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REVIEW ARTICLE

The future of piped water

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ABSTRACT

While the past decades have seen substantial gains in access to safe drinking water around the world, the challenge over the next 50 years will be to maintain and expand these gains. Ageing infrastructure, deferred maintenance and financial woes, combined with shifting demands and climate change, threaten the functioning and long-term sustainability of water systems. This article examines three facets of piped water supply – infrastructure, management and financing – assessing the stressors, drivers of change and paradigm shifts affecting each. The review sheds light on the future of piped water, the successes that may be found and the remaining gaps to be addressed.

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Introduction

Recognizing that safe, reliable and affordable water supply is critical for health, livelihoods and well-being, the United Nations' Sustainable Development Goal (SDG) 6.1 aspires to achieve universal and equitable access to safely managed water by 2030. 'Safely managed' refers to water that is free from contaminants, available when needed and on-premises (Joint Monitoring Programme, 2019). In setting this objective, the United Nations and countries committing to the SDGs built upon prior global commitments, moving from a goal that incorporated rough consideration of access to water sources most likely to be safe to a goal that explicitly accounts for water quality, the time and effort needed to obtain water, and the reliability of supply. Piped water supply sits at the top of this drinking water ladder, as piped supply on premise implies ease of access, increased likelihood of availability when needed and, often, better water quality. To date, there has been substantial progress towards achieving these objectives. In 2017, 4.8 billion people – 63% of the global population – had access to piped water on premises (WHO, 2021), a 37% increase in the population with access to piped water between 2000 and 2017, with the greatest gains occurring in Eastern and Southeastern Asia (Joint Monitoring Program, 2019).

Key to the future of piped water supply will be continuing to expand service while ensuring the sustained functioning and service quality of existing systems. Many piped water systems are in a state of tenuous stability, if not outright decline. Once constructed, a substantial number of systems experience deterioration in functionality and reliability

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(Nelson-Nuñez et al., 2019), resulting in large deficiencies in the level of service provided by many water systems. While there are high performing water systems, water from many systems is delivered irregularly, is of poor quality and is unaffordable (Grigg, 2018; Mitlin et al., 2019). Approximately 1 billion people receive water from systems that provide intermittent supply (Bivins et al., 2017; Kumpel & Nelson, 2016). Moreover, an estimated 40% of water systems are not in working order at any given moment, and one in four systems are non-functional 10 years after installation (Inter-American Development Bank, 2016). Small and/or rural systems, which constitute the largest percentage of systems, fare particularly poorly in terms of service provision (Kot et al., 2015; McFarlane & Harris, 2018). Studies indicate approximately one-third of rural water systems (piped or handpumps) in India and Sub-Saharan Africa are non-functional (Hutchings et al., 2015). Challenges extend to higher income countries, with smaller or rural systems constituting the majority of drinking water violations in the United States (Fedinick et al., 2017; Rubin, 2013). In sum, even where piped water systems exist, it is not a given that these systems provide water that is accessible, affordable, safe, reliable and sustainable.

Barriers to sustained high-quality piped water supply service are substantial. Climate change threatens supply availability and affects water quality. Population growth and movement is also a challenge, adding pressure on water demands and accelerating a need to expand piped water systems (Alaerts, 2019). Increasing risks to water quality burden water systems with additional expenses and the need to change operational practices. At the same time, the weak financial status of water systems, combined with limited technical and managerial capacities and political factors, contribute to vulnerabilities because they reduce the ability of water systems to prepare for stressors, respond to change and even perform regular operations (Nelson-Nuñez et al., 2019).

In this review and perspective, we examine paradigms for three facets of piped water supply – infrastructure, management and financing – explaining the importance of each, the stresses upon them, the drivers for past changes and the shifts that are likely to occur. Our objective is to illuminate what the future of piped water may entail, including potential successes and remaining gaps. Our perspective highlights that protecting existing gains and expanding access to piped water will require overcoming significant challenges. As such, this paper serves as a call to action: enjoining efforts from the individual to the global level to raise awareness of the importance of access to piped water, and to seek innovative and equitable mechanism for improving water access.

Water supply infrastructure

Infrastructure comprises the heart of piped water systems. Water system infrastructure includes source water intakes, water treatment facilities, storage, transmission and distribution systems, premise plumbing, and monitoring systems. Water systems face challenges across each of these components and failures within any one can disrupt or limit water supply or result in the provision of unsafe or unacceptable water quality.

Degradation of source water quality combined with increasing stringency of water quality regulations are creating pressures upon water systems (Qureshi & Shah, 2014). In addition to naturally occurring substances and pathogens, numerous new contaminants have been introduced into the environment and are making their way into drinking water sources (Hartmann et al., 2018). Land-use change is contributing to the build-up of constituents such as dissolved organic carbon, salt, nitrogen and phosphorus in waterways and reservoirs; while changes in air pollution and deposition is affecting the pH of lakes and reservoirs (Anderson et al., 2017; Gutchess et al., 2018; Meyer-Jacob et al., 2019). Increasing withdrawals and climate change aggravate source water quality problems, as seen, for example, in the increased frequency of toxic algal blooms (Kasprzak et al., 2017). Further, as available freshwater supplies decline, communities are turning to source waters with poorer water quality, requiring higher levels of treatment.

These challenges highlight the need for more flexible water treatment systems that can adapt to future and changing scenarios through either additions to existing treatment processes or operational changes. Historically, the most commonly used mechanisms for water treatment included centralized methods that removed particulates through sand filtration or settling, with chlorination added before distribution (EPA, 2000). The past decades have seen the development of a host of new treatment technologies, including aeration, flocculation, activated carbon absorption, ion exchange, reverse osmosis, advanced oxidation and biofiltration. Innovations in treatment have aimed to remove a greater number and variety of contaminants more efficiently while reducing costs, the creation of harmful by-products and waste streams. Such innovations allow water suppliers not only to treat existing source water but also to shift to alternative sources such as seawater and the reuse of wastewater. Yet, the deployment of these new water treatment technologies is not without obstacles. Widespread deployment often does not occur until it has been demonstrated that new technologies perform sustainably and at scale. Further, water suppliers around the world have already invested in expensive centralized treatment facilities designed to last decades. New technologies may not fit easily within the designs of existing infrastructure and may be expensive and require specialized operational expertise, which small and rural systems may not possess (Qureshi & Shah, 2014; Westerhoff et al., 2019).

Another common water infrastructure challenge is the conveyance and protection of treated water through the distribution system. Many existing water systems have inadequately sized and poorly maintained distribution infrastructure. In rapidly growing cities, populations and demands for water have grown without comparable capacity expansion in the pipe networks, leading to low, or even no, pressure in the network. These water systems, either intentionally or unintentionally, provide water intermittently. Outages that occur even if only for a few hours per week, can lead to contamination of water, impose a health and/or financial burden on consumers, and potentially increase rates of deterioration of infrastructure (Kumpel & Nelson, 2016; Ray et al., 2018). Meanwhile, other water distribution systems have oversized pipes and pumps either because the pipes were sized to accommodate fire flow or because water demands within that system have since decreased due to either water conservation or declining populations. Excess capacity in these distribution systems results in higher operational costs and poorer water quality (Faust et al., 2016; National Research Council, 2006).

Water loss is also a common problem in distribution systems (Vacs Renwick et al., 2019). In developed countries, 15% of all supplied water is estimated to be non-revenue water. In developing countries, non-revenue water constitutes at least 35%, but likely 40–50% of supplied water (Kingdom et al., 2006). Non-revenue water stems from leaks, illegal connections, metering errors and unpaid water bills. New and innovative approaches to leak detection, related to water-use data collection and analysis (e.g., advanced metering, pressure loggers, optimization and data-mining) and to inspection (e.g., traditional acoustic leak detection, thermal imaging, robotic inspection and pressure management), can help water suppliers identify problems in the distribution system and control water losses (Hamilton & Charalambous, 2020). Nonetheless, underground infrastructure is expensive and difficult to repair and replace. Repairs often entail disruptions to overlying properties, affecting traffic, buildings or other services, and a myriad of techniques are needed to repair the many different pipe materials present in a distribution system (EPA, 2018). Further innovations in drastically reducing and controlling water loss and efficiently repairing or extending the lifespan of pipes is urgently needed.

In addition to water loss, degradation of water quality in the distribution system is a concern. Contamination can enter through leaks, cracks or cross-connections; microbes can grow and attach to pipe walls as biofilms; and infrastructure can corrode or leach chemicals into the water. Many systems add a disinfectant residual – commonly chlorine – after treatment to protect water from microbial growth and pathogens as it is distributed. However, chlorine can react with natural organic matter, resulting in unintended and potentially carcinogenic disinfection by-products (DBPs). Due to these risks, many utilities in the United States have switched to chloramines, which is less reactive and minimizes the creation of DBPs; however, this process requires more complicated operations. Some European systems eschew disinfectant residual and instead rely on intensive upgrades and monitoring (Rosario-Ortiz et al., 2016). Even with these advancements, globally most water systems use chlorination due to the low cost and the ease of supply and implementation. Better control of dosing chlorine and removal of organic matter could be used to protect water while mitigating DBPs.

Water systems also face the challenge of maintaining water quality once it has left the distribution system. Premise plumbing, which connects the municipal distribution system to the consumer's point of use, is characterized by high surface area, frequent stagnation and temperature extremes (National Research Council, 2006). Release of metals such as lead from pipes, fittings and connections can be controlled by maintaining stable, non-corrosive water chemistry; however, shifts in the characteristics of source waters (such as increasing salinity) or inadequacies in source water treatment can cause the corrosion of premise plumbing, introducing lead or copper into the water. Opportunistic pathogens such as *Legionella pneumophila* are being increasingly detected in the biofilms of premise plumbing, posing health risks for individuals with underlying health issues. Although premise plumbing is often legally the responsibility of residents, water systems, particularly long-lived water systems, are confronted with the need to ensure that upstream changes within a piped water system do not affect premise plumbing, and therefore water quality, at the point of use (Liu et al., 2017; National Research Council, 2006).

Where water systems do not include centralized treatment or there are high risks to water quality during distribution, decentralized treatment at households or buildings through point-of-use or point-of-entry (POU/POE) treatment is an alternative method of ensuring safe water. POU/POE technologies range from very simple practices (e.g., boiling) to complicated devices (e.g., reverse osmosis). Yet while some hail POU/POEs as a method of ensuring water is safe at consumption, their uptake, continued maintenance, consistent performance and affordability can be problematic (Amrose et al., 2015), in part because their deployment shifts the responsibility for water treatment from an (often) public central treatment facility to consumers. Consequently, the relative safety of water consumed depends upon the finances, capacity and follow-through of the water user.

As failures across one or more components of water systems infrastructure are not uncommon, water system regulatory authorities have begun promoting a risk management approach that addresses water infrastructure as an integrated system (Hrudey et al., 2006). This includes the adoption of a 'multi-barrier approach' whereby several treatment or protective barriers (e.g., source water protection, redundancy in treatment design, and automated, real-time monitoring of distribution systems) are implemented to increase water safety (Plummer et al., 2010). Over 90 countries have adopted the World Health Organization's (WHO) Water Safety Plans (WSPs), which require proactive management of all assets in a water system, from source water to tap (Bartram et al., 2005). Countries that have adopted and successfully implemented WSPs have seen decreases in the incidence of diarrhoeal disease, an increase in knowledge about the water system, better communication between water system stakeholders, better operational control and better overall management of water system assets (Baum et al., 2015; Gunnarsdottir et al., 2012). However, the adoption of risk management requires institutional and cultural change (Baum & Bartram, 2018; Summerill et al., 2010). For risk management approaches to be effective, water suppliers must proactively undertake the honest evaluation of existing systems and practices rather than engaging in reactive risk evaluation.

Advancements in online, automated and remote monitoring systems are also contributing to improved risk management and water quality. The addition of supervisory control and data acquisition systems (SCADA) has increased the operator's ability to detect potential adverse water quality results, manage pumping controls remotely and respond to emergency situations in real time (Cairns, 2014). While the adoption of such automated systems has primarily been undertaken by large, well-resourced utilities, deployment has started to roll out in many low- and middle-income countries (Sharma & Morais, 2019). However, the introduction of intranet monitoring systems, increased digitization of operations and the number of devices used for monitoring have also introduced potential entry points for cybersecurity attacks (Hassanzadeh et al., 2020). As the industry continues to automate to better manage complex water treatment operations such as chemical dosing and pump operation, consideration of cybersecurity is necessary. Opportunities for low-cost and simple monitoring and mobile phone-based systems hold potential for improving system management.

In sum, the provision and maintenance of infrastructure is critical for the future of piped water. It is now technically possible to treat severely impaired waters to potable standards; however, changes in source water quality, emerging contaminants and tightening regulations make it increasingly difficult to achieve that goal. Costs and complications in operations continue to be a concern, particularly with respect to advanced treatment technologies, while legacy infrastructure or regulations may limit the adoption of new technology. Many water systems also suffer from deferred maintenance, with pipes and pumps, water treatment facilities, and other infrastructure operated long past their anticipated useful life. Ageing distribution systems are vulnerable to contamination as well as water losses. Premise plumbing represents threats to water quality in high-income countries, while intermittent supply remains a primary concern in low-income countries. Holistic risk management and control approaches are gaining traction to control health risks; however, infrastructure vulnerability is still of concern.

Management of piped water systems

While infrastructure is a primary component of piped water, for water systems to provide high-quality and sustained service, they must be effectively managed. Management of water systems entails ongoing day-to-day operations of water system infrastructure, ensuring regulatory compliance, financial management, and substantial strategic planning in relation to assets, contingencies and emergencies, business models, and more (Baietti et al., 2006; EUM Utility Leadership Group, 2017; Lombana Cordoba et al., 2021). Effective water system management requires technical, managerial and financial capacity, as well as accountability and oversight (Baietti et al., 2006; Blanchard & Eberle, 2013; Spiller & Savedoff, 1999).

Inadequate management has long been identified as a concern for water supplies, with myriad attempts over the last century to address poor performance through management improvements. Historically, much of the efforts to address poor performance have focused on the structure of water system ownership both as an explanation for water system ailments and as a solution to its management problems. This emphasis on ownership derived from a recognition that differing ownership forms are subject to differing incentives and constraints, each of which affect management decisions, and subsequently, water system performance outcomes. Ownership has also been a focal point because, as described in the section on finances below, economic constraints affect management capacity.

Across the United States and much of Europe, where initially the majority of water systems were privately provisioned, there was a shift to public provision during the early to mid-20th century (Masten, 2010; National Research Council, 2002). As water system performance continued to suffer, and political discourses from outside the water sector focused on the concept of 'government failure', during the 1980s and 1990s there was a movement towards water system privatization (Bakker, 2010). However, many private and privatized systems performed no better, and some faired much worse, than public systems (Bakker et al., 2008; National Research Council, 2002), leading to a continued search for alternative solutions to water system management failures. Consequently, the 1990s and 2000s saw interest in public–private partnerships as the next mantra for improving water system management (Martin, 2009; Tariq et al., 2019). A concurrent trend was corporatization, the process through which public water systems were transformed into legally independent entities that share many of the motivations and functioning of the private sector, yet are state owned and thus under public control (Boag & McDonald, 2010; Post & Ray, 2020). As with prior solutions, results of public–private partnerships and corporatization have been mixed.

While privatization focused on larger systems, attempts to improve the management of smaller or more rural systems during the 1990s and 2000s primarily focused on placing control within the hands of water users (Hutchings et al., 2015). This paradigm shift aligned with the 'participatory' approach being promoted in broader natural resource circles. Community-based management encompasses a variety of structural forms including ownership and management by home-owner associations, cooperatives, or a community as an incorporated or unincorporated unit. The premise underpinning community-based management is that water users have a vested interest in the functioning of the system, and local situation knowledge of the system and its functioning. This proximity can lead to more rapid identification of system failures, more frequent maintenance and a greater willingness of users to contribute financially due to their ties to the system. As with efforts to improve management in larger systems, community-based management has met with some successes, yet in many instances has faced deficiencies (Chowns, 2015; Hutchings et al., 2015).

The lack of broad success in attempts to improve water system management through structural changes in ownership, combined with a recognition of strong variation in performance within each ownership structure, has highlighted the need to look beyond, as well as within, the water system itself to understand management failures and successes (Bakker et al., 2008; Beck, 2019; Beecher, 2013; Post & Ray, 2020). More recent focal points (mid-2000s and later) have been on the institutional and regulatory environment in which water systems are situated (Goksu et al., 2019; Mumssen et al., 2018; OECD, 2012b; UNICEF, 2016), echoing the growing discourse on 'governance' in relation not just to water, but broader questions of sustainability and the economy (Lemos & Agrawal, 2006). Here attention is to the enabling environment and oversight of water systems, including taking steps to add accountability yet ensure water system autonomy, to provide oversight prior to the development of new systems, and to tailor appropriate incentives for water systems management (Baietti et al., 2006; McFarlane & Harris, 2018). Another focal point has been on the internal capacity and culture within the water system. This reasoning stems from studies indicating that well-performing water suppliers are characterized by a strong knowledge base, human and organizational capacities, the ability to learn, customer and business orientations, measurement, and a culture of continual improvement (Baietti et al., 2006; EUM Utility Leadership Group, 2017; Pascual Sanz et al., 2013).

Continued deficits in water management in many systems, despite the long history of attempts to improve it, leads to the question of what next. Change within the water sector tends to be incremental (Lach et al., 2004). Consequently, it is reasonable to expect the immediate future will entail a continuation of current trends, characterized by some systems that are well functioning or are making steadfast improvements, while a good number of water systems struggle to perform and decline in the quality-of-service provision. The global Covid-19 pandemic, and its impact on the finances and management of water supply system (McDonald et al., 2021; Walton, 2020), presents an opportunity leverage political awareness of the criticality of water services for broader improvements; yet it also reflects a potential point of inflection that leads to a downward spiral for water suppliers already at the cusp of breakdown.

The current focus on the enabling environment as a point of leverage for improving water management will likely be ongoing, with a particular emphasis on capacity-building. This is already occurring with national, subnational governments and international donors investing efforts as well as finances in supporting water system management. Key activities include training; the development, dissemination and promotion of self-assessment tools, guidance, best practices, as well as financial support and assistance to water suppliers for activities and actions aimed at capacity improvement (e.g., Blokland et al., 2009; Lombana Cordoba et al., 2021).

Capacity-building efforts will also likely continue to support the development of water system partnerships. Partnerships can serve to build capacity through leveraging of resources; capturing benefits from economies of scale; or filling gaps in relation to certain operational or management responsibilities, such as billing, water quality testing or shared operators. While there are many existing models for partnerships (public–public, public–private, community-based management plus, community–public, etc. (e.g., Bakker et al., 2008; Boag & McDonald, 2010; Hutchings et al., 2015; Silvestre et al., 2018), more novel forms partnerships, including peer-to-peer and network (mutual aid) partnerships, with the specific objective of sharing knowledge and expertise will likely grow. At the international level, peer-to-peer capacity development partnerships, such as the UN's water operator partnership programme, may serve as a model, even in light of its critiques (Beck, 2019). Within countries, higher levels of government are also encouraging peer-to-peer partnerships. For example, within the United States, the Environmental Protection Agency (EPA) and almost every US state have implemented programmes and policies that encourages water system partnerships (EPA, 2017). Following trends in information and communication technology (ICT) for development, there may also be growth in virtual or mixed-modal peer-to-peer or peer-to-expert networks (e.g., see the newly formed Internet of Water and Moonshot Missions). Lastly, there may be growth in the circuit rider approach to capacity-building, through which a partnering agency supports an extension agent or specialist who travels to water systems providing support (Apambire et al., 2016; Kayser et al., 2014).

In sum, despite almost a century of attempts to develop successful paradigms, management remains an immense challenge for piped water systems. 'Solutions' to management shortcomings have historically, and will continue to be, imagined in light of broader discourses related to government, the market and society. The current trend is to recognize the situated nature of water systems and to foster an enabling environment (Mumssen et al., 2018; UNICEF, 2016). The emphasis on building capacity through networks and partnerships, while retaining the local as the locus of control, allows for context-specific approaches to improving management. This strategy has much potential because it provides more nuanced solutions to water systems in need. A downside is it may have limited ability to reach the weakest of systems, as some degree of capacity is required to engage in capacity-building. Water system management requires specific expertise and dedicated trained managers capable of planning, monitoring and adapting. As described below, finances have an important role in enabling this capacity, though they are not a panacea. We must also develop a social, political and institutional environment that views water system management as a priority.

Financing of piped water systems

Expansion of piped water systems to those without access and maintenance of continued water system performance requires finances. Construction, operations and maintenance of infrastructure are costly. Constraints on access to finance limits the ability to both build new and expand existing systems as well as replace and repair infrastructure. A lack of cash on hand and an inability to access capital has also created a significant deferred maintenance problem, increasing risks of system outages and failures.

Estimated investments required to meet the UN's SDG for water are US$1.7 trillion by 2030 (Hutton & Varughese, 2019; OECD, 2018). In middle- and low-income countries, spending will need to be two to five times current levels (Alaerts, 2019). Water system financing concerns are not limited to low-income countries, but rather are globally experienced. For example, within the United States, the American Water Works Association According estimates US$1 trillion is necessary to maintain and expand service to meet demands over the next 25 years (Tiemann, 2017). The already strained financial situation of the water supply sector has been exacerbated by the Covid-19 pandemic, the economic impacts of which are contributing to financial crises for many distressed water suppliers (World Bank, 2020).

Water suppliers obtain funds for piped water supply systems through several means. Tariffs or other use are charged to users in exchange for water services. Taxes raised by any level of government may be used to support water suppliers. Water suppliers also obtain funds through debt financing, usually repayable loans, and issuance of bonds. Funds are also obtained through transfers, generally grants or loans from higher levels of government, official development assistance, non-governmental organizations or charitable foundations. (OECD, 2012a, 2018). Lastly, where water suppliers are private entities or comprised of public–private partnerships, private equity may be a source of revenue.

Most water systems are chronically underfunded. In many instances, initial capital investment for water system development was heavily subsidized either through governmental grants or by overseas development assistance. Tariffs charged are insufficient and, consequently, few piped water systems engage in full cost recovery. Even fewer generate enough revenues to cover future maintenance, asset management and expansion costs (Alaerts, 2019; World Bank, 2017). Financial deficiencies are particularly pronounced in small and rural areas in which there are few options for generating revenue (Machete & Marques, 2021) and limited gains from economies of scale. Debt financing is generally only possible for medium or larger sized systems, or when higher levels of government engage on behalf of smaller systems.

For the past several decades, private equity was anticipated to fill this financing gap; however, private finance for water supply infrastructure failed to materialize to the extent expected, remaining at only approximately 10% of investments (Akhmouch & Kauffmann, 2013; Alaerts, 2019). In part this is due to the risk profile of water systems, including the long-time horizons for investments, the unpredictability of cost-recovery, the political difficulty of enforcing payments and the weak creditworthiness of water systems (Alaerts, 2019; Machete & Marques, 2021; World Water Council & OECD, 2015). Weak regulatory frameworks and concerns about mismanagement or corruption add to the risk of investment (Alaerts, 2019; Goksu et al., 2019; Machete & Marques, 2021; OECD, 2012b). In addition, the large transaction costs of investments are a barrier to investing in smaller water systems, where the relative size of the needs and lack of economies of scale make investments unprofitable (Alaerts, 2019).

Several new innovations in water system financing, including blended finance, intermediary financing institutions and sustainable finance may provide some promise for water sector finance, though they are not without strong limitations.

Blended finance focuses on lowering the risk profiles and transaction costs of water system investments, primarily by shifting some of the risks and costs to the public sector (Alaerts, 2019; OECD, 2019). In this approach, governmental funds or development finance (taxes, grants, concessional loans) are used to encourage mobilization of private capital. This strategy is currently at the forefront of efforts by the World Bank (2021) and strongly promoted by the OECD (2020), though to date this has mostly been successful in attracting finance flows to a small cluster of middle-income countries, with very little going to the water sector (McDonald et al., 2021).

A related alternative is for the public or international donors to act as a financial intermediary, such as revolving funds that provide loans to finance water projects with loan repayments that return to the fund to finance other projects. While the United States has used revolving funds to support water supply for decades, similar approaches are being tested in other countries (Alaerts, 2019; Porciuncula, 2014). Public banks are also potential source of financing for water systems, with some banks such as the Nederlandse Waterschapsbank NV having water systems as its sole mandate (McDonald et al., 2021). Additionally, non-for-profits or other corporations may be another mechanism for financing. For example, the Water Financing Facility, a quasi-corporation and bank, partnered with the Kenyan government and overseas development assistance organizations to create the Kenya Pooled Water fund, which issues local currency bonds and uses the funds leveraged to provide long-term loans to water suppliers. By pooling carefully selected multiple water projects together, the fund reduces financial risk (Water Finance Facility, 2017). A challenge with these approaches is they require an initial source of capital.

'Sustainable finance' may help to fund intermediaries or directly fund water suppliers. As the financial sectors seeks to reorient towards sustainable and/or socially responsible investment and to channel funding away from investments at risk due to climate change, investment in water has infrastructure gained visibility. New financial instruments include 'green' or 'climate' bonds (e.g., Climate Bonds Initiative, 2021) as well as water-specific portfolios, indexes, mutuals and exchange traded funds all aimed at supporting the water sector while making a profit (Bayliss, 2014). It is too soon to tell how effective these funds will be in mobilizing finance for the water sector. While it may leverage new sources of funding, it may also crowd out commercial funds channelled through other means (Alaerts, 2019). Further, the rise of financialization within the water sector has been accompanied by concerns not too dissimilar from those associated with privatization, including the influence of pressures for short-term returns on decision-making and the need for profits being at odds with social objective of water provision (Bayliss, 2014; March & Purcell, 2014).

Even with these emerging efforts, water system finances will likely remain a substantive challenge. Past and newly emerging financing providing funding primarily for capital investments, yet sufficient funds need to be on hand for ongoing operations, asset management and emergency response. There are substantive limitations to which systems will be able to benefit from these new sources of finance. The capacity of the water supply sector to 'absorb' finance is constrained by weak administrative capacity, poor creditworthiness and a potential lack of 'bankable' proposals (Alaerts, 2019; Machete & Marques, 2021). Rural and/or smaller systems will have the greatest difficulty accessing new forms of funding due to their lower capacities and fewer connections across which to spread the costs. Hence, a feedback loop may exist wherein systems with low capacities remain unable to access funds needed to increase capacities.

In sum, the financial needs of the water sector are immense, yet insufficiency of funds to address those needs remains a pressing concern. There are likely more options available for larger systems and those with higher capacities, as those systems are both better positioned to attract external investments and have more avenues for cost recovery through user fees. While the implementation of improved tariff structures may improve internal funding among any size system, such efforts need to be accompanied by campaigns to improve water user willingness to pay and balanced by their ability to pay (Chun, 2014). Affordability remains a huge problem for many water users. Consequently, and particularly in the lowest capacity systems, the future of piped water may well depend on the development of cultural norms and expectations to put pressure on governments to invest or help support investment in water supply. Such 'transfers' will likely need to extend beyond one-time capital expenditures to help include mechanisms that provide sustained revenue streams.

Discussion

The future of piped water will be the result of combined efforts to address ongoing and emerging challenges related to infrastructure, management and finance. Decisions and actions across these three facets of piped water systems are deeply intertwined. Infrastructure choices determine managerial and financial needs, while managerial and financial conditions can affect infrastructure choices and conditions. Figure 1 summarizes the main challenges and opportunities for the future of piped water.

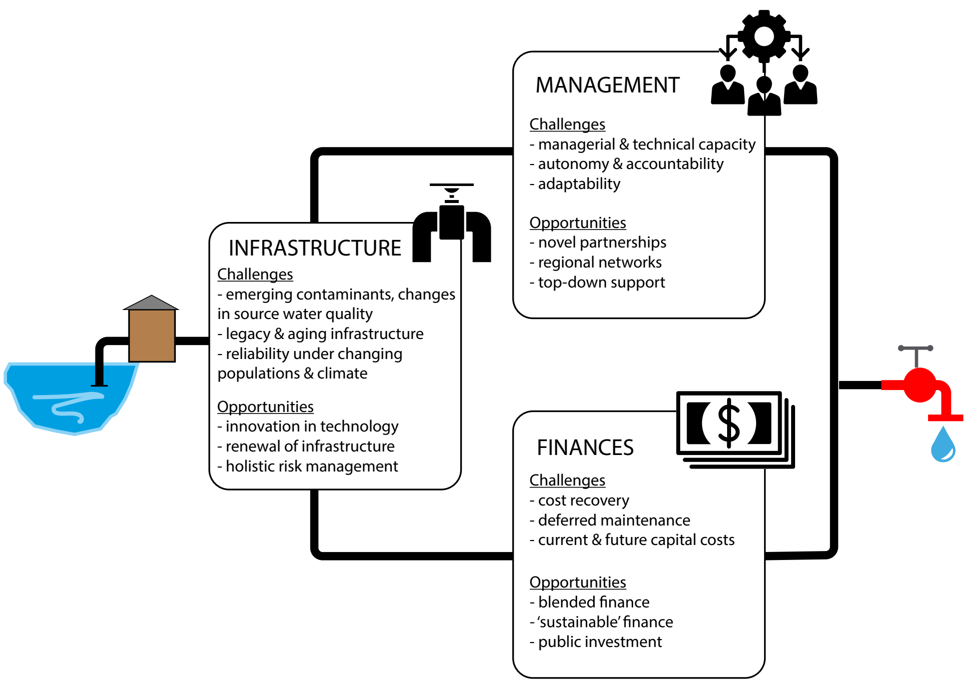

Figure 1. Challenges and opportunities for piped water systems: infrastructure, management and finances.

Notably, while there remain gaps in infrastructure, the largest challenges ahead relate to management and finances. There have been large gains in the expansion of piped systems and innovations in water supply technologies, yet continued and sustained deployment of these advances require increased human and organizational capacity and financial resources. Innovations in managerial and financial models for piped supply are desperately needed. Models focused on ownership or public–private, public–public partnerships have been insufficient for addressing capacity needs. Further, many communities have limited resources, expertise and capacities and cannot be expected to procure and ensure high-quality piped water supply on their own. While trainings, an influx of resources and capacity-building through partnerships may alleviate problems in some systems, we need to consider alternative structures for the management and oversight of water systems that can better ensure their sustained performance. The development of alternative financing models that cover not only capital costs but also sufficient streams of revenues to cover management, operations and maintenance will be critical.

Rural and small water systems require particular attention and assistance. Current models for management and finance are poorly suited for lowly populated areas, and per customer costs are higher when economies of scale are limited. Exacerbating this problem is that rural areas across the world are in a general state of decline as populations continue to migrate towards urban areas, while those that remain are often individuals with limited capacities to pay, administer or manage water systems. Therefore, these small or rural water systems may require different models than those used in larger, urban areas, such as through some form of aggregation through a federalized or other approach. It may also be beneficial to conceive of a multilevel system that provides differing forms of service to differing areas. Innovations from communities within the Global South, including water delivery and kiosk models, may be worth considering, even within the Global North. Key will be ensuring any model provides equitable and quality service. Any policy that allocates responsibility to individuals or households will entail strong variation in those that have and those without access to safe, reliable, affordable water.

While a large percentage of the population can pay at least a portion, if not all, of the cost of water, the poorest of the poor cannot afford to pay. If water is a human right (OHCHR, UN-Habitat & WHO, 2010), water systems cannot demand cost recovery from them. Cross-subsidies, once prominent in water systems, should not be removed from the available policy options. Piped water systems have the advantage of facilitating cross-subsidization in the user base in ways that are infeasible in decentralized systems. Yet, even for communities in which the entire user base is a state of abject poverty, it is a socially and moral imperative to support those individuals.

The current state of piped water and trends within it are not the result of an inevitable path. Rather, struggles to provide and ensure the sustainability of piped supply in many locations around the world are the result of societal choice. The provision of piped water is an internationally recognized objective for which technological solutions exist. Missing is the prioritization of the provision of water such that we direct our political will, our institutions, our financial resources and our ingenuity to addressing the problem. If a safe, reliable, affordable water supply is an expectation and a commitment, we can find ways to provide it.

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