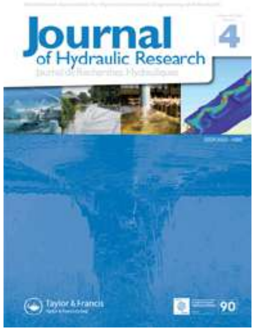

Journal of Hydraulic Research

ISSN: 0022-1686 (Print) 1814-2079 (Online) Journal homepage: www.tandfonline.com/journals/tjhr20

The value of urban drainage systems data: facts, discussions and recommendations

María Alejandra Pimiento, Jesper E. Nielsen, Michael R. Rasmussen, Elodie Brelot, Jean-Luc Bertrand-Krajewski, Alma Schellart, Simon Tait, Thomas Brüggemann, Francois Clemens-Meyer, Jörg Rieckermann, João P. Leitão, Andrea Ciambra, Juan Naves & Jose Anta

To cite this article: María Alejandra Pimiento, Jesper E. Nielsen, Michael R. Rasmussen, Elodie Brelot, Jean-Luc Bertrand-Krajewski, Alma Schellart, Simon Tait, Thomas Brüggemann, Francois Clemens-Meyer, Jörg Rieckermann, João P. Leitão, Andrea Ciambra, Juan Naves & Jose Anta (2025) The value of urban drainage systems data: facts, discussions and recommendations, Journal of Hydraulic Research, 63:4, 417-424, DOI: 10.1080/00221686.2025.2528652

To link to this article: https://doi.org/10.1080/00221686.2025.2528652

JOURNAL OF HYDRAULIC RESEARCH
2025, VOL. 63, NO. 4, 417–424
https://doi.org/10.1080/00221686.2025.2528652

International Association for Hydro-Environment Engineering and Research
Hosted by Spain Water and IWHR, China
Taylor & Francis
Taylor & Francis Group

FORUM PAPER

The value of urban drainage systems data: facts, discussions and recommendations

María Alejandra Pimiento [a], Jesper E. Nielsen[b], Michael R. Rasmussen[b], Elodie Brelot[c], Jean-Luc Bertrand-Krajewski[d], Alma Schellart[e], Simon Tait[e], Thomas Brüggemann[f], Francois Clemens-Meyer[g], Jörg Rieckermann[h], João P. Leitão[h], Andrea Ciambra[a], Juan Naves[a] and Jose Anta[a]

[a]Center for Technological Innovation in Construction and Civil Engineering (CITEEC), Universidade da Coruña, A Coruña, Spain; [b]Department of the Built Environment, Aalborg University, Aalborg, Denmark; [c]GRAIE, Lyon, France; [d]Laboratory DEEP UR 7429, INSA Lyon, Villeurbanne, France; [e]School of Mechanical, Aerospace and Civil Engineering, University of Sheffield, Sheffield, UK; [f]IKT - Institute for Underground Infrastructure, Gelsenkirchen, Germany; [g]SkillsInMotion BV, Utrecht, the Netherlands; [h]Department of Urban Water Management, Eawag, Dübendorf, Switzerland

ARTICLE HISTORY Received 26 March 2025; Accepted 28 June 2025; Open for discussion 1 February 2026

1. Introduction

For the last two decades, rapid urbanization coupled with accelerating climate change have highlighted the importance of collaborative research infrastructures (RIs) and data sharing to enable more efficient urban drainage systems (UDS). Acknowledging this process, the EU granted funding to the Co-UDlabs project under the INFRAIA framework of the Horizon 2020 programme (https://co-udlabs.eu/). Co-UDlabs integrated research infrastructures and innovation activities in UDS to address increasingly relevant public health, flood risk and environmental challenges.

As part of its activities, in 2022 Co-UDlabs organized a workshop entitled 'Tapping the value of urban drainage systems data', at the International Water Association (IWA) World Water Congress held in Copenhagen (Denmark). The initiative brought together over 40 water professionals from Europe, North America, South America and Australia from academia, industry and water utilities (Figure 1).

UDS are vital infrastructures that manage the collection and conveyance of wastewater and stormwater from residential, commercial and industrial areas to treatment plants, where the water can be safely processed, reused where possible, or returned to the natural environment without causing adverse impacts. These systems are essential for protecting public health by reducing human exposure to pathogens and for mitigating environmental impacts by controlling stormwater discharges, thereby decreasing pollution levels in receiving watercourses and minimizing the risk of urban flooding. Specifically, in this document we use the terminology sustainable urban drainage systems (SuDS) to encompass all UDS infrastructures which are not buried pipe infrastructure; this includes e.g. nature based solutions (NBS) and blue-green infrastructures.

The session was built on a 'world café' model (Brown & Isaacs, 2001), a dynamic and participatory discussion format that encourages collaborative dialogue through rotating small-group conversations on focused questions. It included presentations that introduced state-of-the-art research and concepts to the audience and allowed an international exchange of information and opinions that led to the development of recommendations on data quality and assurance in UDS. The workshop investigated three issues arising from new field data collection, storage and analysis capabilities: (i) data quality and assurance of 'big data', (ii) the use of data to enhance system performance and ensure regulatory compliance, (iii) the opportunities and risk to society from 'open data' approaches. Emphasis in the discussion was placed on the role of data for managing combined sewer overflows (CSO), sanitary sewer overflow (SSO), and SuDS, which are typical infrastructures for the UDS community.

Ensuring high-quality data in UDS remains a significant challenge due to sensor communication and maintenance issues, low data literacy, insufficient metrological skills among field staff, and limited incentives for evidence-based management (Blumensaat et al., 2025). The absence of standardized formats for UDS data and metadata further limits the reuse of existing or historical UDS datasets. Although recent advancements in sensors, electronics and communication technologies have eased data collection, open data practices are still not widely adopted in the urban drainage research and practice communities. As a result, there is a persistent

CONTACT Jose Anta jose.anta@udc.es

Figure 1. Tapping the value of urban drainage systems (UDS) data workshop participants.

lack of openly available, high-quality datasets, although public and regulatory pressure for transparency has been increasing in recent years.

Open datasets support benchmarking, modelling, decision-making, and innovation (Mcardle & Kitchin, 2016). In Great Britain, datasets provided by agencies like the Environmental Agency (EA) in England, Natural Resources Wales (NRW), and Scottish Environmental Protection Agency (SEPA) often lack adequate quality control, falling short of international standards and require users to implement additional checks (Villalobos-Herrera et al., 2022). This situation is particularly relevant for sub-hourly rainfall data used in flood estimation and emergency planning, where quality control is more complex.

The integration of real-time monitoring, data platforms, and digital infrastructure in smart urban water management offers new opportunities for data-driven operation and planning. These systems not only improve climate resilience but also contribute to environmental sustainability and urban well-being (Peráček & Kaššaj, 2025). Notable examples include the Stream initiative by UK utilities (https://www.streamwaterdata.co.uk/), which fosters collaboration and innovation in data use across the water sector, and the open Sewage Map (https://www.sewagemap.co.uk/) developed by an NGO to crowdsource and visualize urban drainage infrastructures. Such initiatives exemplify how transparent, shared data ecosystems can support smarter, more inclusive water management strategies.

2. Assessing urban drainage system state through data collection

Data collection enables monitoring of UDS water quantity and quality parameters, providing real-time insight into system state and performance, and environmental impact. It also facilitates the characterization of underground pipe systems and SuDS, allowing engineers to develop and assess a broad range of numerical models of these systems. Often, UDS data exhibit dynamic behaviours over long periods, making consistent and high-quality data collection challenging. This process cannot simply rely on raw data and rather requires a structured approach that also includes accurate metadata to ensure accessibility and operability (Branger et al., 2021). Numerical models of systems are essential for simulating current and future system behaviour under various scenarios to identify and understand system vulnerabilities, and need high-quality data for calibration, testing, etc. Furthermore, as data management evolves, technological advances such as wireless and low-power data transmission, powerful batteries, the Internet of Things (IoT) and artificial intelligence (AI) are revolutionizing data collection as well as processing and analysis methods.

Evidence from the practice of many water utilities shows that the current situation with UDS data is far from ideal: data quantity and quality requirements are underestimated and undervalued, while human and financial resources are insufficient to obtain the full benefits and outcomes of monitoring, which require time to be produced, checked, analysed, and used.

Data collection protocols form the foundation for evaluating the effectiveness of UDS and are crucial for asset design, retrofitting, performance optimization, modelling, and regulatory compliance. However, this process often involves significant costs, requiring careful selection of sampling sites and monitoring equipment, data communication and data transfer workflows as well as data analysis and data validation process to ensure data integrity and reliability (Bertrand-Krajewski et al., 2021; Maheepala et al., 2001). The absence of continuous data collection, coupled with inadequate understanding of data fluctuations, lack of uncertainty assessment and data validation, can impact decision-making and the long-term effectiveness of SuDS (Salehi et al., 2020).

2.1. Participants' perspectives

Workshop participants referred to the importance of improving methodologies for data collection on UDS performance in various fields, including flood risk assessment, CSO monitoring, water quality analysis, and the impact of SuDS. The conversation highlighted a growing need for more automated and resource efficient data collection methods, coupled with robust mechanisms that ensure data integrity and reliability. For example, in Denmark participants reported that utilities and municipalities are encouraged to spend 1–2% of their budgets on data collection to validate performance and improve system understanding, while in Colombia, only basic data are collected nationally, and validation practices are lacking.

The absence of standard terminology for a single parameter (e.g. water levels) emerged as a major challenge, as well as standardized procedures for data collection and quality assurance. This exacerbates data quality issues through the proliferation of errors associated with incomplete or inadequately documented datasets, limiting access to and sharing of crucial data and impeding the comprehensive understanding needed to develop effective management and sustainable development strategies. The implementation of standardized procedures would facilitate data validation, thereby enhancing the accuracy of modelling outcomes and enabling stakeholders to make informed decisions based on reliable and comparable data.

The necessity of standardized, reliable data for regulatory compliance cannot be overstated. However, discussions around legal frameworks and practical challenges surrounding data collection reveal nuanced concerns, particularly regarding privacy and the potential misuse of information. As legal requirements for sewer network inspections and maintenance operations continue to evolve, attention is drawn to the dynamic nature of data collection practices.

An additional challenge lies in the scarcity of financial and human resources allocated to data collection and analysis. It is particularly pronounced in smaller municipalities and developing nations. One participant from South Africa reported that the prohibitively high cost of sensors and transmission systems are problematic. This further exacerbated by unfavourable currency exchange rates, which impede widespread deployment despite growing data needs. This is hampering the acquisition of adequate data needed for a comprehensive, transnational assessment of UDS performance.

2.2. Insights and recommendations from Co-UDlabs

One of the main issues with data collection is the lack of immediate rewards for the effort, making it vulnerable to budget cuts. The cost of data collection is usually negligible compared to the investments or rehabilitation costs of urban drainage systems. While the investment cost is a one-time expense, the monitoring and maintenance costs can become significant throughout the asset's lifecycle.

In contrast with this trend, in England a regulatory requirement (UK Government, 2021) has resulted in substantial funds, of > 1 bn British pound sterling (GBP), being allocated for continuous water quality data collection at every CSO. Estimates suggest that, on average, it will cost around GBP 50,000 to gain access, install electricity supply, and build a kiosk containing multiparameter water quality sensors and communication equipment for near real-time measurement and data transfer. Additionally, equipment maintenance visits every few months to ensure sensor accuracy will result in an estimated annual cost to water utilities of the order of GBP 300 million once the installation program will have been completed in 2035.

Despite these investments, collected data often fall short of providing all necessary information. Although many reliable low-cost sensors are now available, the costs associated with placing and maintaining sensors in hazardous environments remain high. Indeed, in the long-term, human resources for maintenance and calibration are the most expensive cost.

Data collection is often characterized as chaotic, with issues such as low reliability, significant bias, unquantified uncertainties, and insufficient validation singled out as recurrent. Despite the availability of advanced methodologies, poor and inconsistent data quality remains a major problem. Factors such as staff skills, motivation, and local challenges are also as relevant for this kind of activities as is the size of the involved organization. Regulations need to evolve to take account of such data uncertainty (Schellart et al., 2025).

In many cases, there is a significant skills gap between those who collect the data and those who use it. This disconnection means that data collectors often lack a clear understanding of whether the data they generate are suitable for the intended purpose. Improving communication among the different stakeholders involved in the data lifecycle could help bridge this gap, ensuring that data are collected and utilized more effectively.

Improving communication and ensuring that good methodologies and practices are consistently applied could help address these challenges, leading to more reliable and useful data management in both small and large water utilities (Bertrand-Krajewski et al., 2021).

3. Ensuring data quality in utilities and at national scale

Data quality checking is critical to ensure that the collected data are accurate and reliable. To address this challenge, constantly evolving methodologies and technologies are needed in UDS. Data validation is an essential first step to prevent errors from propagating through modelling and decision-making, thereby improving the reliability of the results (Branisavljević et al., 2010; Deletic et al., 2012). Frequent data validation can reveal the underlying causes of incorrect or missing data, thereby improving measurement protocols and preventing the propagation of errors to subsequent records (Clemens-Meyer et al., 2021).

Temporal and spatial resolution issues further impact data accuracy, especially in small-scale urban catchments (Piadeh et al., 2022). End-users should be aware of these constraints. In any case, it is recommended that data analysis be accompanied by detailed documentation on the parameters and methods applied (Clemens-Meyer et al., 2021).

3.1. Participants' perspectives

The workshop participants highlighted some common issues related to data quality assurance, such as the lack of standardization, data collection inconsistent practices, validation tools, insufficient resources, and inadequate documentation.

While common, manual verification of collected data often faces resource constraints and procedures based on 'cut-off' values are usually used. At the water utility level, data quality assurance involves calibration, maintenance, parametric methods and algorithms to detect wrong, abnormal and doubtful values, possibly coupled with statistical analysis, as well as remote access for convenient control of automated recording systems. Some utilities employ technical and standardized procedures to maintain data integrity. However, coverage by trained and dedicated personnel is limited. In Spain, practices vary widely, with some utilities comparing model results to measurements, while others lack any formal assurance.

National data centres, such as meteorological services, play a crucial role in appointing data managers to ensure compliance with minimum requirements for uploaded data, but resource constraints often limit the effectiveness of verification. The availability of UDS information varies by country. Advocating for open data policies should encourage transparency and benchmarking by facilitating data sharing and infrastructure assessment. Enforceable regulations, community engagement, adequate governance, and training and education are essential to disseminate and maintain data integrity. These measures are crucial to ensure the resilience and effectiveness of urban drainage systems amid evolving environmental and social needs.

In general, these issues suggest that better data management practices are needed to ensure the quality and consistency of data, while increased data collection with guaranteed quality and reliability improves system understanding.

3.2. Insights and recommendations from Co-UDlabs

Data validation in water utilities often faces limitations due to a lack of trained personnel or resources. Understanding the reasons behind these limitations is crucial for overcoming them. Firstly, regulators may not mandate data validation or provide commonly accepted codes of practice. Even when required, authorities may not conduct sufficient checks. Additionally, human resources are a significant factor, with shortages of personnel or expertise being common issues. If the final use of the data is unclear from the outset, there are insufficient incentives for proper collection and processing. Consequently, data management may fall to personnel without the necessary skills.

Improving data quality requires not only technical expertise and a clear understanding of the purpose of data collection and quality metrics but also addressing governance-related obstacles and ensuring the reliability of the collected data. Operators generally consider the quality of monitoring data to be good and use it primarily for real-time system monitoring and incident detection (Figure 2). However, monitoring data is rarely used for compliance or long-term planning, likely due to regulatory disconnects rather than distrust in the data (Rieckermann et al., 2024). Low motivation and weak incentives to act, as well as insufficient requirements to achieve better data quality have also been mentioned as limiting factors.

Finally, maintaining a target level of data quality requires significant time and personnel, making it a costly task. Decision makers should acknowledge this from the beginning, as they need to allocate all necessary resources to properly manage the data. Only such an investment will ultimately improve the quality of services provided by the UDS.

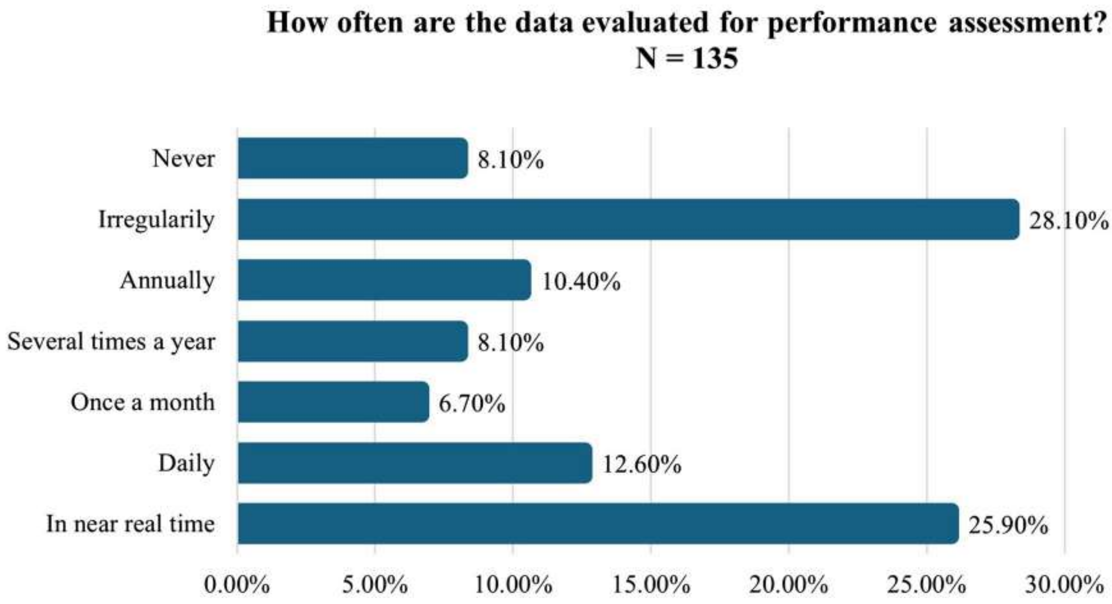

Figure 2. Frequency of data evaluation for performance assessment. Source: Rieckermann et al. (2024).

4. The advantages and disadvantages of default 'open-data' approach in UDS

Recent advances in open data have significantly expanded access to meteorological records, river basins, groundwater levels, water bodies chemical and biological status, and other large-scale datasets. Much of the UDS traditional infrastructures (i.e. sewer systems and their ancillaries) lie underground and are controlled by numerous public utilities and operators, making data sharing complex due to the different software implementations and a lack of national and international data standards. Utilities often hesitate to release data publicly, citing security and public relations concerns (Nedergaard Pedersen et al., 2021). Accessibility varies across the board: GIS data is more widely available than operational data, highlighting disparities in data availability and the need for greater consistency in openness practices. The situation is even more complex with decentralized SuDS infrastructures owned by numerous diversified and independent owners.

The level of openness in data dissemination is often influenced by political and economic actors who play a key role in determining data accessibility. The existence of open data not only fosters innovation but could also support the growth of start-ups by providing valuable knowledge and resources for development if appropriate regulations are set (e.g. about intellectual property and copyright). Furthermore, the democratization of information through the availability of public data promotes transparency and may empower citizens to participate in decision-making processes.

4.1. Participants' perspectives

According to participants, there is an inconsistency in the degree of data openness in UDS due to a lack of collaboration between utilities and researchers to elaborate models, enhance the decision-making process, and analyse risks associated with water scarcity, flooding, pollution and adaptation to climate change. However, a consensus emerges on the substantial advantages of open data, including knowledge dissemination, validation methods, better planning processes, benchmarking capabilities, transparency, accountability, and cheaper and better-quality data. In Germany, open data is becoming more common at the municipal level, although implementation remains inconsistent. In South Africa, political dynamics influence openness, with cities like Cape Town promoting transparency, but concerns about legal liability and political withholding remain significant. Furthermore, incorporation of metadata is crucial to ensure the quality and reliability of open datasets. These datasets would serve as tools for educational, research, and operational purposes.

While open data fosters collaboration, innovation, and public engagement, it also raises concerns about security, privacy, and the potential misuse of sensitive information. The risks of open data include conflicts with the public, legal action, the spread of uncertainties and errors, distrust between private companies, and the potential for data misinterpretation. Water utilities may be reluctant to open data due to the potential for exposing their failings. Achieving the right balance between transparency and safeguarding is essential to support the sustainable development of UDS.

4.2. Insights and recommendations from Co-UDlabs

Currently many water utilities and their supplier SMEs do not clearly see the benefit of sharing data and therefore use specialized, not open-source, software.

Consequently, there is little effort to harmonize data. In some instances, there is even a fear that sharing data could compromise their competitiveness.

Data should be made public to citizens with care, as it creates both opportunities and management challenges. While interest in UDS is often limited to the need for a secure environment, specific groups such as NGOs, citizen science groups, and social media influencers may show growing interest in understanding it. This shift will need to be driven by political and governance motivations, with the aim of reducing the impacts of different hazards and informing the public on issues such as public health.

Open data can improve transparency in governance and decision-making, as supported by the revised Urban Wastewater Directive (European Parliament and Council, 2024). While public access to urban drainage data can encourage public participation (e.g. installation of SuDS on private property, pressure to address pollution from UDS), it must be managed carefully to avoid misinterpretation and conflict. Clear explanations, education, stakeholder consensus, and collaboration with local citizen groups, social scientists, and communication experts are essential for effectively using and understanding the data (Schellart et al., 2025).

Co-UDlabs recent findings indicate that the vision of open data is met with mixed reactions within the sector. While real-time monitoring is widely recognized as a valuable and achievable goal due to its clear benefits for operational performance and incident response, opinions on making CSO data publicly accessible are more divided. Supporters see transparency to foster trust and collaboration, yet many express concerns about data being misinterpreted by the public, especially in the absence of proper validation and contextual understanding. These concerns highlight the need for robust data governance frameworks and targeted communication strategies to ensure that open data initiatives enhance, rather than hinder, stakeholder engagement and public confidence (Rieckermann et al., 2024).

5. Advancing data in urban drainage systems

While urban drainage systems present unique challenges, valuable lessons can be drawn from other environmental and infrastructure-related data collection programs. For instance, the World Meteorological Organization (WMO) Unified Data Policy promotes the open and unrestricted exchange of Earth System data to enhance global capabilities in monitoring and forecasting environmental processes. It emphasizes the integration of emerging data sources, including private sector and IoT technologies, while maintaining a commitment to long-term, high-quality datasets. The policy calls for standardized quality control and international interoperability, advocating for open access to core and research-relevant data to maximize scientific, societal, and economic benefits (WMO, 2022).

In the context of European level RIs, initiatives such as the ENVRI community (https://envri.eu/), with over 25 environmental sciences RIs across domains like oceanography, atmospheric science and biodiversity, are developing robust frameworks for data interoperability, quality assurance, and long-term accessibility. These frameworks emphasize standardized metadata, open data policies, and cross-disciplinary collaborations, which are critical for enhancing data reuse and integration. However, the built environment – including sectors like water treatment, transportation, and telecommunications – remains underrepresented in these efforts. Bridging this gap presents an opportunity for UDS research to align with enduring, broader environmental data ecosystems, fostering in the long term more resilient and adaptive infrastructure management. The Co-UDlabs project has highlighted a persistent gap in both the quality and openness of data collection within urban drainage systems. Examples of the work performed in Co-UDlabs include the generation of well-documented open datasets available at the long-term Zenodo repository, or the development of data analysis tools such as the Urban Drainage Metrology Toolbox or the initiative to develop a common ontology for urban drainage data in collaboration with the JCUD International working group on data and models (IWGDM). As a further step toward community building and long-term improvement, Co-UDlabs promotes the creation of the UDRAIN Working Group through the IWA/IAHR Joint Committee of Urban Drainage to foster worldwide collaboration among urban drainage RIs, with the goal of exploring new strategies to enhance data collection, quality assurance and openness.

6. Conclusions

The outcomes of the conversation between workshop participants suggest a consensus on the critical role of data collection in assessing and improving the performance of UDS. Key findings include the need for standardized methodologies, increased investment in data collection infrastructure, in skilled personnel, and the importance of reliable, accessible data for regulatory compliance, modelling, and decision-making. Looking ahead, there is a recognition of the evolving nature of data collection practices, driven by technological advancements and changing regulatory contexts.

Common concerns revolve around a lack of standardized protocols, insufficient resources for data verification, and limited systematic quality control practices. Challenges also arise in data sharing and collaboration, while there is a growing need for greater transparency and enduring public access to data. These issues hinder effective management and decision-making, highlighting the need for concerted efforts to improve data reliability and accessibility in urban water management. Training and education to develop skills in metrology and its best practices are also a key aspect.

Regarding open data, the participants highlight a complex interaction between the benefits and risks of open data in UDS. While openness fosters transparency, knowledge dissemination and innovation, it also poses risks such as misinterpretations, conflicts, and resistance from stakeholders. Addressing these challenges requires standardized approaches, stakeholder collaboration, education and training, and a nuanced understanding of the socio-economical-political dynamics that shape open data within urban drainage systems.

The conversation at the Workshop is an example of the relevance of UDS data approaches in public policy-making and water management. Public regulators, private companies, and research groups will soon have to deal with unprecedented amounts of data: there will be pressure to make this information openly accessible, to overcome national differences and methodological bottlenecks, and to feed data into the policies that affect the way urban drainage, planning, and infrastructural improvements are made. Data assurance and management will be crucial for public and private organizations to build mutual trust and positively influence sustainable, affordable, and inclusive policies in the future. Decision makers should acknowledge this early on and find the necessary resources to ensure adequate data management, ultimately improving the quality of the services provided by UDS.

Acknowledgements

Co-UDlabs would like to thank the attendees of the WWC workshop for enabling a fruitful discussion about the value of data in UDS.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This work was funded by the EU under the Horizon 2020 program within a contract for Integrating Activities for Starting Communities (Co-UDlabs project. GA No. 101008626); H2020 Research Infrastructures.

ORCID

María Alejandra Pimiento https://orcid.org/0000-0002-7691-7291

References

Bertrand-Krajewski, J.-L., Clemens-Meyer, F., & Lepot, M. (2021). *Metrology in urban drainage and stormwater management: Plug and pray* (J.-L. Bertrand-Krajewski, F. Clemens-Meyer, & M. Lepot, Eds.). IWA Publishing. https://doi.org/10.2166/9781789060119

Blumensaat, F., Bloem, S., Ebi, C., Disch, A., Förster, C., Maurer, M., Rodriguez, M., & Rieckermann, J. (2025). *The UWO dataset – long-term observations from a full-scale field laboratory to better understand urban hydrology at small spatio-temporal scales*. https://doi.org/10.5194/essd-2024-47

Branger, F., Tait, S., Chaffard, V., Brelot, E., Lecomte, V., Mallet, I., & Skipworth, P. (2021). Data communication and storage. In J.-L. Bertrand-Krajewski, F. Clemens-Meyer, & M. Lepot (Eds.), *Metrology in urban drainage and stormwater management: Plug and pray* (pp. 135–154). IWA Publishing. https://doi.org/10.2166/9781789060119_0135

Branisavljević, N., Prodanović, D., & Pavlović, D. (2010). Automatic, semi-automatic and manual validation of urban drainage data. *Water Science and Technology*, *62*(5), 1013–1021. https://doi.org/10.2166/wst.2010.350

Brown, J., & Isaacs, D. (2001). The world café: Living knowledge through conversations that matter. The systems thinker. *Pegasus Communications, Inc*, *12*(5), 1–5. https://theworldcafe.com/wp-content/uploads/2015/07/STCoverStory.pdf

Clemens-Meyer, F. H. L. R., Lepot, M., Blumensaat, F., Leutnant, D., & Gruber, G. (2021). Data validation and data quality assessment. In J.-L. Bertrand-Krajewski, F. Clemens-Meyer, & M. Lepot (Eds.), *Metrology in urban drainage and stormwater management: Plug and pray* (pp. 327–390). IWA Publishing. https://doi.org/10.2166/9781789060119_0327

Deletic, A., Dotto, C. B. S., McCarthy, D. T., Kleidorfer, M., Freni, G., Mannina, G., Uhl, M., Henrichs, M., Fletcher, T. D., Rauch, W., Bertrand-Krajewski, J. L., & Tait, S. (2012). Assessing uncertainties in urban drainage models. *Physics and Chemistry of the Earth, Parts A/B/C*, *42–44*, 3–10. https://doi.org/10.1016/j.pce.2011.04.007

European Parliament and Council. (2024). *Directive (EU) 2024/3019 of the European Parliament and of the Council of 27 November 2024 concerning urban wastewater treatment (recast)*. Official Journal of the European Union. http://data.europa.eu/eli/dir/2024/3019/oj

Maheepala, U. K., Takyi, A. K., & Perera, B. J. C. (2001). Hydrological data monitoring for urban stormwater drainage systems. *Journal of Hydrology*, *245*(1–4), 32–47. https://doi.org/10.1016/S0022-1694(01)00342-0

Mcardle, G., & Kitchin, R. (2016). Improving the veracity of open and real-time urban data. *Built Environment*, *42*(3), 457–473. https://doi.org/10.2148/benv.42.3.457

Nedergaard Pedersen, A., Wied Pedersen, J., Vigueras-Rodriguez, A., Brink-Kjær, A., Borup, M., & Steen Mikkelsen, P. (2021). The Bellinge data set: Open data and models for community-wide urban drainage systems research. *Earth System Science Data*, *13*(10), 4779–4798. https://doi.org/10.5194/essd-13-4779-2021

Peráček, T., & Kaššaj, M. (2025). Legal easements as enablers of sustainable land use and infrastructure development in smart cities. *Land*, *14*(4), 681. https://doi.org/10.3390/land14040681

Piadeh, F., Behzadian, K., & Alani, A. M. (2022). A critical review of real-time modelling of flood forecasting in urban drainage systems. *Journal of Hydrology*, *607*, 127476. https://doi.org/10.1016/j.jhydrol.2022.127476

Rieckermann, J., Derwort, S., & Schellart, A. (2024). *D2.5 Report on smart governance and public access to data (1.0)*. https://zenodo.org/records/14981692

Salehi, M., Aghilinasrollahabadi, K., & Salehi Esfandarani, M. (2020). An investigation of stormwater quality variation within an industry sector using the self-reported data collected under the stormwater monitoring program. *Water*, *12*(11), 3185. https://doi.org/10.3390/w12113185

Schellart, A., Wu, Y., Bertrand-Krajewski, J.-L., Rieckermann, J., & Anta, J. (2025). *D6.4. Space distributed monitoring and data interpretation*. https://doi.org/10.5281/zenodo.14718050.

UK Government. (2021). *Environment Act* 2021. https://www.legislation.gov.uk/ukpga/2021/30/contents

Villalobos-Herrera, R., Blenkinsop, S., Guerreiro, S. B., O'Hara, T., & Fowler, H. J. (2022). Sub-hourly resolution quality control of rain-gauge data significantly improves regional sub-daily return level estimates. *Quarterly Journal of the Royal Meteorological Society*, *148*(748), 3252–3271. https://doi.org/10.1002/qj.4357

WMO, W. M. O. (2022). *WMO unified data policy*. https://library.wmo.int/idurl/4/58009