations: A key technical challenge arose at the Buenos Aires station, where the external water level sensor—managed by a different institution—was not operational. Since accurate discharge estimation depends on water level data, this issue initially threatened the station's functionality. To overcome it, the team developed a method to estimate water levels directly from video images using a deep learning model. This solution restored the operability of the station and also demonstrated the potential of AI-based approaches to complement or replace traditional sensors in image-based monitoring systems.
- Coordinating multiple components under a tight timeframe: The project encompassed software development, field deployment, guideline production, international collaboration, and outreach activities—all within a one-year period. This required strong internal coordination, clear workgroup responsibilities, and the use of agile methodologies. The support provided by WMO and the Inter-American Development Bank (IDB)—through milestone-based planning, peer review processes, and constructive and responsive oversight—was key to ensuring timely delivery and alignment with broader regional goals.

1.4. High-level recommendations

- **Technology Enhancement** (For: Research Institutions, Technology Developers, NMHSs)**:** Invest in both software and hardware improvements, focusing on user-friendly interfaces for non-programmers, weather-resistant equipment, and automated systems. Continue addressing technological limitations through research on tracer visibility and image processing techniques.
- **Infrastructure Development** (For: Basin Authorities, Water Resource Management Agencies, Project Team)**:** Establish robust data management systems with dedicated servers, interactive visualization tools, and standardized APIs to facilitate seamless integration with existing hydrological monitoring networks.
- **Operational Sustainability** (For: NMHSs, Basin Authorities, Private Sector)**:** Implement standardized maintenance protocols and explore partnerships with specialized service providers to ensure long-term station reliability while reducing the resource burden on research teams and water authorities.
- **Knowledge Transfer** (For: WMO Regional Training Centers, Universities, Project Team): Strengthen capacity-building through structured training programs, educational

integration, and expanded field testing across diverse hydrological contexts to build expertise among stakeholders.

- **Standardization Development** (For: WMO ET-Hydrometry, ISO Technical Committees, Project Team)**:** Work toward formal international standards for LSPIV methodology that define calibration procedures, quality control metrics, uncertainty estimation methods, and data format specifications. Conduct intercomparison exercises to validate standardized approaches across different implementations and river environments.
- **Community Cultivation** (For: Project Team, WMO HydroHub, IAHS)**:** Foster a collaborative ecosystem through active feedback channels, open-source development, and strategic partnerships with national hydrological services to accelerate adoption and continuous improvement. Promote co-design practices by involving end users in the development and validation of tools and guidelines, ensuring they respond to real-world needs and constraints.
- **Innovation Integration** (For: Research Institutions, Technology Companies, NMHSs)**:** Leverage emerging AI-based technologies as complementary tools to enhance measurement capabilities, particularly in challenging environments where traditional LSPIV applications face limitations.

1.5. Summary of Expected Final Outcomes

- A new, open-source version of the RIVeR software freely available to the global hydrometric community.
- A comprehensive and accessible Best Practice Guidelines document supporting consistent and accurate LSPIV implementation.
- Operational fixed LSPIV monitoring stations serving as benchmarks for further installations throughout the region.
- Strengthened institutional networks and enhanced technical capacity for hydrometric monitoring across Latin America and the Caribbean.

2. Introduction

2.1 Project Scope

The "RIVeR-LAC" project aims to improve hydrometric monitoring in Latin America and the Caribbean through the advancement of Large-Scale Particle Image Velocimetry (LSPIV) technology. The scope includes three main components:

- Development of an open-source, user-friendly Python version of RIVeR software with a modern Graphical User Interface (GUI) to replace the previous MATLAB-based application
- Creation of comprehensive best practice guidelines for LSPIV implementation, testing, and operation in Spanish and English

Installation and operation of fixed LSPIV monitoring stations in two distinct environments in Argentina:

- A mountainous basin in Córdoba (using an existing station)
- A lowland urban basin in Buenos Aires (Matanza-Riachuelo Basin)

The work is carried out by a consortium including the National University of Córdoba (UNC), the National Water Institute of Argentina (INA), and ORUS (a technology start-up company specialized in water monitoring solutions, more information at www.orus.cam). The core team is integrated by:

Name	Institution
Ph.D. Antoine Patalano	UNC/ORUS
M.Sc. Leandro Massó	UNC/ORUS
Ph.D. Ana Inés Heredia Ligorria	UNC/INA
M.Sc. Mariano Re	INA
M.Sc. Nicolás Ortiz	INA
Ph.D. Pablo García	INA
María Catalina Lago	INA
Ph.D. Carlos Marcelo García	UNC
Ph.D. Andrés Rodriguez	UNC

2.2 Objectives, Outcomes, Outputs, and Key Activities

The project has four main objectives:

- Develop a user-friendly Python version of RIVeR, an open-source software, to promote widespread adoption of LSPIV technology
- Implement LSPIV stations in pilot basins to collect and validate hydrometric data
- Create best practice guidelines for LSPIV data collection and analysis
- Train and disseminate guidelines to organizations throughout Latin America and the Caribbean

Key activities include:

- Translating RIVeR code from MATLAB to Python with a modern React-based GUI
- Creating sequential workflows with basic and advanced modes for different user levels
- Developing and field-testing LSPIV best practice guidelines
- Installing fixed LSPIV station in Buenos Aires pilot basin
- Conducting training workshops and communication activities to promote LSPIV adoption
- Establishing mechanisms for continuous feedback and improvement.

2.3 Results

The RIVeR-LAC project achieved the following results:

1. A new user-friendly Python version of RIVeR with open-source code available on GitHub

2. Comprehensive best practice guidelines for LSPIV implementation in both Spanish and English

3. Operational fixed LSPIV stations in two distinct pilot basins with validated discharge measurements

4. Webinar for NMHSs in Latin America and the Caribbean to train and disseminate the use of RIVeR and the guidelines.

5. Increased technical capacity among water management organizations in Latin America and the Caribbean

6. Improved quality, quantity, and reliability of hydrometric data in Córdoba and Buenos Aires

7. A community of practice around LSPIV technology in Latin America and the Caribbean

8. Enhanced collaboration between academic institutions, water management agencies, and basin authorities in Latin America and the Caribbean

3. Project Implementation Progress

3.1 Main Achievements and Results

The RIVeR-LAC project has delivered on its planned objectives across all four workgroups. This section details the key accomplishments of each workgroup throughout the project's duration.

RIVeR Development Workgroup (RVR-WG)

The RIVeR Development Workgroup successfully transformed the original MATLAB-based RIVeR software into a more accessible, user-friendly platform built on Python and JavaScript. This transition addressed several limitations of the previous version, particularly its dependency on proprietary software, restricted user interface capabilities, and scalability challenges. The software is now available in a public repository since March 21st at https://github.com/oruscam/RIVeR.

Technology Transition and Architecture Design

The team made a shift to Python for the backend development, leveraging its robust image processing capabilities through libraries such as OpenCV, SciPy, Numba and Matplotlib. For the frontend, React was selected for its component-based architecture and ability to create dynamic, interactive user interfaces. This technological foundation has created a more flexible, scalable, and maintainable solution that can evolve with user needs and technological advancements.

The development team also implemented a Command Line Interface (CLI), allowing advanced users greater control for batch processing and automated workflows. This feature, while not initially proposed, enhances the software's utility for technical users.

The CLI can be easily installed from a terminal with:

```
git clone https://github.com/oruscam/RIVeR.git
cd RIVeR
pip install -e .
```

User-Centered Design and Workflow Improvements

A key achievement was redesigning RIVeR's workflow to be more intuitive and sequential. Unlike previous versions where users navigated through various functions often relying on manuals, the new RIVeR guides users step-by-step through different modules using 'Next' and 'Back' buttons. This structured approach ensures that users follow a logical progression, reducing errors and enhancing the overall user experience.

The new version features:

- A simplified interface with guided progression through tasks

- Multilingual support, initially available in English, Spanish and French.

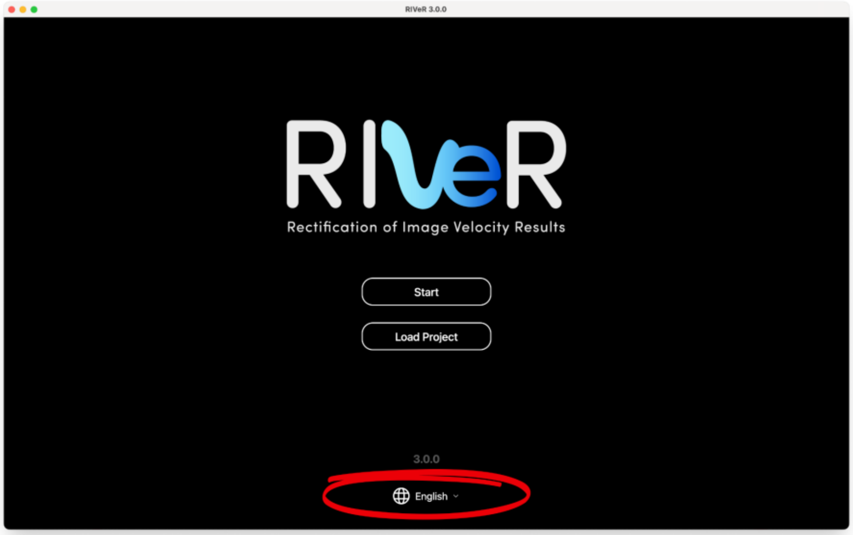

Figure 1: Screenshot of the first window of the new version of RIVeR upon opening, highlighting the option to change the language.

- Intuitive navigation with 'Back' and 'Next' buttons, allowing users to confidently move through the process at their own pace.

Figure 2: Screenshot of RIVeR highlighting the 'Back' and 'Next' navigation buttons.

- Progress indicators showing users their advancement through the workflow

- A default basic mode with an unlockable advanced mode, accommodating both novice and experienced users

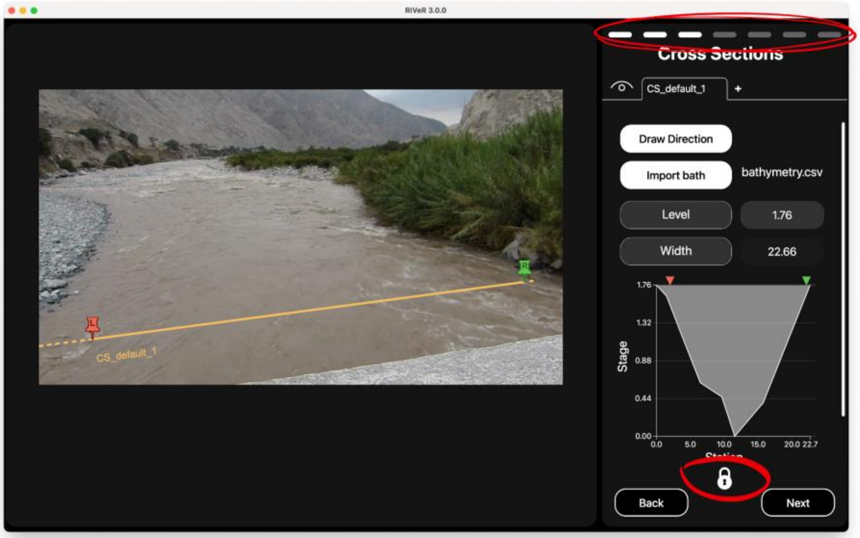

Figure 3: Screenshot highlighting the progress indicator.

- Feedback with warning messages for missing or invalid inputs

- HTML report generation for creating shareable, professional documentation of results.

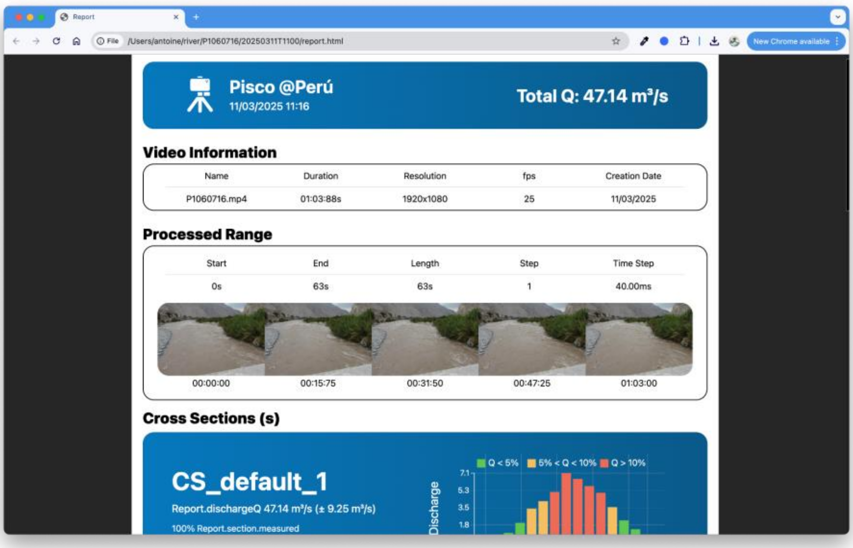

Figure 4: Example of a HTML report generated by RIVeR.

Modular Workflow Implementation

The team developed comprehensive workflows for processing three types of footage:

- UAV (drone) footage with nadir view, requiring simple pixel size calibration due to consistent perspective
- Oblique view footage, involving 2D rectification to account for perspective distortion, requiring four Ground Reference Points
- Fixed station footage, necessitating detailed on-site survey of Ground Reference Points for 3D rectification design

Each workflow includes:

- Video range selection, allowing users to specify start and end times and frame rates
- Pixel-to-real-world transformation appropriate to the footage type
- Cross-section(s) definition with support for importing bathymetry data
- PIV processing parameter selection with both basic and advanced options
- Automated discharge calculation and result visualization
- HTML report generation with customization options

The workflows were designed to minimize required user input, with intelligent defaults that allow users to obtain discharge values by simply clicking through the process without adjusting parameters, while maintaining the option for advanced customization when needed. Annex 1 includes screenshots of the software illustrating a complete processing example.

Open Source Commitment

The team selected the AGPL-3.0 license for RIVeR, ensuring the software remains open, accessible, and community-driven. This licensing choice mandates that modifications are shared under the same terms, fostering collaboration and innovation while still supporting commercial use with proper attribution.

Impact of the Technological Transition on Adoption and Scalability

All of these improvements were made possible by the core technological transition from MATLAB to an open-source architecture based on Python and React. This shift eliminated licensing barriers, enabled the design of a modular and intuitive interface, and allowed the integration of multilingual support and a command-line interface. These features have significantly enhanced the scalability and uptake of RIVeR across user profiles. Non-technical users benefit from a guided, accessible experience, while advanced users can automate tasks and integrate the software into larger workflows. This flexibility has broadened the potential for adoption by National Hydrological Services, researchers, and consultants throughout the Latin America and Caribbean region—and beyond.

INA's Feedback and Validation Process

Throughout the software development process, INA actively participated by providing valuable feedback during multiple revision stages. This collaboration involved processing video material recorded by INA and testing different configurations to evaluate the software's performance and usability. Examples of these validations and detailed comments from INA are summarized in Annexes 2 and 3.

Best Practice Guidelines Workgroup (BPG-WG)

The Best Practice Guidelines Workgroup developed comprehensive guidelines for LSPIV implementation. These guidelines aim to make this technique accessible to new users by simplifying concepts and providing practical instructions. They fill the gap between highly technical documents and the needs of users with little or no experience, ensuring a smooth introduction to the methodology. The guidelines are available in both English and Spanish in a public repository since March 25th at https://github.com/oruscam/lspiv-guidelines.

Guidelines Development and Content

The development of the Best Practice Guidelines began with an extensive background collection and analysis process. This process involved reviewing existing manuals, scientific literatures, national and international guidelines, and previously developed software documentation. The objective was to identify knowledge gaps, inconsistencies, and areas lacking practical guidance, particularly for non-expert users.

The RIVeR-LAC team completed the Best Practice Guidelines in both Spanish and English, making them accessible to a wide audience across Latin America and the Caribbean, and beyond. With active contribution and review from INA staff throughout the development process, the guidelines cover:

- Introduction to image-based velocimetry techniques, including LSPIV principles and applications
- Field work recommendations, including site selection, camera placement, and control points for different measurement scenarios (drone/UAV, oblique view, and fixed station)
- Desk work procedures, including software options, workflow guides, and data processing steps
- Comprehensive appendices covering technical details for advanced users

The guidelines were structured to provide an accessible introduction to LSPIV without overwhelming beginners, while including appendices with more detailed information for advanced users. This approach mirrors RIVeR's basic/advanced design philosophy, starting with fundamental concepts and progressively covering more complex topics.

Visual Communication and Design

Recognizing the importance of visuals for conveying complex concepts, the project team collaborated with a graphic designer to create high-quality, illustrative visuals. These were developed through 3D-modeled scenes representing typical LSPIV measurement scenarios, including drone-based, oblique view, and fixed station setups, ensuring consistency, clarity, and realism.

The visuals are integrated throughout the guidelines to complement the written instructions, especially for beginner users. By clearly illustrating each stage of the LSPIV process, the visuals enhance usability, making the guidelines more intuitive and accessible to diverse users. The Figure 5 below presents a generalized and simplified diagram illustrating all stages for applying LSPIV, from fieldwork to data processing and analysis, using the 3D-modeled scenario to enhance clarity and comprehension.

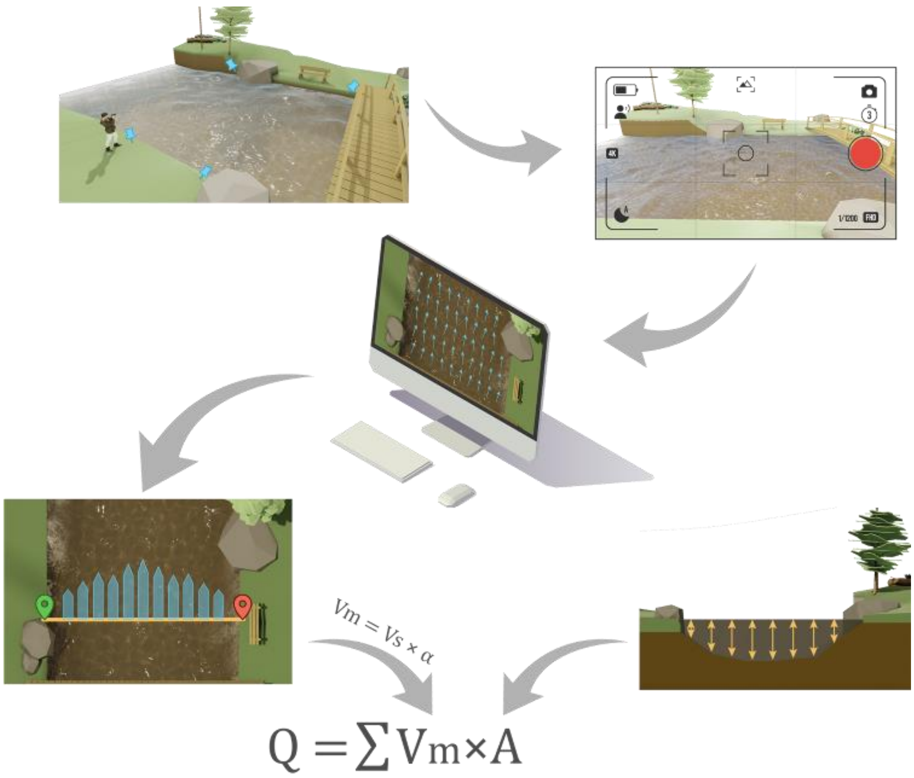

Figure 5: Example of an illustration used in the guidelines, based on a typical 3D-modeled scene.

Field Testing and Validation

A critical achievement was the successful field testing of the guidelines by INA staff in Córdoba. Staff independently followed the guidelines step-by-step without additional support, confirming the document's clarity and usability in real-world conditions. This validation demonstrates that the guidelines effectively communicate the necessary procedures for LSPIV implementation (Figure 6).

The field-testing process was a crucial step in validating the effectiveness and practicality of the Best Practice Guidelines. This phase involved a series of comprehensive trials conducted by INA staff in Córdoba, under real-world conditions. The testing aimed to evaluate not only the clarity and coherence of the guidelines but also their robustness when applied by users with varying levels of expertise.

INA personnel were tasked with following the guidelines independently, without additional support or prior preparation, to ensure a realistic assessment of the document's usability. The step-by-step process laid out in the guidelines allowed the staff to successfully conduct LSPIV measurements, from site selection and setup to data processing and analysis. Feedback was collected regarding any difficulties encountered, ambiguities in the instructions, or opportunities for improvement.

Figure 6: Picture of the field test conducted by INA in Córdoba, using the draft of LSPIV measurement guidelines

This testing phase confirmed that the guidelines effectively communicate the necessary procedures for LSPIV implementation and highlighted areas where improvements could be made to further enhance clarity and user experience.

The results from this phase were instrumental in refining the guidelines, ensuring they are accessible, comprehensive, and suitable for widespread use across diverse contexts. A report generated by INA detailing these validation campaigns is included in Annex 5.

Review Process Implementation

The review process of the Best Practice Guidelines was conducted in two stages to ensure both clarity and accuracy of the document in different languages.

The first stage focused on the review of the Spanish version of the guidelines. During this phase, representatives from various institutions provided valuable feedback on the clarity of the instructions, the accuracy of the technical concepts, and the quality of the visuals. The observations and suggestions gathered during this stage were carefully considered, leading to significant improvements in the document before it was translated into English.

The second stage involved a thorough review of the English version of the guidelines. Feedback from reviewers was once again collected and incorporated, ensuring that the translation accurately conveyed the original intent and technical details of the document.

The review process actively involved key stakeholders, including:

- WMO Secretariat
- The Inter-American Development Bank (IDB)
- National Water Institute from Argentina (INA)
- ET-Hydrometry (WMO)
- WMO HydroHub Think Tank
- Water Survey of Canada, Environment and Climate Change Canada (ECCC)
- Costa Rican Institute of Electricity (ICE)
- Caribbean Institute for Meteorology and Hydrology (CIMH)

To illustrate the positive reception and usefulness of the guidelines, below are some direct quotes from reviewers:

- Salvador Peña (WMO HydroHub Think Tank): *"En general encuentro la guía muy informativa, cubre los aspectos más importantes para poder entender LSPIV desde trabajo de campo a trabajo de gabinete, también mostrando los aspectos teóricos. Cuenta con buenas ilustraciones que ayudan a entender los conceptos."*
- James Bomhof (ECCC): *"This is a great document and will prove very useful to many people, including myself. These are great diagrams!"*
- Cristina Wahrmann (ICE - WMO HydroHub Think Tank): *"¡Qué belleza de figuras!"*

Additionally, the point-by-point reviews from both rounds of evaluation (Spanish and English versions) are included for reference and transparency in Annex 4.

Guide Dissemination and Contribution Process

The Best Practice Guidelines are published as a living document hosted on a dedicated GitHub repository (https://github.com/oruscam/lspiv-guidelines). This approach allows the guidelines to remain dynamic and continuously updated, benefiting from the collective knowledge of users, researchers, and practitioners across the hydrometric community.

The repository is openly accessible, and contributions are encouraged to enhance and expand the document over time. The structure follows a collaborative model where anyone can propose changes, suggest improvements, or contribute new sections following a transparent process.

The guidelines are available in PDF format in the repository, providing an easy-to-download and printable version for users. Additionally, the complete guidelines in both Spanish and English are also attached in Annex 6 for reference.

LSPIV Fixed Stations Workgroup (FS-WG)

The LSPIV Fixed Stations Workgroup made operational LSPIV stations in two distinct river environments.

Existing and New Station Implementation

When the RIVeR-LAC project began, an LSPIV station was already operational in Villa Carlos Paz, Córdoba (Figure 7, Figure 8 and Figure 9), surveying the San Antonio river. This station is one of 10 fully operational LSPIV stations installed and managed in the province of Córdoba by the team in the framework of different projects for various institutions. The development of these LSPIV stations, along with their firmware and web application platform, has been ongoing in Córdoba since 2017, when the first station was installed to monitor the Suquía river.

Figure 7: Recordings of San Antonio river from November 25th 2024, 13:00 (left) and 14:20 (right)

These stations are built using Raspberry Pi computers as their processing core, providing a cost-effective yet powerful solution for field deployment. They were installed through collaboration between the Faculty of Exact, Physical, and Natural Sciences (FCEFyN) and ORUS. Together, they developed an advanced edge recording system that intelligently captures snapshots, records video, and transmits data to a server. All this data is accessible through a web application platform developed by ORUS.

This existing infrastructure provided an established baseline for the project and represented a monitoring solution for a mountainous basin environment. The extensive experience gained from managing these multiple stations allowed the project team to leverage proven methodologies while focusing on the design and installation of a new complementary station in a different geographical context.

Over time, the station in Villa Carlos Paz has produced more than 300 discharge data points, covering a wide range of flow levels—including during sudden flood events where conventional techniques are often not applicable. During the same period, APRHi generated approximately 30 discharge measurements using hydroacoustic techniques. This means that the LSPIV station enabled an order-of-magnitude increase in the number of flow data points collected, significantly enhancing the hydrological characterization of the river.

Figure 8: LSPIV Station installed in Villa Carlos Paz, Córdoba (left) and view of installed equipment (right)

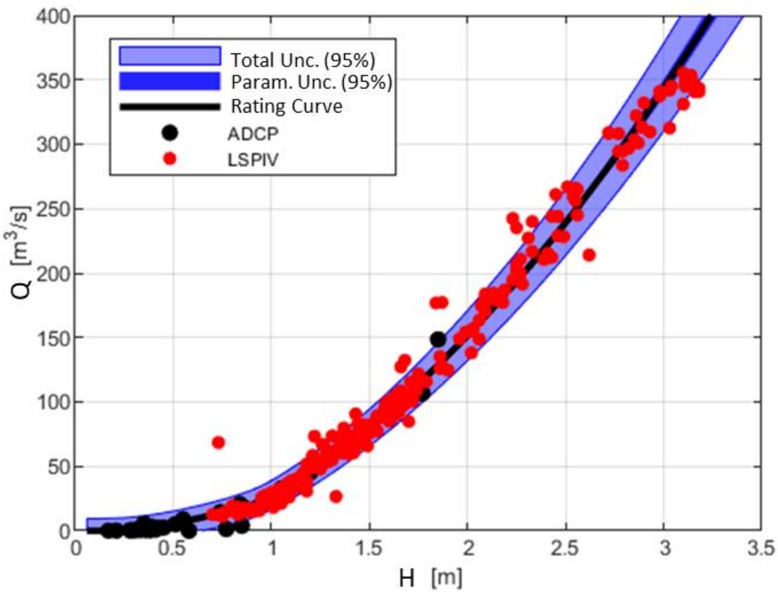

Figure 9: Rating curve, 300 data from 0.7 m to 3.18 m.

Site Selection and Assessment for the Buenos Aires Station

The INA group identified an optimal location for the new fixed LSPIV station. In Buenos Aires, after determining that the monitoring station would be located in the Matanza-Riachuelo basin, the team selected a site on the Riccheri Highway bridge over the Matanza River. This location was chosen for several strategic reasons:

- It represents a lowland basin with flat topography, contrasting with the mountainous basin in Córdoba
- It is situated in the most important urban basin in Argentina, home to six million people
- Its proximity to INA facilitates logistics and maintenance
- There is an established historical link between INA and ACUMAR (the basin authority)

The selected site offered several advantages:

- Good accessibility for installation and maintenance
- Security cameras in the area to protect equipment
- Historical significance as a hydrological measurement section
- Minimal solar reflection that could interfere with image quality
- Limited vegetation that might obstruct the field of view

LSPIV Station Design and Installation in Buenos Aires

On October 30, 2024, the team successfully installed the new LSPIV fixed station in the Matanza-Riachuelo basin. The installation included:

- A metal cabin housing the electronic components
- A solar panel for power
- A high-resolution security camera with night vision capability
- A metal mounting structure anchored to the concrete bridge

The installation was a collaborative effort involving personnel from UNC, INA, ORUS and ACUMAR, demonstrating effective inter-institutional cooperation (Figure 10 and Figure 11).

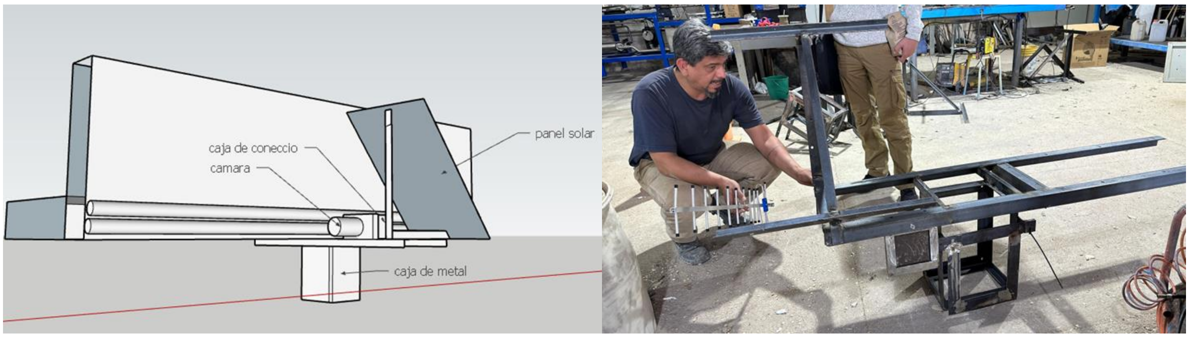

Figure 10: Design of fixed LSPIV station (left) and assembly (right) in Córdoba

Figure 11: Installed fixed LSPIV station (left) and panoramic view from the installation point (right)

Although not developed as part of the RIVeR-LAC project, the Buenos Aires station also incorporates an AI-based water level measurement system that operates at the edge. This feature enhances the station's capabilities by providing automated water level data in addition to discharge measurements (Figure 12).

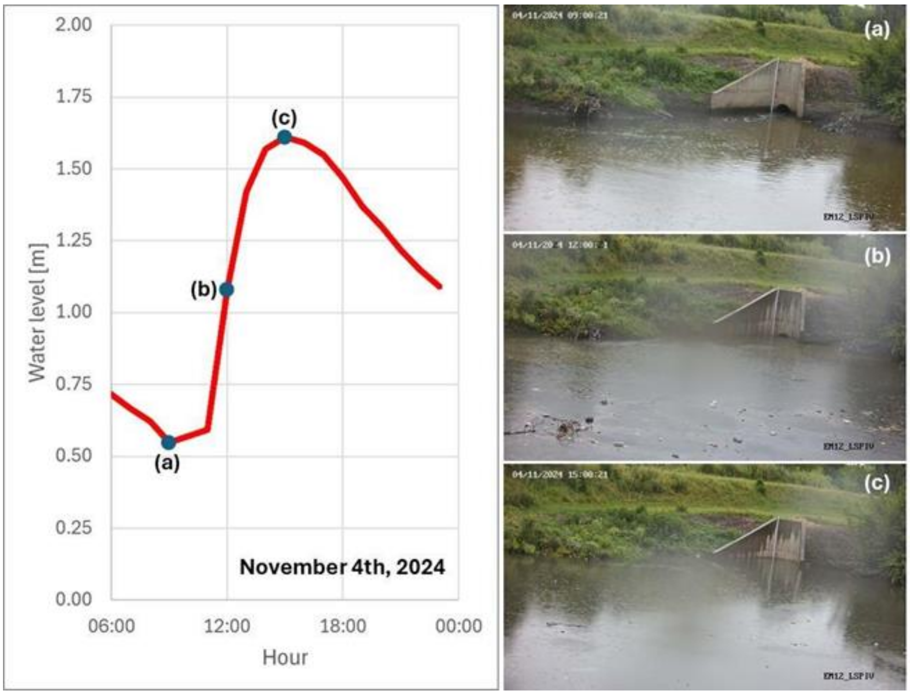

Figure 12. Level recordings with sensor (left) and camera (right).

Calibration and Reference Systems

Following installation of the Buenos Aires station, the team performed topographic survey and reference measurements to convert image-based measurements to accurate discharge values:

- Topographic survey using 76 points measured with differential GNSS, both in water (using a kayak) and on land (using a support quadrant) (Figure 13)
- Flow measurements using ADCP (Acoustic Doppler Current Profiler) to establish baseline discharges
- Topobathymetric surveys of three cross-sections using differential GNSS with centimeter precision (Figure 14)
- Bathymetric surveys using a single-beam echosounder to create a Digital Terrain Model of the area
- Installation of a hydrometric scale in the treated sewage effluent discharge structure within the camera's field of view by ACUMAR

Figure 13: Measurement of points in water with kayak (left) and measurement of points on land with quadrant (right).

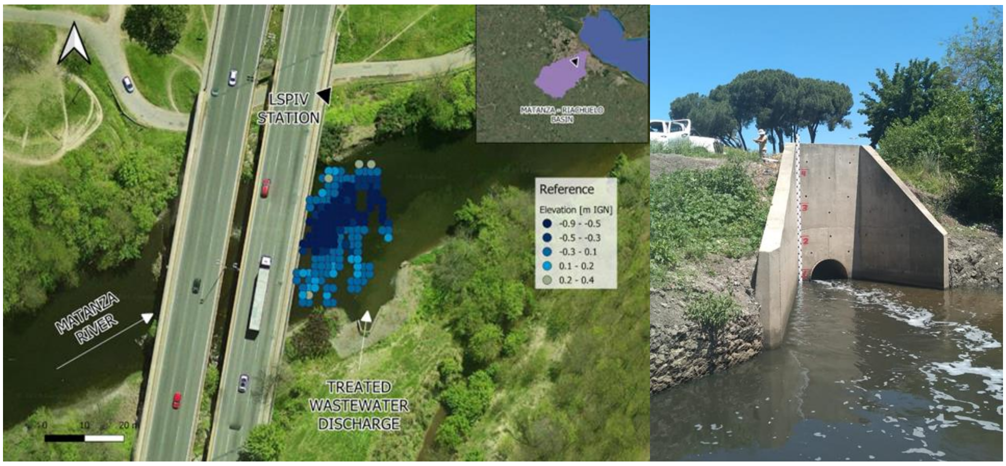

Figure 14: Topobathymetric survey (right) and picture of the installed hydrometric scale by ACUMAR (right)

Operational Validation of Both Stations

With both the Córdoba and Buenos Aires stations operational, the project successfully established LSPIV monitoring in two contrasting environments: a mountainous basin and a lowland urban basin. This dual-station approach demonstrates the adaptability of LSPIV technology across different geographical and hydrological contexts.

Both stations continued to operate throughout the project, providing data for analysis and validation of the LSPIV methodology in different environmental settings. Figure 15 shows a snapshot from the Buenos Aires station alongside the resulting rating curve developed from data analyzed with RIVeR, demonstrating the operational capability of the system to produce quantifiable hydrometric results.

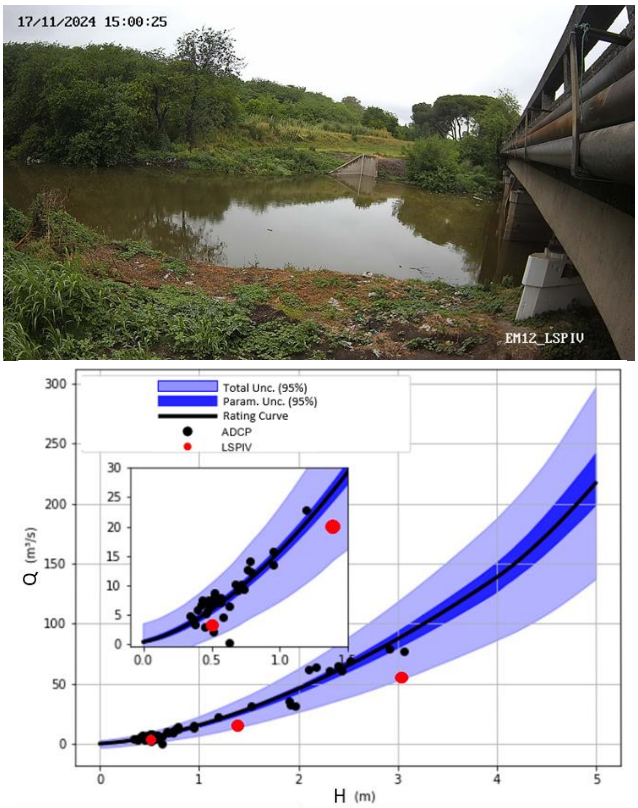

Figure 15: Snapshots of the LSPIV station in Buenos Aires (above) and rating curve with new points from analyzed recordings with RIVeR (bottom)

While the Córdoba station generated a significantly larger dataset, the lower number of discharge data points obtained from the Buenos Aires station can be attributed to several factors. First, the water level sensor installed at the Buenos Aires station—provided externally to the project—was not operational. As a result, an image-based water level estimation method had to be developed, which delayed the start of the station's full operational phase. Second, during the last months of the project, precipitation in the basin was approximately 20% below historical averages, and no significant flow events were recorded, limiting opportunities for measurement. Moreover, LSPIV technology relies on the presence of visible surface tracers—such as ripples, foam, or floating debris—to measure surface velocity. These tracers are often absent in lowland streams during normal flow conditions, which further constrained data acquisition in the Buenos Aires station.

These challenges, along with the methodological adaptations and lessons learned, are addressed in more detail throughout the report.

The data processing for the Buenos Aires station was carried out by staff from INA, with technical supervision from UNC/ORUS. By the end of the project, technicians from INA in both Córdoba and Buenos Aires had been trained in the operation of the station and the use of the RIVeR software, ensuring local capacity for future applications.

Communication Workgroup (COM-WG)

The Communication Workgroup promoted the RIVeR-LAC project through multiple channels, engaging with relevant stakeholders and building awareness of LSPIV technology across the region.

Establishment of a Digital Community of Practice

The project established a community of practice through public GitHub repositories for both the RIVeR software (https://github.com/oruscam/RIVeR) and Best Practice Guidelines (https://github.com/oruscam/lspiv-guidelines). These repositories enable users to request features, ask questions, share experiences, and contribute improvements through enabled discussion features. This digital approach ensures knowledge exchange continues beyond the project, with all interactions documented in both Spanish and English to serve practitioners throughout the region. The open-source licensing encourages collaborative refinement based on real-world implementations across Latin America and the Caribbean.

Workshop

Date: April 8, 2025

Duration: 167 minutes (2 hours 47 minutes)

Recording: YouTube with English subtitles

The RIVeR-LAC webinar on Large-Scale Particle Image Velocimetry (LSPIV) demonstrated strong regional interest and engagement across Latin America and the Caribbean. With 358 registrants, **242 unique viewers**, and peak concurrent attendance of **208 participants**, the webinar succeeded in reaching a substantial audience across **30 countries**. The overwhelmingly positive feedback (**96%** rating the webinar as "**Excellent**" or "**Very Good**") and robust Q&A session indicate both high-quality content delivery and significant interest in the topic of innovative water monitoring technologies. Most attendees (45%) were under the age of 35 and represented a wide range of institutions, including universities, NHMSs, public sector organizations at various jurisdictional levels, private consultants, among others.

A complete summary of the webinar's statistic can be found in Annex 7

Collaboration with Past WMO HydroHub Innovation Calls

The team established meaningful connections with past WMO HydroHub Innovation Call project teams, particularly with Hessel Winsemius from the OpenRiverCam project. Two significant virtual meetings were held:

- June 28th 2024: OpenRiverCam Demo - Hessel Winsemius provided an in-depth overview of the OpenRiverCam library, demonstrating its capabilities in video processing, camera placement, and projection.

- July 5th, 2024: RIVeR workflow Demo - The RIVeR-LAC team shared their approach and explored potential collaborations, comparing similar workflows and discussing future development possibilities.

These collaborations facilitated potential integration of complementary approaches.

Conference and Workshop Participation

The team actively participated in numerous events to share project progress and promote LSPIV technology:

- ACUMAR Workshop (April 17, 2024) - Presentations on hydrological monitoring and LSPIV techniques in the Matanza-Riachuelo basin

- PREVENIR Workshop on flash floods (August 7, 2024) - Presentation on RIVeR-LAC innovations in water management

- Nordic International Hydrometry Workshop (September 25, 2024) - Recorded video presentation

- UNESCO PHI-LAC and TEHLA Webinar (September 25, 2024) - Project presentation to an international audience

- WMO's Tenth Forum of Hydrological Advisors for Region III (October 31, 2024) - Presentation by INA

- ACIC Event in Costa Rica (November 5, 2024) - Online presentation on liquid flow and sediment transport measurements

- 5th Meeting of the HydroBID Community of Practice (November 21, 2024) - Contribution to discussions on water resources management in the face of climate vulnerability

Social Media Engagement

The team created and maintained a dedicated X (formerly Twitter) account (@RIVeR_LAC) to share project updates, technical insights, and related content (Figure 16). Team members also utilized their personal social networks, including LinkedIn, to amplify project messaging and engage with interested audiences.

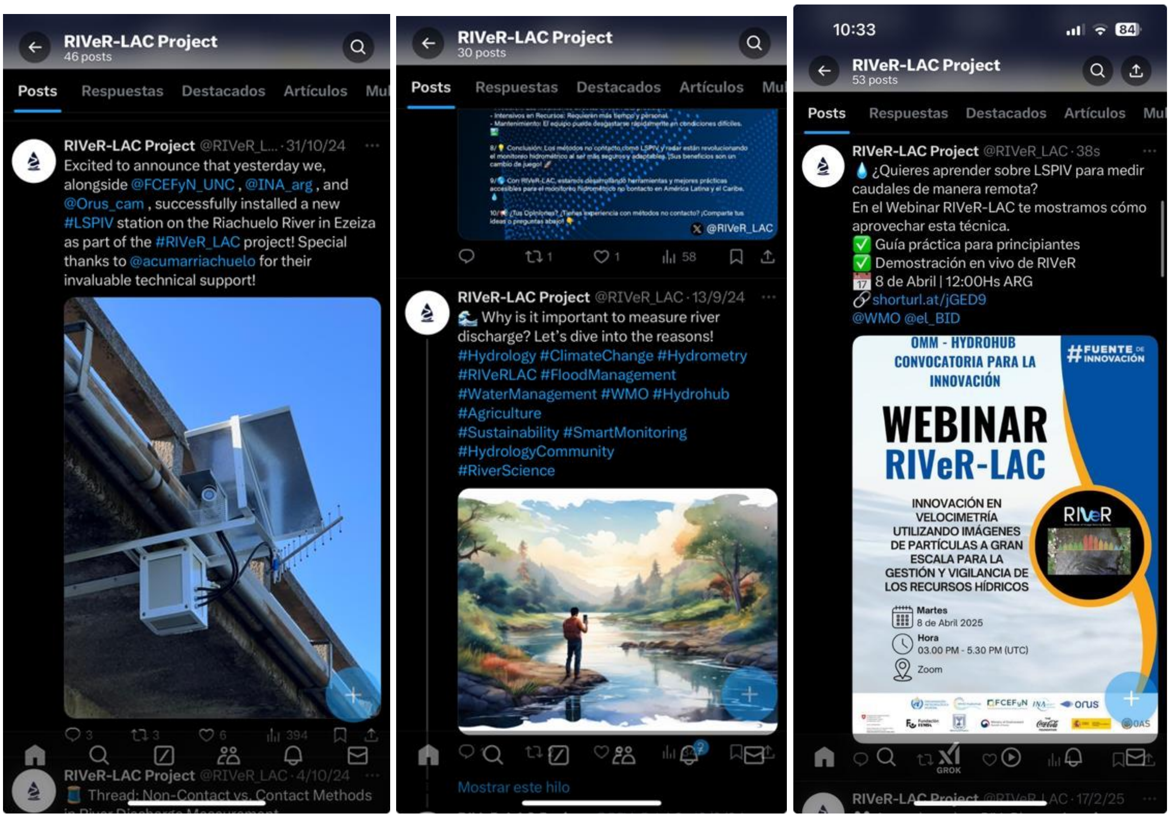

Figure 16: Snapshots of the RIVeR - LAC X account (@RIVeR_LAC)

Formal Agreements

A significant achievement was the formalization of a collaboration agreement between ACUMAR (Matanza-Riachuelo Basin Authority) and INA (National Water Institute). This agreement, approved and signed by both institutions, establishes a framework for joint activities at the Buenos Aires fixed station, ensuring continued operation beyond the project's formal conclusion.

3.2 Risk Assessment

Risk Log and Mitigation Measures

Throughout the RIVeR-LAC project, various risks were identified and managed across all workgroups. This section outlines the key risks encountered and the actions taken to mitigate their impact on project outcomes.

RIVeR Development Workgroup (RVR-WG)

Software Development Risks

Risk: The transition from MATLAB to Python and React presented technical challenges and potential delays in development.

Mitigation: Early framework and language selection in the first month ensured all team members were comfortable with the tools before coding began. The team adopted a parallel development approach, working on multiple components simultaneously. This allowed for early testing and debugging, minimizing integration issues later.

Risk: Uncertainty about user interface requirements and workflow design could lead to development inefficiencies.

Mitigation: The team implemented early MVP (Minimum Viable Product) releases to gather feedback and refine the design iteratively. The adoption of Scrum methodology in Trello facilitated regular reviews and adjustments to development priorities.

Risk: Ensuring software compatibility across different operating systems and environments.

Mitigation: The team selected cross-platform technologies and conducted continuous testing across various environments. The choice of web technologies for the frontend ensured broader compatibility compared to platform-specific solutions.

Open Source Implementation Risks

Risk: Challenges in maintaining the balance between open-source accessibility and sustainable development.

Mitigation: The selection of the AGPL-3.0 license addressed this risk by ensuring that the software remains open and accessible while supporting commercial use with proper attribution. This licensing approach protects ongoing development while fostering community collaboration.

Best Practice Guidelines Workgroup (BPG-WG)

Content Development Risks

Risk: Delays in drafting the Best Practice Guidelines compared to initial schedule.

Mitigation: The team restructured work priorities to accelerate content development. Active collaboration with INA staff throughout the process ensured multiple contributors were involved, helping overcome the initial delays. By the time of the third progress report, the guidelines development was back on schedule.

Risk: Ensuring content is accessible to beginners while remaining technically accurate.

Mitigation: The guidelines were structured with a progressive approach, starting with basic concepts and adding complexity gradually. Advanced technical information was placed in appendices, ensuring the main document remained accessible while providing comprehensive information for experienced users.

Risk: Lack of adoption by NMHSs.

Mitigation**:** To maximize the likelihood of adoption by National Meteorological and Hydrological Services (NMHSs), the design of the guidelines (content, structure, tone, visuals, etc.) was continuously reviewed by experienced INA personnel throughout the development process. This ongoing feedback helped tailor the guidelines to meet the practical needs and expectations of potential users, enhancing their relevance and usability. During the peer review phase, feedback was also collected from staff of various institutions from other countries, which contributed to improving the guidelines' clarity and applicability. While this regional interaction was valuable, the need to strengthen international engagement for broader adoption is acknowledged and addressed in the final recommendations, and can be further supported through concrete actions by the Regional Association III Committee on Hydrology and Water Resources (C-HWR, RA III) and the Regional Association IV Hydrological and Water Coordination Panel (HCP, RA IV).

Field Testing and Validation Risks

Risk: Potential for guidelines to be difficult to understand or implement in practical field conditions.

Mitigation: Field testing was conducted by INA staff who independently followed the guidelines step by step without additional support. This practical validation confirmed the document's clarity and usability, and provided feedback for refinements.

Visual Communication Risks

Risk: Difficulty in clearly communicating technical concepts through text alone.

Mitigation: The team worked with a graphic designer to develop 3D-modeled scenes illustrating key concepts, enhancing understanding through visual aids. Provisional figures were used during drafting, with plans for professionally designed visuals in the final version.

LSPIV Fixed Stations Workgroup (FS-WG)

Technical Implementation Risks

Risk: Installation challenges in the Buenos Aires site, including physical mounting, power supply, and data connectivity issues.

Mitigation: The team leveraged their extensive experience from installing 10 previous LSPIV stations in Córdoba. A meticulous site assessment was conducted to identify potential issues before installation. The team also designed a system with solar power and multiple data transmission options to ensure reliability.

Risk: Vandalism or theft of equipment in public locations, threatening long-term station sustainability.

Mitigation: The fixed station was installed near the entrance of a residential neighborhood, specifically chosen for its surveillance infrastructure and lower risk of vandalism. The location already featured community-operated security cameras, and remarkably, once local residents learned about the project's importance, they proactively engaged by installing additional lighting to improve nighttime visibility and monitoring. This spontaneous community support was invaluable for site protection and demonstrated how local stakeholders can become key allies in environmental monitoring efforts. Beyond this community engagement, the team also designed a secure metal enclosure for the equipment and maintained coordination with local authorities (ACUMAR). This territorial integration—where community interest and active participation combined with institutional support—proved essential for the sustainability of the monitoring station.

Environmental Risks

Risk: Difficulty in obtaining reliable water level data from external sensors operated by other institutions, which are needed to trigger the camera system at the station.

Mitigation: The team incorporated an AI-based water level measurement system that operates at the edge, providing complementary data when surface velocity measurements might be challenging. The system was also designed to be most effective during high flow events, when surface patterns are more visible.

Calibration and Reference Risks

Risk: Inaccurate calibration leading to unreliable measurements.

Mitigation: Comprehensive reference measurements were taken, including topographic surveys, flow measurements with ADCP, and bathymetric surveys. The installation of a hydrometric scale within the camera's field of view provided an additional reference point for water level validation.

Communication Workgroup (COM-WG)

Stakeholder Engagement Risks

Risk: Limited engagement from target audiences and stakeholders could reduce project impact.

Mitigation: The team diversified communication channels, participating in multiple events such as workshops, conferences, and webinars. They also leveraged social media platforms, including a dedicated X account (@RIVeR_LAC), to reach broader audiences.

Knowledge Transfer Risks

Risk: Technical complexity could limit the adoption of LSPIV technology by new users.

Mitigation: The team developed multilingual materials (Spanish and English) and focused on making both the software and guidelines accessible to beginners. They participated in targeted events for hydrological services in Latin America and the Caribbean to promote understanding and adoption.

Risk: Ensuring continuity of knowledge and technology beyond the project's conclusion.

Mitigation: The establishment of institutional agreements, such as between ACUMAR and INA, supports the continued operation of installed stations. The open-source nature of the software and comprehensive guidelines also promotes ongoing development and adoption by the community.

Risk Management Outcomes

The project team's proactive approach to risk management resulted in successful mitigation of most identified risks. Minor delays in some activities, particularly in the early drafting of the Best Practice Guidelines, were quickly addressed and did not impact the overall project timeline. By the third progress report in November 2024, all activities were on schedule according to the traffic light monitoring system.

It's important to note that the RIVeR-LAC project scope was particularly ambitious for a one-year timeframe. The project simultaneously undertook software development (transitioning from MATLAB to Python/React), created comprehensive technical guidelines in multiple languages, installed and calibrated monitoring stations in diverse environments, and conducted extensive outreach activities. Despite these parallel tracks requiring significant coordination and resource management, the team successfully delivered all planned components within the original timeline.

3.3 Challenges or Deviations from the Original Proposal

Technical and Operational Challenges

- **Transition from MATLAB to Python and React:** The conversion of RIVeR software to Python and its new frontend in React posed some technical challenges, particularly in adapting previous functionalities and optimizing image processing. This was addressed through an iterative approach with continuous testing and the implementation of a modular interface.
- **Calibration and data accuracy in Fixed Stations:** During the installation of the LSPIV station in Buenos Aires, it was found that the water level sensor at the study section was not operational, affecting the ability to correlate surface velocity data with water levels. To solve this issue, the team developed a Deep Learning-based water level measurement system that estimates water levels from image patterns captured by the station. This solution was validated through field observations and not only addressed the original sensor limitation but also opens the possibility of integrating this methodology into future stations, reducing dependence on physical sensors.

Logistical and Organizational Challenges

- **Delays in Best Practice Guidelines:** The initial drafting of the Best Practice Guidelines experienced delays due to the extensive effort required to define the document's structure, content scope, tone, and overall layout. This process involved close collaboration with INA, ensuring that the guide was both technically robust and accessible to a broad audience. Significant time was dedicated to refining the presentation format, including the integration of visual elements to enhance usability. Despite these initial challenges, the team successfully recovered the timeline through a structured review process and field testing, validating the guide’s practicality before its finalization

- **Security concerns at the Buenos Aires Station:** The location in an urban area with high exposure to vandalism posed a risk. To mitigate this, reinforcements were installed in the structure, and existing security cameras were leveraged for surveillance.
- **Delays in RIVeR Development:** Our ambitious scope required reprioritization of feature development to maintain our timeline. We made the strategic decision to postpone secondary features like image stabilization and camera calibration, as they weren't critical to the core workflow. This adjustment allowed us to focus resources on essential functionality while keeping the project on schedule. The postponed features remain on our future development roadmap.

Lessons Learned and Adjustments

- **Iterative development approach:** The need for continuous testing with users for software adoption and guideline implementation highlighted the importance of agile methodologies in technological development. Early MVP releases of RIVeR allowed the team to identify usability issues and refine the interface based on real-world feedback.
- **Strengthened institutional collaborations:** Partnerships with ACUMAR, APRHi and INA were key to resolving logistical challenges and improving field implementation. The institutional agreements established during the project will ensure the continued operation of LSPIV stations beyond the project's completion.
- **Future scalability considerations:** The implementation in contrasting basins (mountainous and lowland) provided insights into necessary adaptations for future expansions of LSPIV usage. In particular, the Buenos Aires station demonstrated the need for automated data filtering to remove erroneous velocity estimates during low-flow conditions, where surface turbulence is minimal.
- **Reflections on the Innovation Call and regional context:** The structure of the WMO HydroHub Innovation Call—with its milestone-based timeline and international visibility—proved highly effective for maintaining project focus and momentum. Additionally, working within the Latin America and Caribbean region highlighted the importance of multilingual communication, institutional coordination, and flexible technical approaches to accommodate the diversity of hydrometric capacities across countries.

4. Review and Consolidation of Results

The RIVeR-LAC project builds upon over a decade of experience in image-based velocimetry in Argentina, consolidating efforts into a refined version of the software and its supporting documentation. This initiative represents a milestone in technological development for hydrometric monitoring in the country, synthesizing accumulated knowledge and setting a foundation for future scaling, regional adoption, and broader dissemination of LSPIV technology. The following sections outline the key opportunities and challenges that will shape the continued impact of this work.

4.1 Opportunities and Challenges at the National, Regional, and Global Levels

Opportunities for Project Adoption and Scale-Up

The implementation of LSPIV technology through the RIVeR-LAC project has demonstrated significant potential for expansion at the national, regional, and global levels. The adoption of image-based flow monitoring techniques is gaining momentum due to their cost-effectiveness, non-intrusive nature, and scalability. The following opportunities have been identified:

- **Regional commitment to hydrometric innovation:** The Latin American and Caribbean (LAC) region is actively seeking new hydrological monitoring strategies. This commitment was evident in recent events such as the RA III Hydrometry Course held in August 2023 in Cusco, Peru, and the Closing Workshop of the In-country Trainings on Hydrological Observation and Instrumentation (Hydrometry) in November 2023 in San Jose, Costa Rica (RA IV).
- **Scalability to other countries and institutions:** The project has generated interest from various National Meteorological and Hydrological Services (NMHSs) in LAC. The availability of standardized data formats and best practice guidelines in Spanish and English will significantly enhance technology transfer, enabling broader regional testing under varying hydrometric conditions and comparison with international hydrometry measurement standards.
- **Open-Source development model:** The choice of an AGPL-3.0 license for RIVeR ensures that the software remains accessible and adaptable. This open-source approach encourages collaboration among research institutions, NMHSs, and private sector developers, fostering continuous improvement.
- **Open-Access and collaborative Best Practice Guidelines:** In addition to the software, the Best Practice Guidelines for LSPIV were developed with a strong emphasis on collaboration and continuous improvement. The document is hosted in a public repository, where users can suggest modifications and enhancements, ensuring that the guide evolves based on real-world applications and user feedback. Furthermore, it is published under a Creative Commons BY-ND 4.0 license, which allows free distribution while maintaining the integrity of the original content.
- **Expand training and knowledge transfer:** As part of the project's knowledge transfer efforts, a webinar was conducted to present the Best Practice Guidelines and the RIVeR software. The session included live demonstrations of LSPIV data processing, providing participants with practical insights into its implementation. This initiative served as a foundation for further expanding training resources.

Challenges Impacting Implementation and Scale-Up

Despite the strong potential for widespread adoption, several challenges must be addressed to ensure the successful scaling of LSPIV technology:

- **Training and capacity building:** The adoption of LSPIV requires specialized training for hydrologists and technicians. While the best practice guidelines provide a solid foundation, structured training programs are needed to build local expertise and ensure proper implementation.
- **Resistance to change in traditional hydrometry practices:** Many NMHSs still rely on conventional flow measurement techniques and may be hesitant to adopt image-based methodologies. Demonstrating the accuracy and reliability of LSPIV through comparative studies with traditional methods will be essential for gaining institutional trust.
- **Data standardization and interoperability:** Ensuring that LSPIV-derived data can be seamlessly integrated into existing hydrological databases remains a challenge. While initial efforts were made in collaboration with INA, APRHi, and ACUMAR to align LSPIV data formats with their systems, full integration has not yet been achieved. Further work is needed to develop standardized data protocols, metadata structures, and validation procedures to facilitate broader adoption. Aligning these efforts with international standards—such as those promoted by the Open Geospatial Consortium (OGC)—and facilitating compatibility with systems like the WMO Hydrological Observing System (WHOS) will be key to enabling regional and cross-border hydrometric data sharing. Expanding collaboration with other institutions and NMHSs will also be essential.
- **Financial constraints for Large-Scale deployment:** While LSPIV is cost-effective compared to traditional methods, initial investment in equipment, software adaptation, and personnel training may be a barrier for some NMHSs. Funding from international organizations such as the Inter-American Development Bank (IDB) could support further expansion.
- **Environmental and geographical limitations:** LSPIV performance depends on visible surface tracers and adequate lighting conditions. Some water bodies, especially in low-turbulence environments, may require additional techniques such as artificial seeding of tracers or the use of alternative image-based approaches (e.g., STIV). In addition, weather and climate conditions—such as intense rainfall during high-flow events, condensation in humid environments, fog or strong winds—can affect both video quality and equipment performance. These challenges may require adjustments to station design, specific maintenance routines, operational adaptations, or even modifications to the image processing algorithms to ensure reliable and continuous measurements. A key advantage of the Best Practice Guidelines developed in this project is that, while specifically tailored for LSPIV, a significant portion of the methodology is applicable to a wide range of image-based velocimetry techniques.

Global Context of LSPIV and RIVeR-LAC Positioning

The RIVeR-LAC project isn't developing in isolation, but rather as part of a growing global community interested in image-based hydrometry. Several research groups and agencies worldwide have developed their own LSPIV solutions in recent years, including OpenRiverCam (Netherlands), PIVlab (Germany), KU-STIV (Japan), and Fudaa-LSPIV (France), among others. While these tools share common principles, they differ in focus – some prioritize field acquisition, others emphasize processing algorithms, and yet others target specific user groups. RIVeR-LAC stands out through its comprehensive approach that addresses the entire workflow from field measurement to data integration, with particular attention to usability in resource-constrained environments. The multilingual software and bilingual guidelines directly tackle language barriers that often limit technology adoption in many countries. Our experiences in Argentina, particularly the implementation in contrasting environments (mountainous and lowland rivers), offer valuable practical insights for the wider LSPIV community. These field-tested approaches can inform implementations in similar contexts worldwide. Looking ahead, the project can benefit from stronger connections with global hydrometric standards and networks. Integration with OGC protocols and potential compatibility with WMO's Hydrological Observing System (WHOS) would enhance RIVeR-LAC's international utility. Through continued participation in international forums/workshops like IAHS, IAHR, and WMO expert teams, we can both share our regional insights and incorporate global best practices into future development.

Strategic Recommendations for Overcoming Challenges

To address these challenges and maximize the impact of LSPIV adoption, the following strategies are recommended:

1. Expand training and knowledge transfer:
    - Continue developing an online training program for NMHSs, universities, and water management agencies, incorporating interactive modules, case studies, and field applications to reinforce learning.
    - Leverage insights from the recently conducted webinar to refine training content and expand outreach efforts.
    - Organize follow-up pilot workshops in different countries to demonstrate the technology's benefits and practical applications, ensuring local adaptation and capacity building.
2. Strengthen institutional collaboration and advocacy:
    - Collaborate with WMO HydroHub, WMO's expert team on hydrometry (ET-Hydrometry), and relevant global organizations such as the International Association of Hydrological Sciences (IAHS) or the International Association for Hydro-Environment Engineering and Research (IAHR) to promote LSPIV standardization and broader recognition within international hydrological monitoring frameworks.
    - Establish technical working groups to develop and align data integration strategies, including standardized data formats, metadata structures, and interoperability protocols, to ensure compatibility with national and regional hydrometric networks.
3. Development of Open Hardware Solutions:

- Build upon the team's expertise in hardware and firmware solutions developed over the past years to create smart continuous survey capabilities, following the same open approach used for the RIVeR software and guidelines.
- Utilize the team's experience with custom hardware integration and firmware optimization as a foundation for future development, addressing workflow limitations while expanding system capabilities.

4. Enhance data accessibility and interoperability:
    - Ensure that LSPIV data aligns with international hydrological data standards.
    - Promote the open-source development model to encourage community-driven improvements.
5. Seek additional funding for regional expansion:
    - Engage with development agencies such as IDB, UNDP, and regional governments to support large-scale testing and deployment.

Develop a cost-benefit analysis highlighting the financial advantages of LSPIV over traditional methods.

5. Sustainability and Cost-Efficiency of the Project

The RIVeR-LAC project combines sustainable design and cost-effectiveness to create lasting impact beyond its initial timeframe. By using the open-source RIVeR software and sharing comprehensive best practice guidelines, we've developed affordable, expandable hydrometric monitoring solutions that are particularly valuable for organizations with limited resources across Latin America and the Caribbean.

Our approach prioritizes knowledge transfer and partnership building, helping national hydrological and meteorological services (NMHS) and water agencies successfully incorporate LSPIV technology into their regular operations. The following sections explore our sustainability strategy (5.1), cost-efficiency (5.2), and some unexpected positive outcomes (5.3) that have emerged to support wider adoption of this technology throughout the region.

5.1 Long-term sustainability plans

The long-term sustainability of the RIVeR-LAC project builds on four key pillars: ongoing technical development, open-access technology, institutional adoption, and capacity building. From this point forward, ORUS will lead these sustainability efforts with strong collaboration and formal partnerships with FCEFyN-UNC and INA.

Technology Development and Innovation

Continued development by the core team: The RIVeR-LAC team will maintain and enhance the RIVeR software, regularly update the Best Practice Guidelines, and operate the fixed LSPIV stations beyond the project's completion. This ongoing work will rely on provincial, national, and international funding programs, continuing our decade-long commitment to the technology.

Expansion to complementary techniques: Building on our experience with LSPIV, we will expand development to include other innovative monitoring approaches:

- Space-Time Image Velocimetry (STIV) implementation, leveraging our team's existing expertise
- Advanced water level detection using artificial intelligence, extending the methods developed during this project
- Development of RIVeR Edge, a streamlined version of the software optimized for Raspberry Pi hardware to allow direct deployment on LSPIV stations, planned for 2026. This edge computing solution will enable real-time flow calculations without internet connectivity, automated processing during high-flow events, and reduced data transmission requirements.

Open-source community engagement: The RIVeR software remains available as open-source (AGPL-3.0 license), encouraging improvements and customization by developers and researchers worldwide. This collaborative approach keeps the technology adaptable to evolving hydrological monitoring needs. To ensure active community engagement:

- **Governance structure:** ORUS (www.orus.cam) will establish formal governance protocols as the primary maintainer of the GitHub repository. A technical committee with representatives from ORUS, FCEFyN-UNC, and INA will meet regularly to review contributions and establish development priorities, with annual public roadmaps for transparent planning.
- **Video tutorials:** The team will create comprehensive tutorial series covering software installation, basic operations, and advanced features, available on the project's YouTube channel (https://www.youtube.com/@orus-xm3dn), with regular updates to reflect software improvements.
- **Community support channels:** Community feedback will be actively solicited through user surveys to prioritize feature requests and guide development.
- **Academic integration:** FCEFyN-UNC will incorporate RIVeR into undergraduate hydrology and computer science curricula, creating a pipeline of student contributors through a formal internship program with ORUS for promising students.
- **Strengthening a national network-of-networks for the application of image-based velocimetry in hydrological monitoring**: One key aspect that would ensure sustainability, as the number of methodology users grows, is the integration of observations. This project featured stations that are part of both the APRHi and INA/ACUMAR networks, demonstrating how synergies between these efforts can be collectively leveraged. This example shows that we are not starting from scratch—there is already a solid foundation to expand upon.

Knowledge Sharing and Documentation

Best Practice Guidelines as a living document: Our guidelines are hosted in a public repository for continuous updates and contributions from global users. The Creative Commons BY-ND 4.0 license ensures broad accessibility while maintaining content integrity, facilitating adoption based on real-world applications.The repository will be actively maintained with:

- Regular reviews and updates by the core team over the next several years, complemented by the engagement of international experts invited to form a dedicated reviewing community
- Annual comprehensive revisions incorporating user feedback and new methodological advances
- Translation into Portuguese planned for 2025 to expand accessibility in Brazil and other Portuguese-speaking regions

Training and capacity building: Building on our successful webinar and demonstrations, we will develop comprehensive training programs:

- Standardized training materials and self-paced learning modules
- Regional virtual workshops in collaboration with WMO Regional Training Centers
- Online certification program for technicians and hydrologists
- Hands-on field training sessions in multiple countries within the LAC region

- A "train-the-trainers" program where certified professionals can conduct local training
- Integration of LSPIV methodologies into regional university curricula through academic partnerships
- Around ten professionals from INA's Buenos Aires and Córdoba centers are trained to incorporate image-based velocimetry (LSPIV) operations into their regular tasks.

Institutional Integration and Partnerships

Integration into monitoring networks: While we have made initial progress with INA, APRHi, and ACUMAR, we will continue working to formally integrate LSPIV data into national and regional hydrometric databases. Strengthening relationships with water agencies will be crucial for long-term operational adoption. The station installed on the Matanza River is part of a plan to enhance the basin's rating curves for management under a comprehensive sanitation framework. Currently, this curve has limited data for higher flow rates. Depending on rainfall events, this LSPIV

Industry relationships: We will build strategic partnerships with water utilities, hydropower operators, agricultural organizations, and environmental agencies that benefit from improved hydrometric data.

Financial Sustainability Plan

To support ongoing development while keeping the core technology open-source, we'll implement several practical funding approaches with a structured timeline:

Service-based revenue:

- Professional services program offering custom development for organizations with specialized monitoring requirements
- Technical consulting for complex implementations or challenging monitoring sites
- Service level agreements with regional water management agencies
- Value-added data services and analytical reports for organizations needing deeper insights
- Tiered support packages for different institutional needs and budgets
- System integration services with existing hydrological monitoring networks

Knowledge transfer revenue:

- Hands-on training workshops for technicians and water managers
- Certification program for professionals working with LSPIV technologies
- Specialized training modules for different sectors (hydropower, agriculture, urban water management)
- Partnerships with regional professional associations to recognize certification
- Advanced certification levels for system integration specialists and data analysts

Funding and partnerships:

- Continued applications for research grants and international development funds
- Proposals to international funding agencies for expansion projects
- Strategic industry partnerships with hydropower operators
- Consortiums with environmental monitoring agencies for multi-basin implementation
- A sustainable funding model balancing service revenue, knowledge transfer, and grants/partnerships

Financial targets and sustainability metrics:

- Progressive movement toward self-sustainability through diversified revenue streams
- Gradual reduction in reliance on grant funding as service and training revenue increases
- Long-term goal of establishing fully sustainable operation with balanced funding sources

By combining technological innovation, knowledge sharing, institutional engagement, and these phased sustainable funding models, the RIVeR-LAC project is positioned to grow beyond its initial scope and become an essential resource for hydrometric monitoring throughout Latin America and beyond. ORUS is committed to maintaining the core technology as open-source while building a sustainable business model around services and knowledge transfer that adds value to the entire hydrometric community.

5.2 Cost-efficiency of the project / the solutions

The RIVeR-LAC project was designed to be cost-effective, ensuring that LSPIV technology can be widely adopted without imposing significant financial burdens on institutions. The following factors contribute to its economic sustainability:

- **Use of Open-Source software (RIVeR):** By transitioning RIVeR to Python and React under an AGPL-3.0 license, the project eliminates the need for expensive proprietary software like MATLAB. This significantly reduces software licensing costs for institutions adopting LSPIV.
- **Low-Cost hydrometric monitoring with LSPIV:** Unlike traditional flow measurement methods that require costly in-situ sensors, field visits, and maintenance, LSPIV enables non-intrusive, remote hydrometric monitoring. This reduces long-term operational expenses, making it an economically viable alternative, especially for resource-limited NMHSs.
- **Cost-effectiveness of Fixed LSPIV Stations:** The installation of fixed LSPIV stations represents a particularly cost-effective approach. Each station costs approximately 2,000 USD (including materials and installation), which is significantly lower than the cost of commonly used instruments such as Acoustic Doppler Current Profilers (ADCPs) ranging from 30,000-70,000 USD and Acoustic Doppler Velocimeters (ADVs)

costing between 10,000-25,000 USD. As detailed in Annex 8, the operational costs reveal even more dramatic differences, with LSPIV requiring only 100 USD per measurement day compared to 1,200 USD for conventional methods. This operational efficiency stems from LSPIV stations requiring only 1-2 personnel for data processing versus 3 specialized technicians needed for traditional methods. Additionally, LSPIV provides continuous measurement capabilities that ADCPs and ADVs cannot match. The comprehensive cost analysis in Annex 8 demonstrates that over a five-year operational period with monthly measurements, the total cost of ownership (TCO) for an LSPIV station (8,000-9,000 USD including operational expenses) is approximately 10-16 times lower than equivalent ADV (82,000-97,000 USD) or ADCP (102,000-142,000 USD) systems. This dramatic cost advantage, combined with benefits like non-contact measurement and the ability to monitor during extreme events, makes LSPIV technology particularly valuable for water resource monitoring programs with limited budgets, especially throughout Latin America and the Caribbean.

- **Best Practice Guidelines for standardized, low-cost implementation:** The development of the Best Practice Guidelines ensures that institutions can implement LSPIV efficiently, avoiding costly trial-and-error approaches. By providing clear methodological guidance, the project reduces the financial risks associated with technology adoption.
- **Scalability with minimal additional investment:** The modular nature of RIVeR and LSPIV technology allows institutions to start with minimal investment (e.g., using drones or existing cameras) and expand gradually. This flexibility enhances cost-efficiency, as users can scale their operations based on available resources.
- **Sustained funding strategies:** The RIVeR-LAC team has a track record of securing funding from provincial, national, and international programs. This model will continue to support further development, maintenance, and expansion, reducing dependency on one-time project grants.

Additional Considerations:

On the comparison with Conventional Water Level Sensors

While the cost-efficiency analysis presented in this report focuses primarily on comparisons with traditional flow measurement instruments such as ADCPs and ADVs, it is important to acknowledge that, in many hydrological monitoring programs, the combination of water level sensors and stage-discharge relationships remains the most common and cost-effective approach for continuous discharge estimation. For example, installing a basic ultrasonic water level sensor typically requires an initial investment of around USD 3,000, with annual maintenance costs of approximately USD 600. However, costs can vary significantly depending on the technology used—for instance, radar, bubbler, or pressure sensors may involve higher initial investments and different maintenance needs depending on installation conditions. Once a reliable rating curve is established through field measurements, these systems offer an efficient and economical means of monitoring river discharge over the long term. However, the LSPIV approach brings distinct advantages that complement or, in some cases, substitute traditional monitoring methods:

- Non-contact operation reduces vulnerability to vandalism, fouling, and damage during high-flow conditions.
- Early-stage measurements allow discharge data collection even before a stage-discharge relationship is fully developed, which is particularly valuable in ungauged basins or in rivers with rapidly changing morphology
- Enhanced flood event capture, as LSPIV can measure flow during extreme events—such as flash floods—when traditional sensors may be overwhelmed, submerged, or where rating curves extrapolated from lower flows are unreliable.
- Improved safety by minimizing the need for field deployments during hazardous conditions.
- Adaptability to complex environments, such as highly urbanized or sediment-laden rivers, where rating curves require frequent recalibration.

Rather than replacing conventional water level monitoring, LSPIV is most effective when used as a complementary tool, strengthening hydrological observation networks. Its integration can significantly enhance flood monitoring, validate or extend existing rating curves, and improve the ability to measure flow in sites that are otherwise difficult or dangerous to instrument.

On Regional Cost Variations

It is also important to note that the cost estimates presented in this report are based on operational conditions and labor costs specific to Argentina. In other countries across Latin America and the Caribbean, differences in salary structures, logistics costs, and equipment availability could lead to higher overall project expenses. A more detailed, regionally tailored cost-benefit analysis would therefore be valuable to better inform future implementations across diverse economic contexts.

5.3 Additional Positive Outcomes

The RIVeR-LAC project has generated several positive outcomes that were not originally anticipated, demonstrating the broader impact and adaptability of LSPIV technology:

Improvement of maintenance protocols by basin authorities: As a direct result of the fixed LSPIV station installed on the Matanza-Riachuelo Basin, ACUMAR modified its maintenance scheme for the monitoring section. To ensure optimal camera visibility, the authority increased the frequency of maintenance operations, keeping the margins free of solid urban waste and low vegetation. This effort also ensures that the hydrometric scale remains unobstructed, allowing both visual inspection and automated image-based water level measurement. This modification highlights how the integration of LSPIV technology can encourage institutional improvements in site management and monitoring practices.

Strengthened institutional cooperation: The collaboration between UNC, INA, ACUMAR, and APRHi has fostered a stronger interinstitutional network, which will be valuable for future hydrometric monitoring initiatives. The ongoing communication established during the project has led to improved data sharing protocols and clearer definitions of responsibilities between organizations.

Potential for AI-enhanced monitoring: The successful implementation of a Deep Learning-based water level measurement system using the fixed station's camera has proven effective. This innovation may encourage similar developments aimed at automating and enhancing image-based monitoring systems across the region.

Incorporation of the guidelines into academic programs: The Best Practice Guidelines will be used as study material in undergraduate and postgraduate courses at the Faculty of Exact, Physical, and Natural Sciences (FCEFyN) - UNC, promoting their dissemination and adoption among future professionals.

6. Conclusions, Limitations and Recommendations

6.1 Conclusions

The RIVeR-LAC project has effectively demonstrated the feasibility and advantages of using Large-Scale Particle Image Velocimetry (LSPIV) for hydrometric monitoring in Latin America and the Caribbean (LAC). The transition of the RIVeR software to an open-source platform (Python and React) under an AGPL-3.0 license has eliminated dependency on proprietary software, making LSPIV technology more accessible to institutions with limited financial resources. By developing a user-friendly interface with a sequential workflow and multilingual support, the software has significantly improved usability and broadened its potential user base.

The creation of Best Practice Guidelines, published under a Creative Commons BY-ND 4.0 license, provides a standardized framework for implementing LSPIV techniques. While the document is specifically tailored for LSPIV, many of its methodological principles are applicable to other image-based velocimetry techniques, enhancing its value as a general reference. The decision to host the guidelines in a public repository ensures ongoing collaboration and improvement through user feedback and contributions.

The project has also proven the economic feasibility of LSPIV technology. The use of fixed LSPIV stations, which cost approximately 2,000 USD each, presents a highly affordable alternative compared to traditional instruments like ADCPs, ADVs, and current meters, which can be prohibitively expensive for resource-limited NMHSs. As detailed in Annex 8, LSPIV's operational costs are also substantially lower, requiring fewer personnel and enabling continuous monitoring. Over a five-year period, the total cost of ownership for LSPIV can be up to 16 times lower than conventional methods, further enhancing its attractiveness for sustainable monitoring programs throughout the region.

Collaboration with INA, APRHi, and ACUMAR has laid essential groundwork for integrating LSPIV data into existing monitoring networks. Although full integration has not yet been achieved, significant progress has been made in defining data protocols and aligning monitoring practices. Furthermore, the project’s outreach efforts, including a webinar with live demonstrations of RIVeR and LSPIV processing, have been instrumental in promoting technology adoption and facilitating knowledge transfer.

The commitment of the RIVeR-LAC team to continue developing the software, updating the guidelines, and operating the fixed stations beyond the project's official timeline further strengthens the sustainability of this initiative. Ongoing support from provincial, national, and international funding programs will be essential for future growth and regional dissemination.

The project has also led to unexpected positive outcomes. The adaptation of maintenance protocols by ACUMAR, aimed at enhancing the monitoring conditions of the fixed LSPIV station, demonstrates how LSPIV implementation can drive institutional improvements. Moreover, the successful application of a Deep Learning-based water level measurement system suggests promising avenues for enhancing hydrometric monitoring systems in the future.

Overall, the RIVeR-LAC project has established a practical, accessible, and scalable approach to hydrometric monitoring. The integration of open-source tools, comprehensive guidelines, and institutional collaboration provides a strong foundation for further dissemination and adoption of LSPIV technology throughout the LAC region and beyond.

6.2 Limitations

Despite the successful implementation of the RIVeR-LAC project and the development of the Best Practice Guidelines, certain limitations were identified that may affect the applicability and effectiveness of the LSPIV technology under specific conditions:

Environmental Constraints: The Matanza-Riachuelo Basin, being a lowland river with generally low turbulence and poor surface pattern visibility, presents a significant challenge for image-based velocimetry. The effectiveness of LSPIV largely depends on the presence of distinguishable surface patterns, which are often absent during low-flow conditions or in water bodies with limited surface texture.

Limited Field Testing: Although the guidelines were validated through field testing by INA personnel in Córdoba, further testing in various hydrological and geographical contexts is required to fully assess their adaptability and robustness. The practical applicability of the guidelines in other countries or under different operational conditions may present unforeseen challenges. New users, especially those in WMO Regional Association III (South America) and Regional Association IV (North America), are encouraged to read the guidelines and then design the method application, locally assessing the possible scenarios that could develop before, during, and after the measurement. The contribution scheme in the guidelines would allow for the incorporation of recommendations for these new users, but will depend on the participation of those new users.

Technological Limitations: While the LSPIV technology has proven effective in several scenarios, it is not suitable for all river environments. Its accuracy can be compromised by various factors, including river width and variable depths, the presence or absence of well-defined surface tracers, and lighting and recording conditions. Wide rivers may present challenges in achieving sufficient resolution for accurate measurements, while inadequate lighting or poor-quality recordings can hinder image processing. Additionally, the absence of visible surface tracers can significantly reduce the effectiveness of the technique, especially under low-flow or calm water conditions.

Moreover, LSPIV relies on the assumption that the surface velocity is greater than the mean flow velocity, typically corrected using an empirical factor (α). This assumption introduces uncertainty that depends on site-specific hydraulic conditions, and its effect can vary depending on flow regime, channel geometry, and tracer distribution. While this approach is commonly accepted, users should be aware that errors in estimating this factor can affect the reliability of the discharge calculation.

Adoption Challenges: The acceptance of the guidelines by NMHSs across the region remains uncertain. Despite the continuous collaboration with INA to tailor the guidelines for practical use, their implementation will ultimately depend on institutional interest, training, and capacity-building efforts. Additionally, efforts were made to promote adoption through a dedicated webinar presenting the guidelines, aimed at increasing awareness and providing practical demonstrations to potential users. However, further engagement and dissemination activities will be essential to encourage broader acceptance and integration of the guidelines.Moreover, the lack of recognized international standards specifically for image-based velocimetry techniques may hinder broad acceptance by traditional hydrometric communities who rely on established standard methods with well-documented uncertainty characteristics.

The continuity of HydroHub's support for these types of initiatives should leverage the lessons learned from this project—particularly regarding the composition of the teams receiving support. In the case of RIVeR-LAC, the effective integration of academic/university institutions, national hydrological services and water agencies, and innovation/start-up actors provided a robust, multidisciplinary approach to problem-solving. This model can serve as a reference for future initiatives aimed at adopting or scaling emerging technologies.

Software Limitations: Although the transition from MATLAB to a Python-based open-source platform has broadened accessibility, the software still presents some limitations. Users unfamiliar with programming may encounter difficulties when attempting to customize or extend functionalities beyond the default configurations.

6.3 Recommendations

1. **Expand Field Testing and Validation** (For: NMHSs in RA III and RA IV, WMO HydroHub, Universities)**:** Continue testing the guidelines across a wider range of hydrological and geographical contexts to ensure their robustness and adaptability. Conducting additional field campaigns in various countries, river types, and flow conditions will provide valuable insights for further refinement. It is recommended that National Meteorological and Hydrological Services (NMHSs) in WMO Regional Association III (South America) and Regional Association IV (North America, Central America and the Caribbean) conduct field tests of these guidelines under their specific local conditions to validate applicability, identify any regional adaptations needed, and contribute to further refinement of the methodology. WMO HydroHub could coordinate these validation efforts and collect feedback.
2. **Strengthen Training and Capacity-Building Efforts (**For: WMO Regional Training Centers, Universities, Project Team): Promote workshops, webinars, and collaborative training sessions aimed at increasing the technical capacity of NMHSs and other stakeholders interested in applying LSPIV technology. The use of the guidelines as study material in undergraduate and postgraduate courses at FCEFyN-UNC is an important step toward this goal.
3. **Enhance Software Capabilities** (For: Project Team, Orus, Open-Source Developer Community): Continuously improve the Python-based RIVeR software by optimizing

performance, expanding functionalities, and enhancing the user interface. Providing more user-friendly options for non-programmers, as well as developing detailed tutorials, will facilitate broader adoption.The open-source developer community should be encouraged to contribute to these improvements.

4. **Enhance Hardware Capabilities (LSPIV stations)** (For: Research Institutions, Technology Developers, NMHSs): Research institutions and technology developers should develop and test specialized hardware configurations optimized for LSPIV applications, including weather-resistant camera housings, automated recording systems, and integrated processing units. Focus on engineering solutions that ensure both physical durability and operational reliability, with robust telecommunications, error-resistant data transmission protocols, and fault-tolerant software architecture to minimize downtime from technical failures. Design systems with reduced maintenance requirements through self-diagnostic capabilities, modular components for easy replacement, and extended service intervals. Exploring these comprehensive resilience measures alongside cost-effective hardware solutions will maintain measurement quality while enabling dependable, low-maintenance deployment across diverse and challenging environments. NMHSs should provide feedback on these developments based on their operational requirements.
5. **Improve Data Visualization, Access, and Systematization (LSPIV stations)** (For: Project Team, NMHSs, Basin Authorities, Water Resource Management Agencies): Basin authorities and water resource management agencies, with support from the project team should develop dedicated data servers, web applications, and APIs to streamline data storage, retrieval, and visualization. They should implement interactive dashboards and real-time monitoring interfaces while strengthening the systematization of LSPIV flow measurements through the development of a comprehensive video repository and flow estimation tools specifically designed for water resources management stakeholders. These enhancements will facilitate data sharing and integration with existing hydrological monitoring systems.
6. **Establish Sustainable Maintenance Frameworks (LSPIV stations)** (For: NMHSs, Basin Authorities, Private Sector)**:** NMHSs and basin authorities should develop standardized maintenance protocols and explore partnerships with specialized companies or local organizations for the ongoing maintenance of LSPIV stations. Private sector entities could offer maintenance services to reduce the time burden on research teams and NMHSs while ensuring consistent station operation through regular cleaning, calibration, and hardware updates. They should consider implementing remote monitoring capabilities to identify maintenance needs proactively and reduce field visits. WMO HydroHub and ET-Hydrometry could play a crucial role in developing international standards and best practices for LSPIV station maintenance, facilitating knowledge sharing between regions, and supporting capacity development for sustainable maintenance frameworks across member countries.
7. **Address Technological Limitations** (For: Academic Institutions, Research Centers, WMO ET-Hydrometry)**:** Academic institutions and research centers, potentially coordinated by WMO's Expert Team on Hydrometry (ET-Hydrometry), should conduct further research and development are recommended to address technological limitations, including improving

tracer visibility in difficult conditions, enhancing camera calibration techniques, and improving image processing under various lighting and recording scenarios.

8. **Promote Collaboration and Feedback Mechanisms** (For: Project Team, WMO HydroHub, WMO ET-Hydrometry, relevant global organizations)**:** The project team, with support from WMO HydroHub, WMO ET-Hydrometry and relevant global organizations (such as IAHS, IAHR), should maintain and strengthen the feedback channels established during the project, particularly through the GitHub repository where users can contribute to the guidelines' continuous improvement.They should embrace co-design practices by actively involving end users in the development and validation of tools and guidelines, ensuring they respond to real-world needs and constraints. Incorporating user feedback and regularly updating the document will ensure its relevance and practicality over time.. They should establish a dedicated working group focused on LSPIV standardization. This group should develop common protocols for validation against traditional methods, create standardized benchmarking datasets for software testing, and define best practices for uncertainty estimation. Regular intercomparison exercises between different LSPIV implementations could help identify areas requiring further standardization.
9. **Increase Visibility and Adoption** (For: WMO Regional Offices, and Project Team)**:** WMO Regional Offices, in collaboration with the project team, should continue dissemination efforts through webinars, conferences, and partnerships with NMHSs and other relevant institutions. Special attention should be given to promoting the guidelines through formal agreements, similar to those established with INA and ACUMAR.
10. **Leverage AI-based Innovations** (For: Research Institutions, Technology Companies, NMHSs)**:** Research institutions and technology companies should explore the integration of AI-based tools, such as the Deep Learning-based water level measurement system implemented during the project, to enhance LSPIV applications. NMHSs should test these innovations in operational settings to evaluate their effectiveness in complementing t traditional LSPIV measurements, particularly in environments where conventional methods face limitations.
11. **Develop Formal Standardization Frameworks** (For: WMO, ISO Technical Committees, OGC, Project Team): Work toward establishing formal international standards for LSPIV methodology that define quality control procedures, uncertainty estimation methods, and minimum technical requirements. WMO's Expert Team on Hydrometry should consider leading efforts to develop technical standards that could eventually be adopted by ISO or become WMO recommended practices. These standards should include calibration protocols, data format specifications, metadata requirements, and uncertainty reporting guidelines to ensure consistency and comparability across implementations.
12. **Standardize Data Formats and Metadata** (For: Project Team, WMO, ISO, OGC): Develop standardized data formats and comprehensive metadata specifications for LSPIV-derived measurements to ensure interoperability with existing hydrological databases and modeling systems. These standards should align with WMO Hydrological Observing System (WHOS) requirements and Open Geospatial Consortium (OGC) or International Organization for Standardization (ISO) standards to facilitate seamless data exchange between different hydrological information systems and across national boundaries.

6.4 Reflections on the WMO HydroHub Innovation Call Process

The structure of the WMO HydroHub Innovation Call played a key role in supporting our project's success. The milestone-based approach provided clear timelines and deliverables, helping us maintain momentum throughout the year. The regular virtual meetings kept us accountable, though we found they required substantial preparation time that occasionally competed with implementation work. For future calls, a more streamlined reporting approach with fewer but more focused virtual meetings might help balance oversight with execution time.

The review processes offered valuable feedback that significantly strengthened our outputs. We particularly appreciated the constructive and responsive oversight from WMO and the IDB, which provided both accountability and flexibility throughout implementation. This allowed us to adapt to challenges while maintaining focus on our core deliverables.

Our project actively engaged with different technical areas within WMO, promoting synergies across related initiatives. Additionally, WMO's institutional communication channels were instrumental in expanding the project's reach—particularly during the webinar—by enabling broad regional engagement and providing visibility and credibility to the event at the international level.

Based on our experience, we would like to offer several insights that could benefit future Innovation Calls:

Multi-stakeholder consortiums: Our project's success was largely due to the diverse consortium we assembled (academic institutions, government agencies, and a technology startup). This multi-actor approach created powerful synergies and facilitated both technical problem-solving and adoption processes. We recommend that future calls explicitly encourage or require such partnerships.

Focused objectives: While we successfully delivered all planned components, our experience suggests that focusing on fewer objectives with greater depth might be more effective than pursuing multiple parallel tracks. This would allow more thorough development and testing of innovations.

Sustainability planning: From the outset, more explicit emphasis on sustainability strategies would help ensure innovations continue beyond the funding period. This could include dedicated funding for transition activities or specific requirements for institutional adoption commitments.

Early alignment with WMO initiatives: While we eventually discovered valuable synergies with other WMO areas and previous Innovation Call winners, these connections could be more explicitly identified during the call announcement. Making these potential collaborations a stated requirement would enhance coherence across WMO's innovation ecosystem.

Clarified evaluation process: At times, we received feedback from multiple sources with varying perspectives and priorities. Greater clarity from the beginning about which entity has primary evaluation authority (WMO Secretariat, Think Tank, ET-Hydrometry, etc.) would help teams better respond to feedback and prioritize recommendations.

The one-year timeframe was ambitious but achievable for our multi-component project. Future WMO HydroHub Innovation Call projects might benefit from either focusing on fewer components for deeper development when pursuing multiple parallel tracks of similar complexity.

Overall, our experience with the Innovation Call was highly positive. The combination of financial support, technical guidance, and institutional backing created an excellent environment for implementing hydrometric innovations with regional impact. With the refinements suggested above, we believe the program could become even more effective at fostering practical innovation in hydrological monitoring.

7. Annexes

The following annexes are included as attached files, providing complementary documentation and supporting materials related to the development, validation, and dissemination of the RIVeR-LAC project:

1. **Snapshots of the new RIVeR software:** Screenshots illustrating the functionalities and interface of the updated version.

2. **Summary of feedback during RIVeR development - INA (Trello cards):** Collected comments and suggestions from INA during the software development process.

3. **RIVeR validation report - INA:** Detailed validation report generated by INA, including testing procedures and results.

4. **Point-by-point review responses of the Best Practice Guidelines:** Documentation of reviewer comments and corresponding responses during the guideline revision process.

5. **Validation campaign report and feedback on the guidelines by INA:** Summary of field testing and feedback collected from INA during validation campaigns.

6. **Best Practice Guidelines in both languages (PDF format):** The complete guidelines in Spanish and English, available as downloadable files.

7. **Webinar attendance report, statistics, and feedback:** This report presents a summary of participants, engagement statistics, and collected feedback following the webinar held to introduce the guidelines.

8. **Cost-effectiveness of Fixed LSPIV Stations:** Comprehensive economic assessment comparing LSPIV stations with traditional hydrometric methods (ADCPs and ADVs) in the Argentine context. Includes itemized breakdown of LSPIV station components, installation costs, operational requirements, and five-year total cost of ownership calculations, demonstrating significant cost advantages of LSPIV technology for sustainable hydrometric monitoring.