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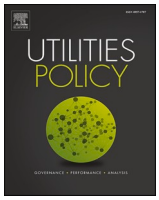

Full-length article

Digital solutions in search of a problem? Balancing short-term and long-term needs in water utilities

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ABSTRACT

Digitalisation has gained interest in the broader water sector, with data-driven solutions seen as key to this development. Digital technologies are often portrayed as solutions to current and future challenges and potential applications have been identified across all areas of urban water management. However, their implementation in water utilities remains limited. This paper examines how the use of data-driven solutions aligns with and addresses the perceived needs of water utilities. It is based on an interview study with 23 key informants from Swedish water utilities involved in implementing and using data-driven solutions in urban water management. Our findings suggest that these solutions are not yet well-aligned with the technical and organisational structures of utilities. While they can address the long-term needs of water utilities with promises of improved efficiency and performance, they are less equipped to meet short-term needs which call for simple, immediate-impact solutions. Although implementing data-driven solutions should be justified by actual organisational needs, we must distinguish between the short-term and long-term needs of water utilities. Prioritising short-term needs may be more efficient in the short run but can be detrimental in the long run, which creates an ambidexterity dilemma for water utilities. Utilities should formulate digital vision or strategies that consider both the short-term and long-term needs of utilities to benefit fully from digitalisation.

1. Introduction

In recent years, digitalisation has gained increasing attention within the global water sector under labels such as 'digital water' (Sarni et al., 2019), 'the fourth water revolution' (Garrido-Baserba et al., 2020), and 'Water 4.0' (Sedlak, 2014). With the rise of new digital technologies such as artificial intelligence (AI), Internet of Things, and big data analytics, new opportunities (and challenges) for urban water management have emerged. As stated by Sarni et al. (2019, p.5), digital technologies are transforming water just as they '*are transforming many aspects of our world – from our cities, to our homes and personal lives*'. Digitalisation is thus often described in terms of an anticipated transformation (Walter, 2024), with possible implications for power structures (Amankwaa et al., 2024; Solis and Bashar, 2022), customer relations (Liu et al., 2016), supplier dependencies (Cahn et al., 2023a, 2023b), and strategic priorities (Damman et al., 2023). In a time when water utilities face many challenges, caused by ageing infrastructures, climate change, and urbanisation (Bennich et al., 2023; Ferguson et al., 2013; Hoffmann et al., 2020), among others, digital technologies are often depicted as a solution to present and future challenges in urban water management (Fu et al., 2022; Walter, 2024). Changing demands, with a greater focus on efficiency and performance, are expected to push water utilities towards digitalisation (Boyle et al., 2022).

An essential part of digitalisation is the use of data-driven solutions, based on, for instance, AI tools such as machine learning and deep learning, wherein the availability of data and information is key (Berg and Phillips, 2017). With continued digitalisation, the amount of available data is expected to increase exponentially (Brynjolfsson and McAfee, 2014). This 'datafication' (Galliers et al., 2015; Newell and Marabelli, 2015) enables the use and combination of detailed data from various sources to let new insights emerge (Garrido-Baserba et al., 2020; Mayer-Schönberger and Cukier, 2013). For instance, the Covid-19 outbreak illustrated how human wastewater can be used to collect epidemiologic data (Polo et al., 2020), and combining monitoring with

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hydrometeorological data can provide forecasts on water microbial quality (Sokolova et al., 2022). Data-driven solutions can be employed within essentially any part of urban water management, such as anomaly detection (e.g. leakage detection and localisation), system prediction (e.g. short-term demand forecasting), asset management (e.g. sewer defect assessment), system operation (e.g. real-time and smart control), and planning and maintenance (e.g. leakage prediction) (Balla et al., 2022; Fu et al., 2022; Negm et al., 2024). An up-and-coming area for use is leakage and non-revenue water reduction (Grievson, 2023), as advances in digitalisation have enabled the previously hidden water and wastewater pipe networks to become increasingly visible and manageable. While not limited to AI, many of these new solutions are today based on or framed as various AI applications.

However, prior studies have shown that there is an implementation gap between the state-of-the-art solutions and the reality at most utilities (Fu et al., 2022; Sirkiä et al., 2017; Therrien et al., 2020). The adoption of data-driven solutions is, in general, slow (Doorn, 2021; Rapp et al., 2023), and some argue that water utilities are not yet ready for a digital revolution (Blumensaat et al., 2019). Even though utilities reportedly aim to increase the use of data-driven solutions, such as various AI applications, most reported use cases are experimental rather than fully integrated into daily operations (Fu et al., 2022; Rapp et al., 2023). Several technical and non-technical barriers prevent the implementation and use of data-driven solutions. Prior studies from the water sector have reported various barriers, including a disconnect between research and practice (Pianosi et al., 2020; Sowby and Walski, 2021), explainability issues caused by the 'black box' nature of algorithms (Fu et al., 2022), insufficient data availability, quality, and security (Cahn et al., 2023a; Ruddell et al., 2020), incompatibility with existing digital systems (Okwori et al., 2024; Sirkiä et al., 2017), costs of software and hardware (Sirkiä et al., 2017), and lack of appropriate skills and capabilities (Boyle et al., 2022; Sarni et al., 2019).

Given the grand expectations related to digitalisation, how can we understand the slow adoption of data-driven solutions in water utilities? If the promise of these technologies holds, addressing these barriers and increasing the use of these tools should be a top priority of water utility managers. Yet, the idea of 'digital water' and the push to digitalise largely come from leading water technology companies rather than water utilities themselves (Walter, 2024). Is it possible that the technology providers and other digital champions have exaggerated the promise of these technologies? As emphasised by prior studies, meeting actual needs within the organisation is a key to implementing digital technologies in water utilities (Arnell et al., 2023). However, some have started to question the enthusiasm related to digital technologies and how effectively they can address the needs of water utilities (Blumensaat et al., 2019; Fu et al., 2022). This paper thus sets out to address the question: how do data-driven solutions align with the perceived needs of water utilities?

This paper is based on a qualitative study of the Swedish water sector, primarily drawing upon semi-structured interviews with 23 water utility professionals. Water utility professionals have an important role in implementing and using digital technologies at utilities (Manny et al., 2021; Therrien et al., 2020), which motivates the need to study the perspective of these actors (Denzin and Lincoln, 2008). Specifically, we focused on data-driven solutions for urban water management used in, for example, decision support. Drawing upon the innovation literature, we illustrate how it is a matter of balancing the short-term and long-term needs of water utilities, where the latter needs greater attention if the utilities aim to increase the use of digital technologies and advance the digitalisation of their operations.

2. Theoretical background

Digital water belongs to a broader societal trend of adopting digital technologies, where the impact of these technologies is expected to be visible in any sector and industry in society (Legner et al., 2017; Westerman et al., 2014). However, the impact of digital technologies is not the same across sectors since different sectors have different characteristics and the ability to adopt innovation and change (Dolata, 2009). Infrastructure sectors, such as water and energy, are typical examples of 'large technical systems' (Hughes, 1983), which in their mature stages are stable and predominantly display incremental and slow change trajectories (Loorbach et al., 2010; Markard, 2011). Innovation tends to find its way into these systems if there is a good alignment with the existing (e.g. technical, organisational, and cultural) structures of the systems. For instance, the effective implementation of innovation should not only fit with the goals of organisations, but also the existing technologies, business models, and socio-political contexts (Blomkvist et al., 2020; Blomkvist and Nilsson, 2017). For instance, the energy sector, in comparison to the water sector, has seen several policy incentives that have facilitated and pushed the adoption of digital technologies (Geels et al., 2021; Sovacool et al., 2017). Overall, digitalisation will likely be adopted at varying rates and yield differing outcomes across industries.

Prior studies addressing digitalisation in established organisations have highlighted the need to formulate digital strategies (Chanias et al., 2019; Matt et al., 2015; Saarikko et al., 2020) and build dynamic capabilities to manage the adoption of digital technologies (Vial, 2019; Warner and Wäger, 2019). The use of digital technologies may not only trigger changes in business processes but also in value proposition and organisational identity (Hanelt et al., 2021; Verhoef et al., 2021). In the innovation literature, the act of balancing current operational activities (exploitation) with exploring and experimenting with new activities (exploration) is often referred to as 'organisational ambidexterity' (March, 1991; Tushman and O'Reilly, 1996). Both exploitation and exploration activities are essential for organisations, where the latter enables organisations to remain competitive and survive in changing and uncertain environments. While prioritising exploitation is more effective in the short run, it can be self-destructive for organisations in the long run. Organisations can achieve ambidexterity by creating separate research and development departments or business development units (structural ambidexterity) or by allowing employees to prioritise between exploitation and exploration activities in their day-to-day work (contextual ambidexterity) (Birkinshaw and Gibson, 2004). In practice, however, managing ambidexterity is challenging for most organisations, which has also been reported in the case of digitalisation (see e.g. Kronblad et al., 2023; Svahn et al., 2017).

The large-scale adoption of new technology is seldom a smooth trajectory, and some of the challenges noted could apply to many industries. However, the water sector has some unique characteristics. Earlier research has proposed that innovation in the water sector is less driven by rational factors such as profit-seeking and market competition, and more by social factors (Bennich, 2024a). Notably, the main activities of water utilities revolve around daily operations (Bennich et al., 2023). Due to their public mandate to provide critical societal services, utilities tend to prioritise reliability and stability over innovation and change (Hartley, 2005). Moreover, the sector is controlled mainly by centrally placed quasi-monopoly actors, rather than market forces and competition (MacGillivray et al., 2006). Innovation activities are managed by actors such as utility managers, with subjective perceptions of societal expectations and risk tolerances (Kiparsky et al., 2013, 2016; MacGillivray et al., 2006). Utility managers are rarely rewarded for successful innovations but may face repercussions for failed attempts. In addition, the hidden nature of the infrastructure, substantial sunk costs in assets, regulatory compliances, scarce resources on an organisational level, and lack of visions on individual and local scales have been highlighted as barriers towards innovation in this type of sector (Alm et al., 2021; Bennich et al., 2023; Sherman et al., 2020). Due to these characteristics, the water sector is sometimes perceived as less innovative and slow to adopt new (technical) innovations in comparison to other sectors (Markard, 2011; Wehn and Montalvo, 2018). However, due to the nature of digital technologies, some argue that

digitalisation can 'leapfrog' traditional infrastructure development (see e.g. Sarni, 2020; Verma, 2021).

Hence, in light of the characteristics of the water sector and water utilities more specifically, we investigated how well digital technologies align with and address the needs of water utilities. In the following section, we explain how we studied the potential use of data-driven solutions in urban water management.

3. Method

3.1. Research context

The empirical context of this paper is Sweden, a wealthy North European country. In Sweden, 290 municipalities of various population and geographical sizes are responsible for providing urban water services. The responsibility lies with single municipality urban water management units or with multi-municipality companies with several municipalities as owners. Given their critical societal service, the water utilities are regulated and governed by national and international law. Similar to other European countries, many Swedish utilities supply a small customer group, except for a few major utilities that are usually located around the larger cities. The water utilities are non-profit and tariff-based organisations, where budgets need to be approved by politicians in the municipal council. The municipal council also decides on the water tariff, which sets the boundaries for water utility activities. In Sweden, approximately 90 per cent of the population relies on the public provision of urban water services (SCB, 2021).

Similar to the global water sector, digitalisation in the Swedish water sector is underway, where utilities are digitalised to various degrees (Arnell et al., 2021). In most cases, parts of the urban water systems are digitalised and automated (such as remote control of treatment plants) while other parts are less digitalised (such as the piped network) (Malm et al., 2019). Within the sector, there are various digitalisation initiatives, such as a 'digitalisation network' driven under the realm of the industry association 'Swedish Water' (see Svenskt Vatten, 2023), which aligns with the global trend of promoting 'digital water' (Bennich, 2024a; Walter, 2024). In addition, Sweden usually ranks high in international digitalisation indices (see e.g. EU, 2023; OECD, 2018). Thus, this further stresses the validity of investigating the slow adoption processes in Sweden, a developed country with all the preconditions for digitalisation.

3.2. Data collection and analysis

This paper is based on a qualitative research study, primarily drawing upon semi-structured interviews with key informants from Swedish water utilities. The empirical material stems from two datasets of interviews with, in total, 23 informants from 12 different municipal water utilities in Sweden, all of medium to large size (see Table A1 in the appendix). The compilation of informants and utilities was not aimed at forming a complete representation of the Swedish water sector. Instead, the sample represents parts of the sector that are in the process of adopting new digital technologies and have started to shift towards the idea of 'digital water'. Thus, smaller utilities were not included in the dataset since they were deemed less likely to represent early adopters of new digital technologies (see e.g. Bennich, 2024a).

The informants had various roles and positions at the water utilities to facilitate a rich understanding of the use of data-driven solutions (see Table A1 in the appendix). The interviews were of a descriptive and interpretative character to facilitate the understanding of the perspectives of the informants (McIntosh and Morse, 2015). A semi-structured approach was used during the interviews, meaning that they followed a predetermined set of questions (interview guide) but also allowed for deviations and nuances in the material (Denzin and Lincoln, 2008; Valentine, 2005). One dataset, including 14 interviews, concentrated more generally on digitalisation in the water sector, while the other, consisting of nine interviews, focused more specifically on decision support for urban water management. Some of the informants were part of both datasets. In addition, one of the authors was involved in a case study developing decision support for the rehabilitation of urban water pipes in a medium-sized water utility inSweden, which added additional knowledge and understanding of the challenges water utilities face related to digitalisation. Hence, the two datasets of interviews, informants with different roles and perspectives, and the additional case study provided several opportunities to triangulate the findings (Yin, 2018).

For the data analysis, we adopted a thematic analysis approach to categorise identified aspects (or items) (Braun and Clarke, 2006; McIntosh and Morse, 2015). In this paper, we use the term *aspect* as a broad term to illustrate an opinion, experience, fact or similar expressed by the informant that was related to a specific question or was expressed during the subsequent discussions. The aspects were identified from both transcripts and observational notes made during interviews. The aspects were, thereafter, grouped and combined into main themes using an iterative approach, adapted mainly from the process described in Mayring (2000). As we began to analyse our collected material, we focused on factors related to data-driven solutions in general, problems that digital technologies were or were not able to address, and problems related to the implementation and usage of these technologies. As such, a broad picture of the informants' perspectives on data-driven solutions emerged, as well as the connection to the water utility organisation and their operational and strategic work. To further strengthen the validity of our findings, we compared our findings with prior literature and theoretical concepts during the analytical process (Yin, 2018). In the end, we identified three broader main themes - 'Strategic aspects', 'Technical aspects', and 'Organisational aspects' - under which the identified aspects were categorised (see Table A2 in the appendix).

4. Findings

In the following section, we present the findings from our study of data-driven solutions in urban water management. The findings are structured following three main themes: strategic, technical, and organisational aspects. The findings synthesise information and viewpoints from the informants included in this study, either as individuals or as a group. Additional example quotes are provided in Table A2 in the appendix.

4.1. Strategic aspects

One of the purposes of water utilities is to provide a secure water supply and wastewater management, as well as climate adaptation of the city. And digitalisation enables us to do more with the resources we have at our disposal.' – Informant 3.

As explained by the informants, water utilities face several challenges that impact urban water management. Investments and maintenance of urban water systems are long-term decisions that require anticipation and preparation for societal challenges that pose risks over time. For instance, the informants explained that demographic changes alter the capacity demand for urban water services, which makes long-term planning more difficult. Similarly, several of the informants anticipated that water utilities need to prepare and take action for climate change adaptation, where both water quality and quantity are affected. In addition, they expected changing regulations on national and international levels with stricter requirements on, for example, environmental monitoring. Altogether, according to respondents, these challenges alter the needs of water utilities and make operation, management, and planning related to urban water management more uncertain and challenging.

One of the informants explained that these issues were rarely given priority in the past when the urban water systems were not 'stressed to the limit' as they are today. Similarly, another informant noted that

these challenges explain why utilities have started to explore the adoption of new digital technologies. With the current development of digital technologies, the informants explained, utilities face a technological shift. Technologies previously deemed too expensive or cutting-edge for implementation are now becoming an integrated part of everyday life and society. Consequently, the informants expect that new possibilities for efficient operation and management of urban water systems have emerged. As one of the informants explained, the utilities face an interesting shift from minimal use of digital technologies to considering more advanced data-driven solutions based on AI tools such as machine learning and deep learning.

In general, the informants emphasised that utilities must be better at using their already available data and become more data-driven in their operations. Although the quality and amount of data differ between utilities, most utilities have access to data related to daily operations (e.g. hydraulics and water quality). These data are typically gathered and used by operational personnel who rely on them for the current and ongoing functionality of the systems. However, it is rarely used beyond daily operations and may even be deleted after it has fulfilled its original purpose. The informants emphasised that these data could serve other analytical purposes and aid in, for example, long-term planning and strategic decision-making. As one informant explained, new data-driven solutions can combine data from different sources, enabling new types of analysis and insights to emerge. In addition, some of the informants emphasised that the use of more advanced data-driven solutions aligns with a broader ambition to increase observations in, and surveillance of the system, where new types of data relevant to urban water management may be gathered.

As exemplified by the informants, the data-driven solutions can be applied to different parts of urban water management. For instance, data-driven solutions can facilitate the prioritisation of rehabilitation projects in a cost-efficient manner. The piped drinking water and wastewater networks are geographically dispersed systems, sometimes spanning thousands of kilometres in one municipality. In some cases, utilities manage several such systems. Hence, the informants explained that maintaining and rehabilitating these systems are both costly and cumbersome. Due to budgetary restrictions, water utilities need to be mindful of their priorities. While the experience and expertise of individual employees generally carry much weight in these decisions, the informants emphasised that data-driven solutions can provide additional support and help pinpoint the actions needed. Another example provided by the informants was the use of data-driven solutions, such as AI, for automatic risk classification of wastewater pipes by interpreting closed-circuit television (CCTV) inspections. In addition, they noted that data-driven solutions can be a powerful tool to facilitate communication and information sharing with the public and politicians. Overall, the informants anticipated that data-driven solutions enable them to work more efficiently with the resources at their disposal.

4.2. Technical aspects

‘For a middle-sized utility as us, we need ready-to-use solutions, otherwise we may not manage.’ - Informant 9.

At most utilities, a bundle of different digital systems already exists for the operation and management of urban water systems. While these systems are essential for the daily operations of the utilities, several of the informants also emphasised that their existing systems and ways of working limit their ability to implement new solutions. However, they cannot replace the old systems at once but need to consider the existing systems while implementing new solutions. In general, several of the informants expected their current suppliers (e.g. geographic information system (GIS) and database providers) to incorporate new functionalities (e.g. based on AI) into their existing products and services. New suppliers, however, may provide software and cloud services that are not compatible with competitors’ products or the existing systems at the utilities. At one of the utilities, they had tested a new software for leakage detection on the piped network. As explained by the informants, one of the main reasons for choosing this specific supplier was that they allowed for a certain degree of flexibility. Not only could the utility integrate the software with its existing hydraulic model, but it was also allowed to run it on its own servers (‘locally on premise’ rather than using the cloud), which is an option not always made available by software suppliers. As emphasised by the informants, utilities seek user-friendly solutions that take into consideration existing systems, data, and preferences of the utilities.

However, the informants did not only raise concerns related to the integration of new software. In addition, several of the informants emphasised that the use of data-driven solutions calls for a review of their existing data collection and management. The informants explained that data are often collected and stored in various disparate systems, which makes it challenging to overview the available data. The data are scattered as it has been collected for various purposes, such as technical information related to condition assessments, economic information regarding investments, and failure reports gathered by the municipal communication office. As such, one informant noted, it is rarely clear whether specific data are available and, in that case, who can access it. This situation can lead to what is sometimes referred to as ’dark data’ or ’data graveyards’ (see e.g. Aguado et al., 2021). Several of the informants emphasised that utilities must have their overall data infrastructure in place to facilitate increased use of data-driven solutions. Instead of various disparate systems, several of the informants envisioned a system that handled different types of data and enabled communication between different types of data sources. At some of the utilities, the informants explained that they have started to prepare an adapted database that is ready for increasingly digitalised urban water systems and allows users to access relevant information from various parts of the system.

Furthermore, addressing the lack of (good quality) data was raised as a necessity by several of the informants. As explained by the informants, it does not matter how ‘fancy’ or ‘advanced’ their models or software are if they do not have good quality data to feed them (‘garbage in, garbage out’). At some utilities, insufficient information regarding the piped network is a big concern. As explained by the informants, some utilities still rely on information that is only available in paper format. In other cases, the information is not documented in either paper or digital format, but the utility relies on the experience of individuals. These individuals are sometimes former employees who have either changed jobs or retired. For utilities that lack basic information about their systems, data may be obtained through non-intrusive investigations (such as acoustics and water meters) or CCTV filming within the (mainly wastewater) pipes. However, depending on the type of data, gathering data can be both a time-consuming and costly task. As exemplified by one informant, they anticipate that the replacement of mechanical water meters with smart water meters in households will be done within a 10-year period. Similarly, some information is not possible to obtain without excavating pipes (e.g. pipe material and surrounding soil type), which often needs to be done in conjunction with other planned work (e.g. rehabilitation of pipes).

The informants also raised concerns related to what data to collect and how to classify it. As one of the informants noted, these are complex systems where it is not always obvious what information is relevant or important to gather. For instance, many different parameters can impact the risk of new leakages on the piped network. In addition, they may start to collect new types of data available through other actors, such as weather data, telecom information, and internet search statistics. Even though the informants gave several examples of such ‘new’ data, they still indicated that they needed support to know what and how to collect data going forward. As stated by the informants, some common sector-wide systems (such as ‘VA-banken’, which is a GIS-based tool to manage information related to the piped network) provide a particular structure for how to collect and classify data. In other cases, however, it is less clear. Several of the informants mentioned that security aspects are

challenging and are currently interpreted separately by the individual utilities, and they called for greater guidance on how to approach these matters.

4.3. Organisational aspects

'In my view, the initial step is to know the demand. If the demand is to identify pipes for rehabilitation, an advanced AI model may not be necessary to fulfil that requirement. And in that case, we might not need an AI model for now.' – Informant 4.

As emphasised by the informants, the implementation and use of digital technologies must be driven by actual needs in the organisation. The informants explained that to manage a successful implementation, with corresponding changes in ways of working and organisational processes, it must have proven value for the organisation. Some of the informants, who had tested an AI model for assessing the condition of water pipes, explained that the model did not provide them with any new insights. Instead, they perceived the model as 'inflexible' and 'untransparent' due to the black box nature of AI-algorithms. In their opinion, their current ways of working based on expertise and simpler analytical tools were perceived as more valid and reliable. However, they acknowledged that once such models start to perform better than conventional methods, it becomes interesting as there is 'money to be saved'.

Consequently, several of the informants emphasised that they depart from the actual needs of the organisation when they test new solutions. One informant explained that they either target areas where the organisation face the most severe challenges or start with the 'low-hanging fruits' to yield quick returns. The informants explained that most of the projects are driven by individual and engaged employees. However, they emphasised that bottom-up efforts cannot solely drive change but requires the entire organisation to be on board, including top-down interest from management. Apart from management on all levels of the organisation, this also applies to the operational personnel who need to be willing to adjust accordingly. As emphasised by the informants, implementing digital technologies may require new ways of working that challenge long-standing traditions and routines within the organisation. One informant, who was involved in implementing an AI model at one of the utilities, explained that even though the tool was in place and gave promising results, the maintenance team was not on board. Instead, the model had no substantial impact since the intended users did not adjust their routines accordingly.

In addition, the informants emphasised that implementing new technologies that break with current traditions is a challenge for an already constrained organisation. Apart from requiring time and resources, it may also call for new types of competencies not usually present at water utilities, such as data scientists and data engineers. In addition, it requires communication and the transfer of knowledge between personnel with different types of competencies, such as data scientists and water experts. However, as one informant explained, it is already a challenge to hire personnel with adequate skills without adding the requirement of digital competence.

In summary, the findings suggest that the use of data-driven solutions aligns with the strategic goals of water utilities, where the informants anticipated that these solutions could help them improve the efficiency and performance of their operations. However, the use of data-driven solutions is not yet well-aligned with the technical and organisational structures of water utilities, which currently hinder the effective implementation of these solutions. Additional example quotes that further illustrate the perspective of the informants are provided in Table A2 in the appendix.

5. Discussion

Our findings highlight several strategic, technical and organisational barriers faced by water utilities aiming to implement and use data-driven solutions in urban water management. This paper set out to address a more fundamental question related to the adoption of digital technologies: Are digital technologies addressing the needs of water utilities? Our findings suggest that while data-driven solutions can benefit the long-term needs of water utilities, they are not as well-suited to address their short-term needs. The implementation of data-driven solutions is not yet well-aligned with the utilities' current technical and organisational structures, which creates what the innovation literature would refer to as an 'ambidexterity dilemma'.

5.1. The ambidexterity dilemma

In line with conventional beliefs (see e.g. Boyle et al., 2022; Negm et al., 2024; Walter, 2024), our findings suggest that digital technologies can be part of the solution to addressing current and future challenges in urban water management. While earlier research has shown that digitalisation is not likely to have as dramatic consequences as in, for example, entertainment or finance industries (Bennich, 2024b), there is considerable value to be gained from digitalisation of the water sector. Our informants expressed concerns that future demands and conditions for the provision of urban water services will change (e.g. due to climate change and new regulations), which urges them to seek new tools and ways of working to make more efficient use of existing resources. Due to the availability of data and the economic feasibility of new digital technologies, they saw the potential of using data-driven solutions to prepare for a changing environment. As emphasised by our informants, data-driven solutions can be used for both operational tasks (such as using AI for CCTV-interpretation) and more tactical tasks (such as prioritising between renewal projects), which enables them to make better use of available resources. Data-driven solutions are thus expected to be able to achieve the perceived *long-term* needs (i.e. improved resource efficiency and performance to meet changing demands) of water utilities.

However, data-driven solutions appeared to be less equipped to address the *short-term* needs (i.e. ensuring efficient daily operations) of water utilities. Instead, adopting these technologies appeared to create problems and challenges due to misalignments with the current technical and organisational structure of utilities. For instance, the informants explained how existing digital systems are built for specific purposes that do not allow for new or more strategic use of available information. Instead, they reported that it is difficult to share data across the organisation and to integrate new software into the existing systems. Consequently, it makes the implementation and use of data-driven solutions challenging and cumbersome as they do not fit with the existing technical systems. Similarly, the organisation needs to adjust practices and ways of working to facilitate the use of data-driven solutions. As such, the utilities need to build acceptance and trust in these technologies, which may call for new types of competencies and expertise currently not present at water utilities. In addition, many employees have little possibility to engage in exploration activities in their day-to-day work. The implementation of data-driven solutions adds a layer of complexity rather than simplicity to urban water management. On the contrary, our informants explained that they seek 'simple' tools to implement and use. However, these short-term needs may be met just as well by other, non-digital solutions that are better aligned with the current structures of water utilities. As long as simpler non-digital solutions are sufficient to address these short-term needs, conventional solutions are likely to prevail over new digital technologies.

This tendency creates what the innovation literature would call a typical ambidexterity dilemma. On the one hand, the utilities need to manage current operations that guarantee safe and reliable services at a reasonable cost for their customers. At the same time, the utilities need to plan and prepare for a future where different demands and conditions for urban water management may be present. However, balancing the current needs with future (sometimes unknown or uncertain) needs is often challenging for established organisations (March, 1991; Tushman

and O'Reilly, 1996). Similar ambidexterity dilemmas have been observed for organisations undertaking digitalisation from a wide range of industries, such as law and automotive (Kronblad et al., 2023; Svahn et al., 2017). It is thus reasonable to expect that many findings of this paper are also applicable and relevant to other industries and types of organisations.

However, this becomes a particular challenge for water utilities that primarily revolve around daily operations and that prioritise stability and reliability over innovation and change (Bennich et al., 2023; Hartley, 2005). Similar to prior studies (Arnell et al., 2023), our informants emphasised that the implementation of digital technologies should meet the actual needs of the organisation. To justify the implementation and use of data-driven solutions that break with conventional ways of working, the informants stressed that these tools should have 'proven value' for the organisation. However, addressing the long-term needs of utilities will likely not reap immediate benefits and build on the combined rather than individual effects of various data-driven solutions. In the transition phase, it may even cause temporary disturbances to the efficiency and performance of daily operations. Hence, focusing too much on immediate benefits and proven value entails the risk that short-term needs are prioritised at the expense of the long-term needs of water utilities. While this study has explicitly focused on the use of data-driven solutions, this challenge is also present for other non-digital solutions that deviate from current practices.

5.2. Implications for practice and policy

Similar to prior studies (Fu et al., 2022; Rapp et al., 2023), the reported use of data-driven solutions in this study was still experimental or aspirational. If water utilities consider digital technologies to be part of the solution to current and future challenges in urban water management, several actions are needed.

From a practice perspective, water utilities can facilitate the adoption of digital technologies (such as data-driven solutions) by formulating digital visions or strategies that consider both the short-term and long-term needs of utilities. As reported by our informants, most digitalisation initiatives are driven by individual and visionary employees. However, it is likely difficult for individual employees to manage the technical and organisational changes needed to facilitate the adoption of digital technologies. In addition, it makes utilities dependent on individual employees who may retire or change employers. Building a digitally mature organisation does not only require a digital infrastructure for data collection, management, and analysis, but also digitally competent and savvy employees. As reported by prior studies, organisations need to formulate digital strategies that encompass top-down as well as bottom-up initiatives to digitalise (Chanias et al., 2019; Matt et al., 2015; Saarikko et al., 2020). In addition, formulating digital strategies can strengthen employees' mandate to prioritise exploration activities in their day-to-day work (i.e. contextual ambidexterity).

From a policy perspective, the adoption of digital technologies can be facilitated through various measures. First, actions are needed that enable utilities to shift the focus from daily operations and strengthen their ability to prioritise long-term and strategic development. This shift can be facilitated through strengthened funding schemes of utilities or encouraging municipal or regional collaborations in terms of development and innovation (i.e. structural ambidexterity). This ability is important on a general level to allow utilities to prepare for future needs. Second, providing guidelines or regulations can simplify and drive digitalisation processes in utilities. As was emphasised in our Swedish case study, it is often up to the individual utility to navigate digitalisation processes. However, since these technologies are not yet well-aligned with the current technical and organisational structures of utilities, it is unclear how to manage changing circumstances following digitalisation (e.g. concerning security). Therefore, water utilities need help to establish sector-wide standards, which can be done by, for instance, sector-wide national industry associations. Hence, guidelines and regulations that facilitate and drive the implementation and use of digital technologies, similar to what we have witnessed in the energy sector (Geels et al., 2021; Sovacool et al., 2017), can facilitate continued digitalisation in water utilities. In the water sector, where there is a local (municipal) monopoly rather than proper market mechanisms, there is less financial motivation for technological change, and the role of regulations may be more important than in other sectors. Initiatives such as the Drinking Water Directive (2020/2184) in the European Union, which emphasises the importance of reducing water leakage in urban water systems, can incentivise utilities to increase the use of new solutions, such as digital technologies, that focus on reducing leakages.

5.3. Limitations and avenues for future research

The suggested implications for practice and policy presented above are targeted at increasing the use of digital technologies at water utilities. While it is beyond the scope of this paper to make an international comparison, we believe our results are representative of many similar international settings (the majority of European countries, North America and parts of Asia) where digitalisation is at a similar stage. However, the results may be less valid for utilities operating in more digitalised national water sectors or areas with underdeveloped infrastructures (e.g. large parts of Sub-Saharan Africa and parts of Asia). These gaps call for further studies from a variety of national contexts.

Furthermore, an equally important topic is the implications that follow from the increased uptake and use of these technologies. As suggested by prior studies, increasing the use of digital technologies can impact power structures (Amankwaa et al., 2024; Solis and Bashar, 2022), customer relations (Liu et al., 2016), supplier dependencies (Cahn et al., 2023a, 2023b), and strategic priorities (Damman et al., 2023). The use of digital technologies can thus change the organisational and technical structures of utilities and call for new policies that regulate data transparency and integrity, among others. In other words, introducing new technology into the water sector can have unintended effects in the long run on organisational and institutional levels, for which organisations may need to be prepared. While exploring these consequences was beyond the scope of this paper, it presents another important avenue for future research.

6. Conclusions

Similar to other sectors, the use of digital technologies is gaining traction in the broader water sector due to the many perceived benefits. However, the adoption of digital technologies in urban water management is slow. Prior studies have identified several barriers that prevent the successful adoption of digital technologies in water utilities. In this paper, we departed from the fact that some utilities have started to question the initial excitement of using digital technologies to solve all problems and have aimed to address a more fundamental question related to the use of such technologies: how do data-driven solutions align with the perceived needs of water utilities?

Our findings suggest that the adoption of digital technologies, such as data-driven solutions, indeed can address the needs of water utilities and can be a significant part of the solutions to current and future challenges in urban water management. However, we need to make a distinction between the short-term (i.e. ensuring efficient daily operations) and long-term (i.e. improving the efficiency and performance of the operations) needs of utilities. The benefits of digital technologies are often expressed in terms of improved efficiency and performance, which are perceived as important to meet future challenges following a changing environment in which water utilities operate. The exact nature of these challenges, however, is still uncertain and will be clearer in the future. According to the informants, the daily needs of utilities call for simple tools with immediate benefit and impact, whereas digital technologies often fail to address these needs as they are not yet aligned with

the technical and organisational structures of utilities. The social importance and critical nature of urban water services constitute yet another aspect that keeps focus on short-term challenges and hinders utilities from addressing long-term needs due to more immediate concerns. Short-term needs thus tend to prevail over long-term needs and, ultimately, slow down the adoption of digital technologies in water utilities. As a result, the utilities face a typical problem of ambidexterity, where they need to balance daily operations and current needs with the future and more ambiguous needs of utilities, which present challenges for the adoption of digital technologies.

CRediT authorship contribution statement

A. Bennich: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **V. Bergion:** Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **D. Nilsson:** Writing – review & editing, Conceptualization.

Declaration of competing interest

The authors confirm that they have no known conflict of interest.

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Appendix

Table A1
List of informants.

Interview	Informant	Role	Utility size[a)]
Dataset 1 – digitalisation in the water sector			
Interview 1	Informant 1	Strategic analysis engineer	Large
Interview 2	Informant 2	Chief information officer	Large
Interview 3	Informant 3	Digitalisation strategist	Large
Interview 4	Informant 4	Operating engineer	Large
	Informant 5	Water/wastewater engineer	
	Informant 6	GIS-engineer	
Interview 5	Informant 7	Water/wastewater engineer	Large
Interview 6	Informant 8	Water/wastewater engineer	Medium
	Informant 9	Piped network development engineer	
Interview 7	Informant 10	Water/wastewater engineer	Large
Interview 8	Informant 11	Investment planner	Large
Interview 9	Informant 12	Development engineer	Large
Interview 10	Informant 13	Water/wastewater engineer	Large
Interview 11	Informant 14	Strategic analysis engineer	Large
Interview 12	Informant 1	Strategic analysis engineer	Large
Interview 13	Informant 15	Water/wastewater engineer	Large
Interview 14	Informant 16	Investigative project engineer	Large
Dataset 2 – decision support for urban water management			
Interview 15	Informant 17	Piped network strategic analysis engineer	Large
Interview 16	Informant 18	Drinking water piped network engineer	Large
Interview 17	Informant 19	Water/wastewater engineer	Medium
Interview 18	Informant 20	Water and wastewater division manager	Medium
Interview 19	Informant 10	Water/wastewater engineer	Large
Interview 20	Informant 21	Piped network operational manager	Medium
Interview 21[b)]	Informant 22	Water/wastewater engineer	Medium
Interview 22[b)]	Informant 14	Strategic analysis engineer	Large
Interview 23[b)]	Informant 23	Water and wastewater division manager	Medium

a) Medium utility size: covering a population of 10,000 to 100,000 inhabitants. Large utility size: covering a population of 100,000 inhabitants and above.
b) These interviews did not follow the format of a semi-structured interview. However, they covered a similar set of questions that was used in the other semi-structured interviews.

Table A2
Identified themes and aspects.

Themes	Aspects	Informants	Informant perspective (example *quotes*)
Strategic aspects	Changing demands impact the provision of urban water services.	Informants 2, 3, 4, 5, 6, 7, 19, 21	"The demands on water operations are increasing, and that is a challenge, especially for small municipalities" (Informant 2). "Laws and regulations on environmental monitoring are more important today compared to 30 years ago. Our watercourses are overfertilized and more sensitive now than before" (Informant 3).
	Data-driven solutions are becoming more conventional and available.	Informants 1, 2, 3, 10, 13	"It is not bleeding edge technology anymore; it is everywhere and part of our everyday life in another way. So people are used to it, 'of course we should

(*continued on next page*)

Table A2 (*continued*)

Themes	Aspects	Informants	Informant perspective (example *quotes*)
			have this'. Even so, they believe we will fall behind if we do not get started soon" (Informant 1).
			"In the water sector, we have gone quickly from barely anything to using AI, when many barely are digitalised" (Informant 10).
	Data-driven solutions provide new opportunities to complement already existing analyses and methods.	Informants 2, 11, 12, 13, 14, 15, 17	"It is challenging to handle many different parameters and AI is an attractive tool for addressing this" (Informant 17).
			"Today, we use hydraulic modelling; we check water velocity, pressure, and usage. But it is still rather subjective. I believe AI technology can complement the analysis and also relate it to operational disturbances, other events, water quality, etc." (Informant 14).
	Opportunity to make better use of already existing data.	Informants 1, 2, 3, 4, 5, 6, 10, 12, 13, 14, 17, 19, 22	"By using our data and information we can make better decisions, both short and long-term. Because we are not very data-driven in our decision-making today. I believe it must increase because much of the information is already there, and all we have to do is start using it" (Informant 12).
	Automate processes and support decisions.	Informants 2, 7, 8, 9, 10, 11, 12, 15, 16, 17	"An AI model for automatic interpretation and risk classing of wastewater pipes, it does not need to be that difficult" (Informant 17).
			"To get help with this, to choose the right object for renewal and reinvestment. Especially since there are so many [pipes]" (Informant 11).
	Save time and resources. 'Do more' with resources at their disposal.	Informants 1, 2, 3, 13, 14, 15, 16, 21, 22	"One thing about the water sector is that much [maintenance] is neglected, and one could argue that anything we do makes it better. But I believe it is important to do things in the right order; we have very limited resources to work with and cannot do everything at once" (Informant 13).
			"Should we really use the resources for this, or can the money bring a bigger bang for the buck elsewhere?" (Informant 21)
Technical aspects	Consideration of previous IT systems and the possibility of integrating different systems.	Informants 2, 12, 13, 14, 17, 21	"It would be amazing if we had a control system that worked with any product. You could use Siemens or ABB, all with the same control system" (Informant 2).
	Allow for flexibility (e.g. run on own servers) and avoid lock-ins; simple design.	Informants 1, 2, 3, 10, 12, 13, 18, 22	"Many utilities struggle with rehabilitation plans, and it is better to keep it simple so that the work can continue" (Informant 10).
			"First, we have to demand flexibility to avoid lock-ins" (Informant 12).
	Overview of data collection and management.	Informants 3, 8, 9, 10, 13, 18, 21	"We need an order in our data set. We need to know our systems here and now to be able to drive change going forward. In my experience, half the benefit of development projects has been to inventory what we know and what we do not know" (Informant 3).
			"It can be very poorly documented. Especially water leakages, which sometimes have not been registered where it was at all" (Informant 10).
	Address quality and lack of data; ambition to measure more.	Informants 4, 5, 6, 7, 10, 13, 14, 19, 20, 21, 23	"Data management takes time, both to collect it and to quality assure it. While it might not be a problem, it takes time. It would benefit us if people handled data in a better way" (Informant 7).
			"What we need is more leak detection" (Informant 21).
	New types of data.	Informants 2, 3, 4, 5, 6, 10, 19, 23	"One example is that we have integrated ourselves with the energy utility and collect data digitally from them. Now we can analyse the energy efficiency of our assets" (Informant 2).
			"We may not have all the information we want today, but we need to make an effort to predict what parameters we should gather today" (Informant 6).
	Classification of data	Informants 1, 3, 7, 12, 13, 14	"I wish we had clearer guidelines from the industry on what you can and cannot do [with the data]" (Informant 3).
			"Many municipalities use 'VA-banken', so there is some structure in how we store data" (Informant 7).
Organisational aspects	Address existing needs in the organisation.	Informants 2, 3, 17	"It is a matter of priorities; where in the organisation do we have most problems or opportunities? Which are the 'low-hanging fruits' we can start with? Because I believe in the low-hanging fruits when it comes to digitalisation, we have to show that it is possible to do things" (Informant 3).
	New solutions need to have proven value and perform better than conventional methods.	Informants 2, 4, 5, 6, 7	"If you want to succeed with digitalisation and the journey of change, something must become better" (Informant 2).
	Digital initiatives are primarily driven from the bottom up.	Informants 8, 9, 12	"At some water utilities, there are a few people who really push this development. In my experience, it is mostly bottom-up. Regulations can push certain aspects of it, but thus far, in my experience, it is mostly on the initiative of utilities to go in this direction" (Informant 12).
	Communication within the organisation and with external stakeholders.	Informants 2, 8, 9, 13, 17	"How does the public handle and interpret access to information from, e.g. hydraulic models, CCTV films, capacity measurements, and mapping of cloudbursts?" (Informant 17)
	Management and employees must be on board.	Informants 1, 3, 8, 9, 11, 12, 14	"Some are positive towards new technologies, some experience that they have enough to do as it is. We have to explain that it takes time to change routines and such, but that it will pay off in the end" (Informant 1).
			"There is a certain degree of management problem when it comes to digitalisation./ … /It has to be top-down, we need a vision and goals in the organisation that enables this" (Informant 9).
	Need competence and knowledge within the organisation.	Informants 1, 2, 3, 8, 9, 10, 12, 13, 20	"It is difficult to attract these talents; everyone wants them, and the water sector is not the most attractive candidate to go to" (Informant 13).

Data availability

The authors do not have permission to share data.

References

Aguado, D., Blumensaat, F., Baeza, J.A., Villez, K., Ruano, M.V., Samuelsson, O., Plana, Q., 2021. Digital Water: the Value of meta-data for Water Resource Recovery Facilities. The International Water Association.

Alm, J., Paulsson, A., Jonsson, R., 2021. Capacity in municipalities: infrastructures, maintenance debts and ways of overcoming a run-to-failure mentality. Local Econ. 36, 81–97. https://doi.org/10.1177/02690942211030475.

Amankwaa, G., Heeks, R., Browne, A.L., 2024. Powershifts, organisational value, and water management: digital transformation of Ghana's public water utility. Util. Policy 87, 101724. https://doi.org/10.1016/j.jup.2024.101724.

Arnell, M., Ahlström, M., Wärff, C., Miltell, M., Vahidi, A., 2021. Digitalisering Av Den Svenska VA-branschen (Svenskt Vatten Utveckling No. 2021–21). Svensk Vatten AB.

Arnell, M., Miltell, M., Olsson, G., 2023. Making waves: a vision for digital water utilities. Water Res. X 19, 100170. https://doi.org/10.1016/j.wroa.2023.100170.

Balla, K.M., Bendtsen, J.D., Schou, C., Kallesøe, C.S., Ocampo-Martinez, C., 2022. A learning-based approach towards the data-driven predictive control of combined wastewater networks – an experimental study. Water Res. 221, 118782. https://doi.org/10.1016/j.watres.2022.118782.

Bennich, A., 2024a. The digital imperative: institutional pressures to digitalise. Technol. Soc. 76, 102436. https://doi.org/10.1016/j.techsoc.2023.102436.

Bennich, A., 2024b. Navigating Digital Waters: Exploring the Digital Transformation of Urban Water Systems (Doctoral Thesis). KTH Royal Institute of Technology, Stockholm.

Bennich, A., Engwall, M., Nilsson, D., 2023. Operating in the shadowland: why water utilities fail to manage decaying infrastructure. Util. Policy 82, 101557. https://doi.org/10.1016/j.jup.2023.101557.

Berg, S.V., Phillips, M.A., 2017. Data availability as a key tool for regulating government-owned water utilities. Util. Policy 49, 30–37. https://doi.org/10.1016/j.jup.2017.06.012.

Birkinshaw, J., Gibson, C., 2004. Building Ambidexterity into an Organization. MIT SMR.

Blomkvist, P., Nilsson, D., 2017. On the need for System alignment in large water infrastructure: understanding infrastructure dynamics in Nairobi, Kenya. Water Altern. (WaA) 10, 283–302.

Blomkvist, P., Nilsson, D., Juma, B., Sitoki, L., 2020. Bridging the critical interface: ambidextrous innovation for water provision in Nairobi's informal settlements. Technol. Soc. 60, 101221. https://doi.org/10.1016/j.techsoc.2019.101221.

Blumensaat, F., Leitão, J.P., Ort, C., Rieckermann, J., Scheidegger, A., Vanrolleghem, P. A., Villez, K., 2019. How urban Storm- and wastewater management prepares for emerging opportunities and threats: digital transformation, ubiquitous sensing, new data sources, and beyond - a horizon scan. Environ. Sci. Technol. 53, 8488–8498. https://doi.org/10.1021/acs.est.8b06481.

Boyle, C., Ryan, G., Bhandari, P., Law, K.M.Y., Gong, J., Creighton, D., 2022. Digital transformation in water organizations. J. Water Resour. Plann. Manag. 148, 03122001. https://doi.org/10.1061/(ASCE)WR.1943-5452.0001555.

Braun, V., Clarke, V., 2006. Using thematic analysis in psychology. Qual. Res. Psychol. 3, 77–101. https://doi.org/10.1191/1478088706qp063oa.

Brynjolfsson, E., McAfee, A., 2014. The Second Machine Age: Work, Progress, and Prosperity in a Time of Brilliant Technologies, first ed. W. W. Norton & Company, New York London.

Cahn, A., Katz, D., Ghermandi, A., Prevos, P., 2023a. Adoption of data-as-a-service by water and wastewater utilities. Util. Policy 81, 101492. https://doi.org/10.1016/j.jup.2023.101492.

Cahn, A., Katz, D., Ghermandi, A., Prevos, P., 2023b. Initiating data-as-a-service adoption in water utilities: a service design approach. Util. Policy 84, 101656. https://doi.org/10.1016/j.jup.2023.101656.

Chanias, S., Myers, M.D., Hess, T., 2019. Digital transformation strategy making in pre-digital organizations: the case of a financial services provider. J. Strat. Inf. Syst. 28, 17–33. https://doi.org/10.1016/j.jsis.2018.11.003.

Damman, S., Schmuck, A., Oliveira, R., Koop, S., Stef, H.A., Almeida, M. do C., Alegre, H., Ugarelli, R.M., 2023. Towards a water-smart society: progress in linking theory and practice. Util. Policy 85, 101674. https://doi.org/10.1016/j.jup.2023.101674.

Strategies of qualitative inquiry, 3. In: Denzin, N.K., Lincoln, Y.S. (Eds.), 2008. Handbook of Qualitative Research. Sage Publications, Los Angeles.

Dolata, U., 2009. Technological innovations and sectoral change. Res. Pol. 38, 1066–1076. https://doi.org/10.1016/j.respol.2009.03.006.

Doorn, N., 2021. Artificial intelligence in the water domain: opportunities for responsible use. Sci. Total Environ. 755, 142561. https://doi.org/10.1016/j.scitotenv.2020.142561.

EU, 2023. The digital economy and society index (DESI) [WWW Document]. European Commission. URL. https://digital-strategy.ec.europa.eu/en/policies/desi. accessed 7.2.23.

Ferguson, B.C., Brown, R.R., Deletic, A., 2013. Diagnosing transformative change in urban water systems: theories and frameworks. Glob. Environ. Change 23, 264–280. https://doi.org/10.1016/j.gloenvcha.2012.07.008.

Fu, G., Jin, Y., Sun, S., Yuan, Z., Butler, D., 2022. The role of deep learning in urban water management: a critical review. Water Res. 223, 118973. https://doi.org/10.1016/j.watres.2022.118973.

Galliers, B., Newell, S., Shanks, G., Topi, H., 2015. Call for papers: JSIS special issue on "The challenges and opportunities of 'datification'. The Journal of Strategic Information Systems, Strategic and Policy Perspectives on Social Media Technologies 24, II–III. https://doi.org/10.1016/S0963-8687(15)00033-5.

Garrido-Baserba, M., Corominas, L., Cortés, U., Rosso, D., Poch, M., 2020. The fourth-revolution in the water sector encounters the Digital revolution. Environ. Sci. Technol. 54, 4698–4705. https://doi.org/10.1021/acs.est.9b04251.

Geels, F.W., Sareen, S., Hook, A., Sovacool, B.K., 2021. Navigating implementation dilemmas in technology-forcing policies: a comparative analysis of accelerated smart meter diffusion in the Netherlands, UK, Norway, and Portugal (2000-2019). Res. Pol. 50, 104272. https://doi.org/10.1016/j.respol.2021.104272.

Grievson, O., 2023. Decoding digital water: where are we now? IWA network. URL. https://iwa-network.org/decoding-digital-water/. accessed 2.24.25.

Hanelt, A., Bohnsack, R., Marz, D., Marante, C.A., 2021. A systematic review of the literature on digital transformation: insights and implications for strategy and organizational change. J. Manag. Stud. 58, 1159–1197. https://doi.org/10.1111/joms.12639.

Hartley, J., 2005. Innovation in governance and public services: past and present. Publ. Money Manag. 25, 27–34. https://doi.org/10.1111/j.1467-9302.2005.00447.x.

Hoffmann, S., Feldmann, U., Bach, P.M., Binz, C., Farrelly, M., Frantzeskaki, N., Hiessl, H., Inauen, J., Larsen, T.A., Lienert, J., Londong, J., Lüthi, C., Maurer, M., Mitchell, C., Morgenroth, E., Nelson, K.L., Scholten, L., Truffer, B., Udert, K.M., 2020. A research agenda for the future of urban water management: exploring the potential of nongrid, Small-Grid, and hybrid solutions. Environ. Sci. Technol. 54, 5312–5322. https://doi.org/10.1021/acs.est.9b05222.

Hughes, T.P., 1983. Networks of Power: Electrification in Western Society, 1880-1930. Johns Hopkins University Press, Baltimore.

Kiparsky, M., Sedlak, D.L., Thompson, B.H., Truffer, B., 2013. The innovation deficit in urban water: the need for an integrated perspective on institutions, organizations, and technology. Environ. Eng. Sci. 30, 395–408. https://doi.org/10.1089/ees.2012.0427.

Kiparsky, M., Thompson, B.H., Binz, C., Sedlak, D.L., Tummers, L., Truffer, B., 2016. Barriers to innovation in urban wastewater utilities: attitudes of managers in California. Environ. Manag. 57, 1204–1216. https://doi.org/10.1007/s00267-016-0685-3.

Kronblad, C., Pregmark, J.E., Berggren, R., 2023. Difficulties to digitalize: ambidexterity challenges in law firms. J. Serv. Theory Pract. 33, 217–236. https://doi.org/10.1108/JSTP-05-2022-0120.

Legner, C., Eymann, T., Hess, T., Matt, C., Böhmann, T., Drews, P., Mädche, A., Urbach, N., Ahlemann, F., 2017. Digitalization: opportunity and challenge for the business and information systems engineering community. Bus Inf Syst Eng 59, 301–308. https://doi.org/10.1007/s12599-017-0484-2.

Liu, A., Giurco, D., Mukheibir, P., White, S., 2016. Detailed water-use feedback: a review and proposed framework for program implementation. Util. Policy 43, 140–150. https://doi.org/10.1016/j.jup.2016.09.002.

Loorbach, D., Frantzeskaki, N., Thissen, W., 2010. Introduction to the special section: infrastructures and transitions. Technol. Forecast. Soc. Change 77, 1195–1202. https://doi.org/10.1016/j.techfore.2010.06.001.

MacGillivray, B.H., Hamilton, P.D., Strutt, J.E., Pollard, S.J.T., 2006. Risk analysis strategies in the water utility sector: an inventory of applications for better and more credible decision making. Crit. Rev. Environ. Sci. Technol. 36, 85–139. https://doi.org/10.1080/10643380500531171.

Malm, A., Axell, L., Svensson, G., Røstum, J., 2019. Vattenförluster Från Ledningsnätet – Beräkningsverktyg För En Hållbar Nivå (No. 2019–17). Svenskt Vatten AB.

Manny, L., Duygan, M., Fischer, M., Rieckermann, J., 2021. Barriers to the digital transformation of infrastructure sectors. Policy Sci. 54, 943–983. https://doi.org/10.1007/s11077-021-09438-y.

March, J.G., 1991. Exploration and exploitation in organizational learning. Organ. Sci. 2, 71–87.

Markard, J., 2011. Transformation of infrastructures: sector characteristics and implications for fundamental change. J. Infrastruct. Syst. 17, 107–117. https://doi.org/10.1061/(ASCE)IS.1943-555X.0000056.

Matt, C., Hess, T., Benlian, A., 2015. Digital transformation strategies. Business & Information Systems Engineering 57, 339–343. https://doi.org/10.1007/s12599-015-0401-5.

Mayer-Schönberger, V., Cukier, K., 2013. Big data: a revolution that will transform how we live, work, and think, First Mariner Books edition. An Eamon Dolan Book, Mariner Books. Houghton Mifflin Harcourt, Boston New York.

Mayring, P., 2000. Qualitative content analysis. In: Forum Qualitative Sozialforschung/Forum: Qualitative Social Research, vol. 1. Qualitative Methods in Various Disciplines I: Psychology. https://doi.org/10.17169/FQS-1.2.1089. No 2 (2000).

McIntosh, M.J., Morse, J.M., 2015. Situating and constructing diversity in semi-structured interviews. Global Qualitative Nursing Research 2. https://doi.org/10.1177/2333393615597674.

Negm, A., Ma, X., Aggidis, G., 2024. Deep reinforcement learning challenges and opportunities for urban water systems. Water Res. 253, 121145. https://doi.org/10.1016/j.watres.2024.121145.

Newell, S., Marabelli, M., 2015. Strategic opportunities (and challenges) of algorithmic decision-making: a call for action on the long-term societal effects of 'datification. J. Strat. Inf. Syst. 24, 3–14. https://doi.org/10.1016/j.jsis.2015.02.001.

OECD, 2018. OECD reviews of digital transformation: going digital in Sweden. OECD Reviews of Digital Transformation. OECD. https://doi.org/10.1787/9789264302259-en.

Okwori, E., Viklander, M., Hedström, A., 2024. Data integration in asset management of municipal pipe networks in Sweden: challenges, gaps, and potential drivers. Util. Policy 86, 101689. https://doi.org/10.1016/j.jup.2023.101689.

Pianosi, F., Dobson, B., Wagener, T., 2020. Use of Reservoir operation optimization methods in Practice: insights from a Survey of water resource managers. J. Water Resour. Plann. Manag. 146, 02520005. https://doi.org/10.1061/(ASCE)WR.1943-5452.0001301.

Polo, D., Quintela-Baluja, M., Corbishley, A., Jones, D.L., Singer, A.C., Graham, D.W., Romalde, J.L., 2020. Making waves: Wastewater-based epidemiology for COVID-19 – approaches and challenges for surveillance and prediction. Water Res. 186, 116404. https://doi.org/10.1016/j.watres.2020.116404.

Rapp, A.H., Capener, A.M., Sowby, R.B., 2023. Adoption of artificial intelligence in Drinking Water Operations: a Survey of progress in the United States. J. Water Resour. Plann. Manag. 149, 06023002. https://doi.org/10.1061/JWRMD5.WRENG-5870.

Ruddell, B.L., Cheng, D., Fournier, E.D., Pincetl, S., Potter, C., Rushforth, R., 2020. Guidance on the usability-privacy tradeoff for utility customer data aggregation. Util. Policy 67. https://doi.org/10.1016/j.jup.2020.101106.

Saarikko, T., Westergren, U.H., Blomquist, T., 2020. Digital transformation: five recommendations for the digitally conscious firm. Bus. Horiz. 63, 825–839. https://doi.org/10.1016/j.bushor.2020.07.005.

Sarni, W., 2020. The future of water is digital [WWW Document]. The Solution Journal. URL. https://thesolutionsjournal.com/future-water-digital/ (accessed 16.1.25).

Sarni, W., White, C., Webb, R., Cross, K., Glotzbach, R., 2019. Digital Water: Industry Leaders Chart the Transformation Journey. IWA International Water Association.

SCB, 2021. Population connected to public network. Year 1960 - 2021 [WWW Document]. Statistical Database. URL. http://www.statistikdatabasen.scb.se/pxweb/en/ssd/START_MI_MI0902_MI0902C/MI0902T05/. accessed 4.16.24.

Sedlak, D.L., 2014. Water 4.0: the Past, Present, and Future of the World's Most Vital Resource. Yale University Press, New Haven.

Sherman, L., Cantor, A., Milman, A., Kiparsky, M., 2020. Examining the complex relationship between innovation and regulation through a survey of wastewater utility managers. J. Environ. Manag. 260, 110025. https://doi.org/10.1016/j.jenvman.2019.110025.

Sirkiä, J., Laakso, T., Ahopelto, S., Ylijoki, O., Porras, J., Vahala, R., 2017. Data utilization at finnish water and wastewater utilities: current practices vs. state of the art. Util. Policy 45, 69–75. https://doi.org/10.1016/j.jup.2017.02.002.

Sokolova, E., Ivarsson, O., Lilliestrom, A., Speicher, N.K., Rydberg, H., Bondelind, M., 2022. Data-driven models for predicting microbial water quality in the drinking water source using *E. coli* monitoring and hydrometeorological data. Sci. Total Environ. 802, 149798. https://doi.org/10.1016/j.scitotenv.2021.149798.

Solis, M., Bashar, S.B., 2022. Social equity implications of advanced water metering infrastructure. Util. Policy 79, 101430. https://doi.org/10.1016/j.jup.2022.101430.

Sovacool, B.K., Kivimaa, P., Hielscher, S., Jenkins, K., 2017. Vulnerability and resistance in the United Kingdom's smart meter transition. Energy Policy 109, 767–781. https://doi.org/10.1016/j.enpol.2017.07.037.

Sowby, R.B., Walski, T.M., 2021. Reconnecting water resources research and practice. J. Water Resour. Plann. Manag. 147, 02521004. https://doi.org/10.1061/(ASCE)WR.1943-5452.0001382.

Svahn, F., Mathiassen, L., Lindgren, R., 2017. Embracing digital innovation in incumbent firms: how Volvo cars managed competing concerns. MIS Q. 41, 239–253. https://doi.org/10.25300/MISQ/2017/41.1.12.

Svenskt Vatten, 2023. Digitaliseringsnätverk [WWW Document]. Svenskt Vatten. URL. https://www.svensktvatten.se/om-oss/kontakt/natverk/digitaliseringsnatverk/. accessed 4.16.24.

Therrien, J.-D., Nicolaï, N., Vanrolleghem, P.A., 2020. A critical review of the data pipeline: how wastewater system operation flows from data to intelligence. Water Sci. Technol. 82, 2613–2634. https://doi.org/10.2166/wst.2020.393.

Tushman, M.L., O'Reilly, C.A., 1996. Ambidextrous organizations: managing evolutionary and revolutionary change. Calif. Manag. Rev. 38, 8–30. https://doi.org/10.2307/41165852.

Valentine, G., 2005. Tell me about…: using interviews as a research methodology. In: Flowerdew, R., Martin, D.M. (Eds.), Methods in Human Geography: a Guide for Students Doing a Research Project. Routledge, p. 18. https://doi.org/10.4324/9781315837277.

Verhoef, P.C., Broekhuizen, T., Bart, Y., Bhattacharya, A., Qi Dong, J., Fabian, N., Haenlein, M., 2021. Digital transformation: a multidisciplinary reflection and research agenda. J. Bus. Res. 122, 889–901. https://doi.org/10.1016/j.jbusres.2019.09.022.

Verma, S., 2021. Digitizing The Water Sector: An Opportunity To Improve Water Quality [WWW Document]. Water Online. URL. https://www.wateronline.com/doc/digitizing-the-water-sector-an-opportunity-to-improve-water-quality-0001. accessed 16.1.25.

Vial, G., 2019. Understanding digital transformation: a review and a research agenda. J. Strat. Inf. Syst. 28, 118–144. https://doi.org/10.1016/j.jsis.2019.01.003.

Walter, C., 2024. Digital technologies for the future of the water sector? Examining the discourse on digital water. Geoforum 148, 103918. https://doi.org/10.1016/j.geoforum.2023.103918.

Warner, K.S.R., Wäger, M., 2019. Building dynamic capabilities for digital transformation: an ongoing process of strategic renewal. Long. Range Plan. 52, 326–349. https://doi.org/10.1016/j.lrp.2018.12.001.

Wehn, U., Montalvo, C., 2018. Exploring the dynamics of water innovation: foundations for water innovation studies. J. Clean. Prod. 171, S1–S19. https://doi.org/10.1016/j.jclepro.2017.10.118.

Westerman, G., Bonnet, D., McAfee, A., 2014. Leading Digital: Turning Technology into Business Transformation. Harvard Business Press.

Yin, R.K., 2018. Case Study Research and Applications: Design and Methods, sixth ed. SAGE, Los Angels.