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Chapter 13

Future outlook for urban drainage

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Throughout this book we consider concepts for the urban drainage and water services sector that would be required to support a transition to the contemporary and effective management of urban water systems. After all, water is essential to all life, and the natural water environment provides the raw materials that the sector depends on. Water supply and its return to the water cycle must be safe, secure and as low risk as possible, and ultimately work towards achieving the UN Sustainable Development Goals (SDGs) in the process.

The message here for practitioners is as follows.

- Remember that, as professionals, your client is society, and the environment that sustains society, no matter who is paying for the scheme.
- Begin by thinking as broadly as possible – even for small drainage schemes – both spatially and temporally; from the carbon impacts to people, and how the scheme will be used and sustained over time. Only then should you concentrate on the detail.
- Challenge received 'common-sense' and traditional 'this is how we have always done it' thinking. Innovate to create schemes that are as sustainable as possible.
- Wherever and whenever possible, work with (and not against) natural systems in preference to manufactured resources and the need for complex construction.

13.1. Current and future challenges

13.1.1 Climate change and carbon reduction

Climate change is the single biggest strategic issue facing the sector, followed at pace by affordability. Uncertain and changing rainfall and weather patterns are placing an increasing strain on drainage systems. Combined with population and development growth, and urban creep, this will result in a greater flood risk, increased flows to treatment and more frequent storm overflow discharges with consequent environmental impact to the point that urban drainage systems are not sustainable from a long-term, hydraulic, environmental and financial viewpoint. This will affect the ability to achieve compliance with environmental and regulatory obligations, and to provide safe, secure and healthy environments. Understanding future drainage needs is challenging, due to the diverse range of external pressures and the highly localised nature of networks.

Uncertainty, changing societal demands and needs, combined with accelerated environmental changes and their consequences define the need for a more structured, longer-term approach to ensure that urban drainage systems are sufficiently flexible and resilient to future pressures. Current systems lack flexibility in the face of a changing climate and population, compounded by the fragmented way in which water is presently managed and regulated in most parts of the world. Wastewater and drainage systems are dynamic and have an intricate interaction with other systems and so face a multifaceted set of challenges. Current and future challenges are different in scale, nature and complexity to those previously overcome; in short, the low-hanging fruit has been picked! Continued operation of and investment in traditional approaches – as a way to meet the population's requirements as determined in for example, the EU Water Framework Directive, the SDGs and, in the UK, the Environment Act 2010 (HMG, 2021) – will mean that energy demands will also continue to increase, at a time when reducing energy usage has become the key objective, as will carbon footprints associated with construction, and a recognition to reduce embedded carbon in infrastructure projects (e.g. ICE, 2022).

Sewerage utilities should understand the condition of their assets – including any deterioration – and show leadership in working with the wide range of actors with an impact on drainage systems to assess future pressures (e.g. Defra, 2016). Innovation will be required to enable future pressures to be addressed. One key way to address these challenges is to apply innovative stormwater management techniques, making use of advances in both smart systems and engineering solutions that mimic natural sustainable systems. This is intricately linked to water resources, long-term investment planning and alignment to regulatory cycles. In England, Water UK, the organisation representing the water services providers, established a development programme, 21st Century Drainage, to ensure drainage systems were fit for the future. This has and is developing tools to enable long-term planning and ensure that action is taken ahead of failures that affect services or the environment (see Water UK, 2016).

13.1.2 Ageing systems

Ageing systems refers both to the physical infrastructure that was designed in a bygone era and to historical legacy issues relating to changing frameworks for drainage responsibilities. In Europe, some drainage infrastructure pre-dates 1850. The combined sewer systems built before the 1960s are relatively inflexible to future pressures and present an increasing maintenance and repair burden to sustain a minimum level of service. Ageing infrastructure has resulted in existing legacy issues affecting the underlying performance of drainage systems (e.g. OECD, 2020). Increasing volumes of rainwater and surface runoff entering sewers due to climate change and other factors result in hydraulic incapacity and increased energy costs and therefore increased operational carbon emissions (Zhou *et al*., 2023). Radical changes are required to address the root causes, and how stormwater is managed. In the UK, it is estimated that 30–70% of flows in combined sewers originate from highway drainage, and it will require a huge effort to reduce volumes of stormwater entering the drainage networks. To reduce the amount of flow to the network will require improved management of the system so that the default disposal route for surface water is not into a collection system for sewage treatment, but into a useful resource.

An ageing physical asset base presents additional pressures for the industrialised world, and arrival at the end of asset life is resulting in large programmes of work being required for reinforcement or replacement. Deteriorating performance poses a significant risk to flooding, pollution and river water quality. New asset management practices, that incorporate advances in digitalisation (see Section 13.6), are required to optimise existing and future investment to enhance system efficiency and serve the needs of current and future generations. Improved planning, response and recovery will be required to keep the drainage systems and services functioning effectively. This will also require new ways of doing things. Instead of replacing like with like, future options should start with the question 'What can we make on the surface to do the job of the previous buried infrastructure?' (e.g. WWAP and UN, 2018).

Unless there is a concerted and joined-up intention to reduce the volumes of surface water entering sewers, the current problems of flooding, pollution and a big operational and embedded carbon footprint will continue to grow. Achieving a sustainable and viable asset management plan as a component of a long-term drainage strategy, and an economic case that can be articulated to end users and other stakeholders, is not straightforward. Volatility in the market, with increases in energy and chemical costs in the long term and changes to carbon accounting, are additional unknown factors.

There is a unique opportunity to manage urban water systems in a holistic way that considers the diversity of society's needs and the importance of water to sustain the health of the natural environment. We need to prepare for the unexpected and respond quickly to change and external circumstances. In recognising the changing dynamics and increasing external stresses that control and surround the provision of urban drainage services, we and our infrastructure will need to become more flexible and adaptive, and capable of evolving, while maintaining predictability and stability. Having a resilient and sustainably managed urban drainage network is an imperative.

The socio-economic and natural environment in which we operate is changing. The issues are complex and challenging. Preparing more intelligently for current and future needs is critical in protecting, and fundamental to providing, affordable and resilient drainage infrastructure to mitigate against climate impacts. Understanding complex systems and having the ability to predict how water will behave under different circumstances as it moves through the land phase of the cycle will help mitigate water-related problems in society and improve environmental protection. Transboundary water management will become an increasing issue. So what can we learn from these practices? How do we get agreement between neighbouring upstream countries that it is in both of their interests to adopt a catchment-based approach and develop increased collaboration, as opposed to competition, over the use of water resources within their catchments, such as where there are tensions between agriculture and energy production?

Energy prices and the costs of resources such as fuel and chemicals will continue to rise. Energy price forecasts are highly volatile, creating uncertainty which affects business and economic growth. We will need to be even more efficient in the use of energy and think differently about how we obtain resources and how to use them more sustainably. A circular economy – that is, tapping into all the energy and resources contained within the wastewater we collect, rather than considering it a waste product – will help minimise the use of limited natural resources (Chapter 12). Changing lifestyles and service user behaviour have led to increased sewer abuse, with the disposal of inappropriate materials to sewers in many parts of the world. Coping with future challenges raises not only the question of 'what to do?' but also 'who does what?', 'why?', 'at what level?' and 'how?' A viable response to the current and future challenges requires sufficient capacity, integrity and transparency (achieved by way of coherence between properly engaged stakeholders; see Chapter 4), well-designed engineering and supply chain frameworks to be in place, and adequate and accessible information.

13.1.3 Societal needs and expectations

In the developing world in the 2020s, some 4.5 billion people defecate in the open or have unsafe sanitation, which is responsible for more than 1200 deaths per day of children aged under 5 years. Flooding is endemic and increasing, albeit most countries have not effectively addressed main river flooding and urban drainage is low on agendas. In towns and cities, collection and disposal of municipal wastes are often badly planned and managed, impacting on stormwater systems, and poorly managed sanitation compromises the ability to move to nature-based systems (NbSs) due to the risks to human health. This is the case for even middle-income countries such as India. The challenges of the developing world's needs, as expressed in the SDGs, of providing basic water and sanitation services to all, call for different ways of provision, if this is to be affordable (Leflaive *et al*., 2022). Projections of global financing needs for water infrastructure estimated in 2015 ranged from US $6.7 trillion by 2030 up to US $22.6 trillion by 2050 (Winpenny, 2015), for all water services, not just sanitation. Innovatory initiatives such as those underway by the Bill & Melinda Gates Foundation (2023) to develop new types of toilet are essential if safe water supply and sanitation is to be provided globally.

In the industrialised world, unlike the developing world, alongside decaying infrastructure there are increasingly stringent environmental quality standards and regulatory requirements and growing societal expectations. New thinking and alternative, more innovative ways to deliver a robust, resilient and affordable operating model for water and drainage services are required. Effective asset management principles are needed to safeguard the long-term drainage security and support sustainable social, economic and environmental outcomes. Social and environmental changes are happening at a faster rate than ever before and need to be considered in decision-making when selecting the best operational approach or capital solutions. These issues are becoming of increasing concern and significant drivers for future investment. No longer can we predict with certainty what the major social and environmental drivers will be. Decision-making should be founded on sound evidence, engineering science and economic judgement, but integrated drainage planning and catchment-wide governance will help in planning for future pressures (Chapter 12). Sewers and water mains are often considered to be minor players in the world of urban infrastructures. Gas networks, electricity and telecommunication cables are prioritised in urban areas, as are roads and parking spaces. Urban green areas are also infrastructures occupying surfaces, interacting with stormwater management systems (Tscheikner-Gratl *et al*., 2019). Van Riel *et al*. (2017) show that despite the various utility players operating independently, using traditional silo thinking, they are often willing to change practice. There is an urgent need for more effective transdisciplinary and trans-utility working (e.g. Leach and Rogers, 2020). However, multifunctional systems can also bring added risks, where they are co-dependent and may add costs (e.g. Winpenny, 2015).

In England, Drainage and Wastewater Management Plans (DWMPs) provide a framework for more collaborative and integrated long-term planning (Chapter 5). DWMPs encourage working with other organisations that have infrastructure responsibilities that may interact with drainage, flooding and environmental protection systems (Water UK, 2021) (Chapter 10).

13.2. Emerging responses and sector evolution

Uncertainty, changing societal demands and needs, combined with accelerated environmental changes and their consequences, define the need for a more structured, longer-term approach to ensure that the urban drainage networks are sufficiently flexible and resilient to cope with future pressures. It is important to consider both present uncertainties and how the future may unfold in respect of ‘shocks’ to the drainage systems and impacts on performance and consequences. Future shocks could have a damaging effect on financeability and investor and donor confidence. Employing a dynamic ‘adaptive’ incremental approach will help manage future uncertainty in predictions of potential risks. In developing an understanding to inform a planned and logical robust design strategy, it is important to think about how things may change over time, particularly climate and socio-economic changes. Due consideration should be given to the following (Chapter 12).

- System: spatial and temporal
- Drivers: social and environmental
- Response: insights and skills.

Box 13.1

Business continuity management

It is important to recognise the role that business continuity management has in the context of urban drainage practice; that is, planning for any event that could threaten, or put at risk, one's business. Risk management underpins all business continuity planning, including drainage and, perhaps more importantly, stormwater management. In simple terms

- identify business risks
- analyse them
- manage them.

It is about Mitigation → Adaptation → Optimisation

It is possible to outsource design, operations and maintenance, but not to outsource risk, a concept that many fail to recognise or understand. Loss of money may be forgivable, but loss of, or damage to, reputation is not – and that is why it is important to embrace future challenges.

Scenario planning, while not intended to predict the future, is a tool for thinking about the future based on the following assumptions.

- The future is unlike the past, and is shaped by human choice and action.
- The future cannot be foreseen, but exploring the future can inform present decisions.
- There are many possible futures, and scenarios map a 'possibility space'.
- Scenario development involves rational analysis and subjective judgement.

In the water sector, uncertainty and business continuity management often go hand in hand. There is there for the need for a flexible, adaptive approach to risk management, as outlined in Box 13.1.

There are three key areas where the water sector is already adapting and evolving

- people: skills and capacity planning
- places: planning, finance, and regulatory framework
- artefacts: technology.

Ongoing developments and observations in these areas are discussed in the following sections.

13.3. People: skills and capacity planning

Playing a key role in infrastructure provision, public health, development growth and the economy, 'having the right skills' is critical if we are to meet the long-term needs of society. There is an emerging view that the skills shortage is a very real concern; with a pressing need to address appropriate resources and skills within the sector. In the UK, like many industrialised countries, much of the industry-specific expertise is concentrated in an ageing workforce. With retirement there is a loss of knowledge, so succession planning is important, to upskill early career employees and ensure that graduates and other new entrants are suitable to work in the water industry.

‘To deliver our responsibilities safely and effectively at a sustainable cost, takes an exceptionally skilled and substantial workforce, the sustainability of which is under pressure’ (Energy & Utility Skills Partnership, 2017). Across the world, the water service providers face intense competition for many traditional core skills, while at the same time having to keep pace with change. This is leading to a growing increase in highly specialist expertise and growing complexity within roles. Technology is evolving, and skills need to evolve too. A rapidly evolving technological environment creates the need for more diversity of skills and the people who perform them.

In the developed world, there is an ongoing technological innovation deficit in the water sector, with a continuous need to embrace new technologies to improve operation and performance. With high levels of technical skills and experience, risk can be controlled very effectively. Failure of business planning is all too often the result of poor management, which ultimately comes back to lack of skills. Conversations within the sector repeatedly say that we can ‘grow our own’ skills, but we often fail to do this and there is limited management control over those ‘bought in’. Strategies will only be as good as the infrastructure that supports them, and this includes skills. To target and address potential barriers to implementation and uptake properly will require transition and transformation management with careful incremental change, possibly spanning time frames of several decades.

Elsewhere in the world, many skills deficits occur due to the migration of many of the more capable members of society into developed countries in search of better education and more prosperous lifestyles. This leaves those most committed to their indigenous societies and those who may be poorly educated or are unable or unwilling to leave to undertake the delivery of the highly complex systems and services needed. Although many highly skilled migrants may ultimately return to their home countries, this is the major problem in developing nations, alongside failure to allocate sufficient importance or resources to services such as urban drainage (e.g. DWA, 2012).

Providing a suitably skilled workforce to meet growing aspirations is crucial as an important enabler for the water sector, the overall economy and society, with a need to develop a new, inclusive approach to attracting skills and talent. Many other sectors, especially IT, are seen as far more attractive to the most talented compared with the ‘dirty’ water industry. The water industry is faced with tensions between, on the one hand, short-term affordability and resource prioritisation and, on the other hand, long-term investment and, where businesses are involved, investor returns. Many competing priorities need to be managed. Addressing the skills deficit through a planned programme of replacement will provide continuity and reduce the risk of disruption, including, crucially, risks to financial stability. Having the right skills will enable the sector to remain cost-efficient and competitive, stimulating productivity, investment and, where needed, profitability. Furthermore, any skills strategy also needs to address retention.

A deficit in appropriate skills will restrict the ability of the sector to operate effectively and cost-efficiently. This will be further compounded in a more competitive market for people. Any significant shortage of skills is likely to have an adverse impact on future development and essential wastewater infrastructure projects. A purely sectoral approach will not work, due to international and regional labour markets and the need for many in the workforce to have cross-sectoral expertise (e.g. digital, data, mechanical, electrical, civil and hydraulic knowledge, etc.). For example, the water industry in the UK is competing against high-profile digital, energy, flood resilience, waste and transport projects for the best engineers.

In the UK, the National Infrastructure Commission (NIC) has highlighted several areas of concern, where urgent action is needed to avoid serious risks to delivering the objectives of the National Infrastructure Strategy (NIC, 2023). These relate to reduced capacity caused by significant changes to both physical infrastructure and organisational structures. The skills shortage makes it difficult to attract and develop young professionals. As well as engineers, many people from a range of technical backgrounds are employed in the sector, particularly in science. It is also the same across Europe: ‘Being able to attract and retain young people with STEM [science, technology, engineering and mathematics] qualifications continues to be an issue’ (Energy & Utility Skills Partnership, 2020). Consideration must be given to how long it takes to introduce such changes, including hiring and training people. With changing technology and processes there may be a need to consider what the ‘operator of the future’ will look like and how to provide the appropriate training and support to respond to the inevitable challenges.

Perhaps there is also a need to rethink the principles of human resource management and capacity planning for the modern era, to ensure the sector can deliver value and meet changing demands. Capacity development can be achieved through a process of learning, transferring, acquiring and using new abilities to replace the old way of doing things (DWA, 2012). To maximise available resources it is important to understand the impact these changes may have to enable adjustment to capacity in a timely manner.

> Broader development of technical capacity for the design and operation of water infrastructure and wastewater treatment systems is essential in greening the economy and transition to social sustainability. Promoting adequate technical capacity to support water and wastewater management is thus an important part of the policy package for addressing water challenges in many countries.
>
> (DWA, 2012)

Box 13.2 highlights an example of how, within the UK, the concept of marketisation and the issue of skills affect strategic planning.

13.4. Places: planning, finance and regulatory framework

13.4.1 Current situation

There are very real external pressures that we must prepare for now, to ensure intergenerational fairness (the essence of sustainability, Chapter 12). As a society, we must think very differently about the future – about how we manage too much or too little water; how we reduce, reuse and recycle water and how we begin to value wastewater as the precious resource that it is, to ensure that it is not wasted and seen as something to dispose of as quickly as possible. We need to prepare for a more sustainable future and find the balance between valuing and restoring the natural capital and supporting society’s aspirations for

Box 13.2

Capacity and skills planning

The answer to the overarching key question of ‘What is the market failure we are trying to address?’, is that it is about capability, including user service, continuous improvement, transformation and expected long-term economic growth. There is an urgency to inculcate the importance of the development of a sectoral skills strategy. In terms of strategic positioning, any skills strategy would need to address retention so as not to impact on business or other strategic plans and levels of service.

better places to live and work (Water UK, 2016). The planning process is integral to successful achievement of more effective management and control of stormwater draining to the wastewater networks (Chapter 5), ensuring that it is managed efficiently, effectively and sustainably. With foresight and planning, we can deliver more reliable services and substantive improvements to preserve and enhance the environment. It is therefore imperative that we develop a shared understanding of new and best practices for stormwater management that deliver for public health and planning policy objectives (Chapters 3 and 8).

Capital improvements and infrastructure construction programmes must conform with town planning policies and processes. This is especially important with regard to how land is allocated and utilised. The growing use of NbSs rather than underground infrastructure necessitates changes in urbanism, from a ‘hidden service’ to one that is celebrated in place-making (Chapter 5). Alongside changes in how urban spaces need to be planned and developed in the future, the Fourth Industrial Revolution in the twenty-first century has led to the ‘environmental economy’, and the Decade of Action, where new technologies and artificial intelligence (AI) are changing options and hence decision systems across human society. Popkova *et al*. (2023) state that in this context there is a need to

> ensure environmental justice, energy security, competitiveness, environmental taxation improvement and responsible production and consumption development. Society’s contribution must be coupled with optimising environmental decisions, environmental awareness, improvement of environmental behaviour to protect biodiversity and preference for ESG [environmental, social and governance] investments.

These changes are fundamental to the whole ecosystem of society. The way in which planned uses of space are decided on may need to change drastically, both to maximise the opportunities, for it to be affordable, and to provide long-lasting protection to people and the environment.

Water and other infrastructure projects currently compete for funding with numerous other programmes and initiatives. There are few easy solutions to balancing the complex and sometimes contradictory demands. Upgrading the capacity of ageing infrastructure in an existing development would involve major capital investment. Future demographic changes and the impacts on available capacity will require regular reviews of asset plans to avoid under- or over-investment in the drainage infrastructure. Without a clear programme of action, securing adequate financing for long-term drainage security is at risk (OECD, 2020).

13.4.2 Future expenditure

To build more sustainable systems, there will be a need to develop a strategy for the medium and long terms, such as the DWMPs (Water UK, 2021), which that look at a planning horizon of 25 years or more (Chapter 10). Significant further investment is vital if the drainage infrastructure is to be maintained and enhanced for future generations. Finance and accessing sources of funding are an increasing challenge. Significant investment in both operating and capital programmes will be required to meet water quality standards and service level needs and expectations.

13.4.3 Financial sustainability

Wastewater networks are essential components of urban infrastructure, and their effective functioning is critical for the everyday life of people in the urban environment. This is achieved, among other things, by means of regular, planned maintenance of these systems supported by secure and sustainable investment (Druade *et al*., 2022). The water industry in the industrialised world acknowledges that with an ageing infrastructure, its performance is highly dependent on effective maintenance of ageing assets, such as pumps, sewers and ancillary infrastructure. Prolonging the life of an asset as much as possible or adopting a phased approach to renewal would undoubtedly defer high-cost capital investments. As discussed in Chapter 10, there are many approaches to maintenance, including incident-based, preventive, condition-based or predictive, that is, reactive, proactive or planned. Currently, many maintenance budget owners and managers are actively exploring more cost-effective approaches, such as

- just-in-time maintenance
- reliability-centred maintenance (RCM)
- condition-based monitoring (CBM).

With increasing budgetary pressures, particularly on operational expenditure (OpEx), using resources to inspect and maintain assets based on regular intervals is not necessarily the best approach and a more ‘intelligent’, cost-efficient means of scheduling inspection and maintenance activities is required (Chapter 10). The advent of hi-tech instrumentation and availability of more sophisticated techniques now displaces the past subjective judgement of inspectors (Chapter 9), at least in industrialised countries. As the sector increasingly moves towards increased digitalisation and smart systems, there will be more ‘eyes and ears’ on the assets by means of instrumentation and telemetry, providing data in real time, enabling the use of AI to identify the optimal time for which to schedule inspection and maintenance prior to asset failure. However, whatever maintenance strategy is adopted, a robust management plan is imperative to ensure that the necessary plant and infrastructure requirements can be economically achieved.

Financial and performance improvements can be delivered through an integrated approach to infrastructure investment and delivery, with a principal focus on high-priority catchments and assets. Identifying ‘hot spot’ catchments and a range of solution options will help to prioritise investment to maximise economic benefits and identify those which will have the greatest impact in the shortest timeframe. It is essential that existing assets are exploited or ‘sweated’ wherever possible to augment ‘capacity’ before investing in new projects.

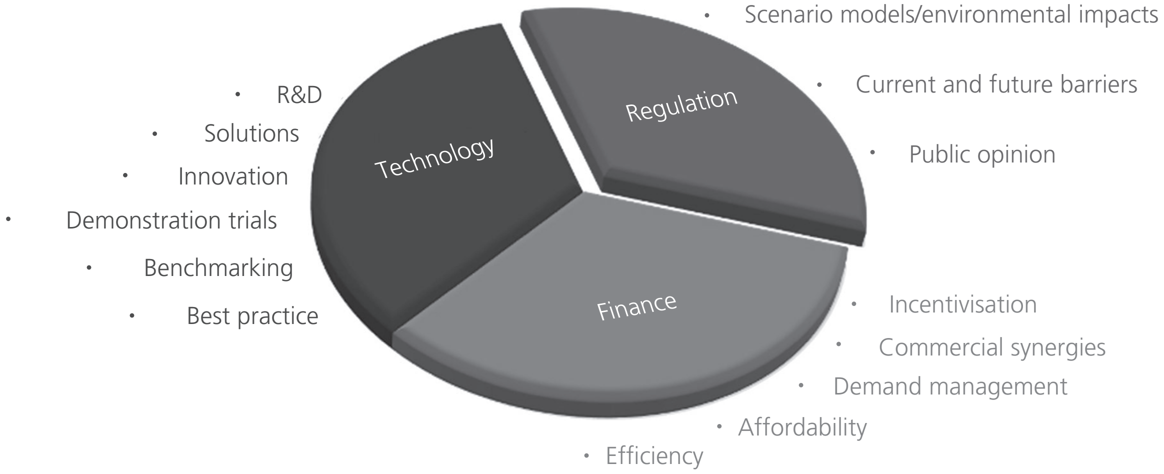
Consideration should be given to developing financing alternatives and opportunities for more equitable charging structures; for example, in Germany, this is proportionate to the amount of generated surface water runoff based on land use or impervious surface area. Balancing differences between residential, commercial and industrial users would promote a better understanding of and personal responsibility for surface water runoff and be effective in improving stormwater-related problems, such as flooding and pollution, and reducing the impervious surface area draining to sewers.

Maintaining fiscal discipline is a necessity to ensure successful delivery of any long-term strategy for urban drainage. Important interlinks between technology, regulation and finance exist but these can be both simple and complex, as demonstrated in Figure 13.1.

13.5. Artefacts: back to basics and mimicking nature

There is a current and growing movement away from hard infrastructure (e.g. energy-intensive concrete and pumping) towards solutions inspired by nature (the so-called ‘soft solutions’), nature-based systems (NbSs). In most parts of the world, there are targets and requirements to reduce both embedded and operational carbon as well as a need for carbon sequestration, which NbSs can help to achieve.

Figure 13.1 Technology, regulation and finance relationships



Practitioners in England are currently faced with finding a drainage option that maximises the value for multiple other criteria that also address the ecological and biodiversity crisis (e.g. Defra, 2023). When multiple drivers are addressed by a holistic solution that mimics nature, these may not necessarily be the more cost-effective and easily delivered options. Another step change for many practitioners, at least in the UK, is that urban drainage systems should now be designed to provide a required level of removal of nutrients to reduce urban diffuse pollution (Natural England, 2022). The requirement not to increase the nutrient loading in receiving watercourses from new developments, which considers the overall increase in effluent associated with new dwellings, has surprised many practitioners. Many developments in areas where nutrient neutrality in England is needed are not progressing until appropriate solutions are identified.

Reducing the volume of stormwater that enters the combined sewer network can maximise opportunities to maintain service and environmental performance, and in effect create capacity within the existing ageing network while the shift in urban drainage practice from buried to above-ground systems takes effect. More readily available capacity within the sewer network will reduce the need for future investment in piped systems and wastewater treatment works upgrades, thereby accommodating future development growth and adaptation to the effects of climate change, ensuring sustainability. However, sewer separation is not necessarily the panacea that many believe, as illustrated by the examples in Chapter 2, Box 2.1, in which separation led to greater water pollution by heavy metals and polyaromatic hydrocarbons (PAHs). The ubiquity of incorrect connections is another problem, as even a single sanitary connection can compromise an entire stormwater drainage system.

There is a growing awareness and acceptance that hybrid drainage systems that make use of blue, green and grey infrastructure are likely to be the most sustainable approach for managing stormwater in many cases

> Nature has ingenious systems for the management and delivery of water in all its phases: precipitation, evaporation, absorption by plants, wetlands, flows to rivers and lakes, and infiltration that recharges

> groundwater and aquifers. No additional infrastructure is required – the water systems are in place, naturally. Once this natural environment has been disrupted by human development, the stormwater created by this development becomes an issue that requires intervention and ongoing management.
>
> (Liptan and Santen, 2017)

While many of the same drivers apply around the world, the UK remains behind other developed countries in the use of such techniques to manage and prevent stormwater entering existing and ageing sewers.

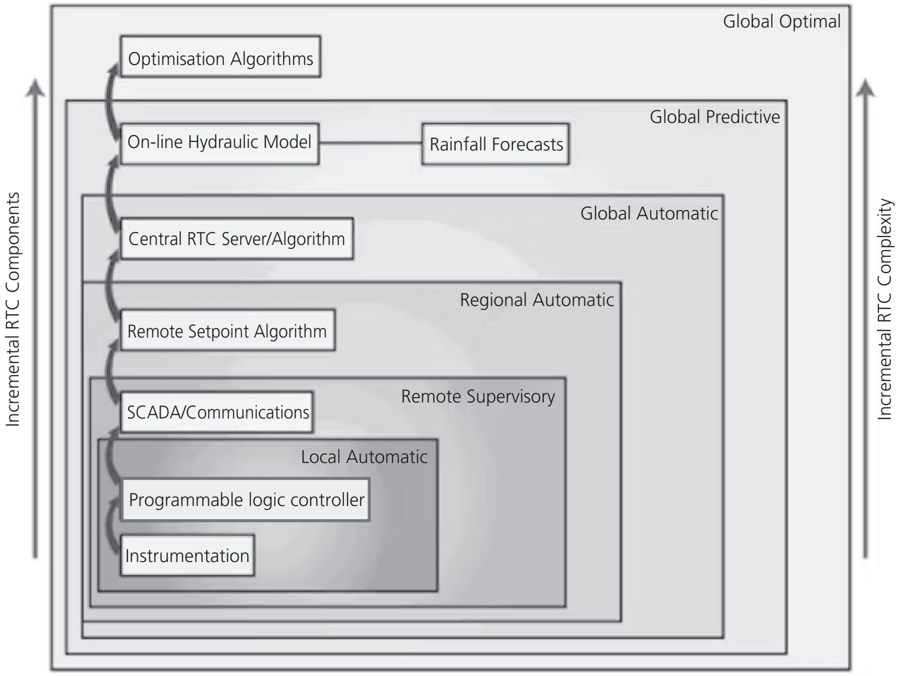
The USA and Australia are more advanced in implementing sustainable stormwater management programmes. The Clean Water Act 1972 (amended in 1987) (CWA) was an important legislative driver in the USA for changing the business approach to stormwater management (Peters and Zitomer, 2021; USEPA, 2022). In response to the impacts of urbanisation on water quality, the CWA provided a regulatory mandate that prohibits the discharge of pollutants into waters of the USA unless the discharge complies with a National Pollutant Discharge Elimination System (NPDES) permit (City of Portland, 2020; *Stormwater Management Manual*). This also opened up various federal and state funding routes for remediation. While water quality was the original key driver, now a combination of both conventional and ‘green’ infrastructure measures are designed to manage water quality and quantity and reduce sewer rehabilitation costs. Practice in Australia has been driven by drought, water scarcity and the rising cost of potable water. Both countries have made significant progress in embedding truly separate drainage systems, in particular the retrofitting of green infrastructure and sustainable drainage systems, within mainstream practice, such that they have become a widely accepted component of the toolkit for effective drainage. Such ‘sustainable’ stormwater management has been successfully implemented in both large- and small-scale applications.

13.6. Artefacts: technology and smart systems

Chapters 9 and 11 outline the journey and current level of computation, instrumentation and technological applications already being used within the drainage sector. The Fourth Industrial Revolution, being referred to as Industry 4.0, is the convergence of existing digital technologies including big data and analytics (data science), Internet of Things (IoT), artificial intelligence (AI), machine learning (ML) simulation, augmented reality and other emerging technological initiatives (Schwab, 2016). In the context of urban drainage networks, all the above approaches can be applied to develop smart drainage systems. Smart systems and AI is a discipline in its own right, with applications across many sectors, with needs for digitalisation in order to achieve efficiencies and transition into the digital era and Fourth Industrial Revolution (Agrawal *et al*., 2018; Finlay, 2018). Smart systems are not entirely new to the water industry. In the industrialised world, the water industry has been at the forefront and has been using what is now known as smart systems and AI for several decades, by means of supervisory control and data acquisition (SCADA) systems to operate assets remotely, such as treatment works and pumping stations. The textbook *Urban Drainage* by Butler *et al*. (2018) has had a chapter on smart systems, albeit previously titled ‘Integrated management and control’, since at least the second edition published in 2004.

Many practitioners will use or rely on smart systems as part of modern daily life; for example, many people in the UK have experienced a smart motorway and will therefore be familiar with the principles of applying this smart approach to managing infrastructure, albeit one that is now perceived to have failed.

Figure 13.2 Adaptive pathway approach towards a global optimised smart system (source Vallabhaneni and Speer, 2011)



Key characteristics of a smart system are that they are cost-effective and adaptive solutions that make use of the existing infrastructure, thereby reducing costly, disruptive and inflexible major construction work, and are used to make intelligent decisions in real time using incoming data. Figure 13.2 illustrates how smart systems are an adaptive pathway approach (Chapter 12). By starting with implementation of local smart solutions at the site scale, growth and capability of smart systems can be integrated in a phased approach towards a global approach that aims towards a fully integrated digital twin (see Section 13.6.2).

A smart urban drainage system is one that makes use of hardware, communication and AI for improved decision-making, to provide any or all of the benefits given in Table 13.1, which provides examples and opportunities to provide smart systems benefits when responding to the current urban drainage challenges.

For some time now the global water industry has been data rich, with its computational records for asset data, time series monitoring, work management systems, incident and user reports and a plethora of other datasets forming an integral part of the core provider activity. However, being data rich is very different to being information rich, let alone data-driven. Emerging technologies and capabilities in data science and AI now open exciting and seemingly endless opportunities for the water industry to generate added value from its data and become an information rich and data-driven industry, in which the performance and condition of the assets is understood, enabling proactive and evidence-based interventions. The ultimate aim is to become more proactive (rather than reactive, which is disruptive, costly and unpredictable, often compared to ‘firefighting’). Water industry practitioners can see the potential that AI creates through better, evidence-based targeted interventions at the optimal point in time.

Table 13.1 Examples of opportunities to implement a smart urban drainage system

Application	Challenges addressed	Description
Reduce storm overflows as a consequence of hydraulic incapacity	Hydraulic incapacity; changing rainfall patterns; increased runoff to sewers	Sewer water level sensors provide real-time visibility of capacity availability within the sewer network. Flow control devices within the network are actively controlled to hold back flow with the objective of preventing storm overflows. Rainfall nowcast products can provide additional predictive capability.
Reduce storm overflows due to causes other than lack of capacity	Blockages or capacity loss due to sewer abuse or sedimentation	Algorithms/ML detects abnormal sewer level response in dry weather and learns when this indicates a blockage formation that requires sewer cleansing. Rainfall nowcast products can provide additional predictive capability.
Targeted rehabilitation investment	Ageing infrastructure	AI applied for sewer CCTV image processing to automatically classify and prioritise defects for rehabilitation.
Proactive/just-in-time maintenance	Efficient use of resources (skilled workers, time, and money)	Asset monitoring of electrical and mechanical components is processed in real time to detect patterns that indicate when maintenance is required (compared with cyclical maintenance visits based on a given time interval).
Smart alarms	Failure detection (e.g. rising main bursts)	AI and ML applied to use existing monitoring data (e.g. pumped flows, pressure deviations) to detect and confirm failures and raise a targeted alarm for response.
Public environmental data notifications	Meeting public expectations (for bathing waters)	Environmental data is validated and verified using AI and made publicly available in real time.
Reduce energy consumption	Increased energy costs	Improved process control at pumping stations to pump flows within optimum pump efficiency range.

13.6.1 Smart, data-driven decision-making

Finlay (2018) provides a pragmatic definition of all AI (including ML, neural networks and real-time control (RTC)) as computer algorithms. The critical benefits of a smart network are in having an immediate and robust view over every asset, its status, condition and performance, and from this being able to process when and how to make fast and cost-effective decisions. Collection systems generally operate in a passive manner. Active management, using AI that is capable of multicriteria evaluation in real time, is improving overall system performance by making balanced decisions on flood risk reduction and pollution prevention (Sun *et al*., 2020). Modern information and communication technologies have a vast array of innovative capabilities (Chapter 9). Harnessing this technology is helping to create more intelligent means of managing and protecting water and wastewater resources. AI and smart technologies, such as adaptive real-time control, ML and neural networks, will provide faster and more reliable data, enabling quicker decision-making and intervention (Kapelan *et al*., 2020). Smart infrastructure will also help operators optimise resource allocation.

A data-driven approach to asset management must be cognisant and not lose sight of the end goal of physical asset management, as this provides the wastewater collection system. The physical assets and the level of service provided ultimately make up the value of a service provider. In the UK's private and regulated water sector this is known as the regulated capital value (RCV). All efforts to implement a smart system must not be at the detriment of investing in the asset health of the actual physical assets that deliver the core services (Chapter 10). Providing core services are the priority and technology choices must deliver improvements to these. Above all other digital transformation objectives, a smart wastewater network must assist in the following.

- Prolonging asset life by identifying the optimal point in time (often referred to as 'just in time') for interventions that avoid costly catastrophic failure. This is colloquially referred to as 'sweating the asset', or extending the asset life as much as possible and postponing high rehabilitation costs until necessary.
- Identifying and eliminating common root causes of failure, as this is the most effective means of ensuring service failures do not repeat themselves.

In developing an environment for analytics and communication, it is vital to invest in research and development in technologies that will help to develop the infrastructure that will best meet provider and user needs in the long term. Linking the physical and digital world and adopting an integrated approach will help enable a seamless transition, as will an acceptance of the use of AI and innovative technologies to develop smart infrastructure and optimise resource allocation.

13.6.2 Digital twins of physical assets

A digital twin (DT) is defined as a virtual representation of a physical asset enabled through data and simulators for real-time prediction, optimisation, monitoring, controlling and improved decision-making (Rasheed *et al.*, 2020). Section 13.6.1 described local and single-objective applications of smart systems, whereas a digital twin is a comprehensive digital version of the physical drainage system. A DT is a layered approach rather than a single piece of hardware or software, and incorporates a range of components such as pumps, pipelines and processes. The DT not only provides real-time material for more informed decision-making, but can also make predictions about how the asset will evolve or behave in the future. In an ideal setting, a digital twin will be indistinguishable from the physical asset both in terms of appearance and behaviour, but has the added advantage of making future predictions. It also provides the possibility for humans to interact physically with the asset using an avatar (Mollerup *et al.*, 2017). According to the Gartner Hype Cycle (Gartner, 2021), there are now increasing opportunities to create DTs and they are being developed for wastewater applications within academia and industry (e.g. Pedersen *et al.*, 2021). A DT can include RTC, which as a technology has been used in the water sector since the 1980s, but more recently has been implemented and demonstrated to reduce storm overflows (Mollerup *et al.*, 2017; Van Loenen *et al.*, 2012; Vezzaro *et al.*, 2014). A data-driven (statistical and stochastic) approach relies only on data and generally disregards the existing and well-established hydraulic and process models, and therefore does not advance the understanding of the physical assets and system processes in the way a DT can.

The current drainage infrastructure DT is the hydraulic model as explained in Chapter 11, requiring the next iteration to be able to run the model in real time using rainfall nowcasting (Chapter 6). While computing power has advanced immensely in the past decades, hydraulic models as built and run now still take a considerable amount of resources and time to compute. For this reason there are few, if any, catchment scale drainage infrastructure models that are running in real time, let alone predicting the future state of the system with sufficient lead time to deploy responses to flooding or pollution.

Given that there has been considerable investment in recent decades in building accurate and high-quality catchment scale hydraulic models, one challenge for IT and data science practitioners is how the sector continues to benefit from the hydraulic models within a digital era; what is required so that hydraulic models can be solved with the required speed to deploy actionable insights, akin to the often nationally owned meteorological prediction models? (Rasheed *et al*., 2020).

13.6.3 Service transformation and strategy

There are numerous water and wastewater service providers and arrangements for institutions and responsibilities worldwide (Chapter 5). Many are public services, operated by or on behalf of municipalities (e.g. Juuti and Katko, 2005). There are also providers who offer a commercial service, as in England, where these are regulated businesses. Whichever model is being used, the service providers will need to address the forthcoming challenges and opportunities, especially those provided by the new Digital Age.

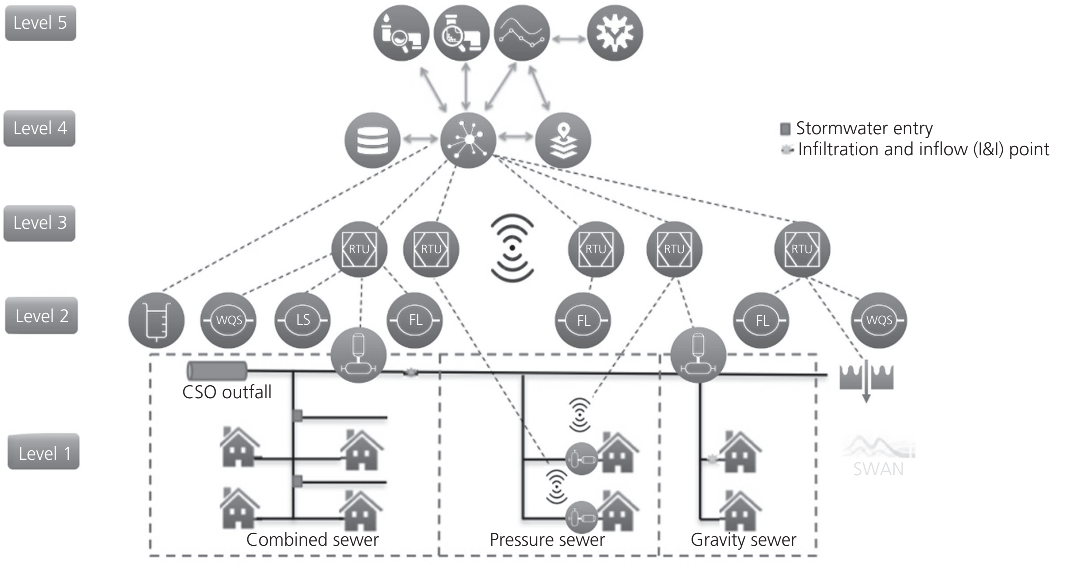
Business leaders within the English water services sector are responding to the changing market environments and the digital business growth environment and are embarking on the journey of transition towards smart networks. Often the transition forms part of wider strategies for digital business capabilities and digital enabling initiatives. In England, industry regulators also require the water sector to develop business plans that embrace the latest technology and smart networks (EA, 2021).

With such fast-moving technology advancement becoming available, the challenge for sector leaders is in selecting appropriate activity areas to which innovative technologies can be applied and that will provide the highest return on investment. From this, developing a clear roadmap to bring all stakeholders together for the digital transition or, as commonly known, the new ways of doing things. Digital transformation is a slow fuse. The rate of technological innovation is exponential and requires organisational and institutional change, which involves people and professions and requires sensitive change management. At the time of writing, the latest market disruptor, which professionals have generally been unprepared for, is the unprecedented update of widely and freely available web-based apps that can write code by taking in ordinary, common speech instructions. Specialist suppliers who produce engineering design and data analysis reports are at risk of being supplanted by web-based apps. Using such an app, a non-specialist can roughly describe their functional design specification and the app scouts the internet for previous examples and user input data to produce designs, analysis and reports.

Implementing a truly smart system requires multidisciplinary collaboration between several specialisms in the water sector, but they might not be accustomed to using the same technical language and working seamlessly to develop a fully integrated solution. Figure 13.3 shows a conceptual framework developed by the Smart Water Networks Forum (SWAN) that depicts a layered approach composed of the parts (disciplines) that make up the smart network. These disciplines include the following.

- Engineers who understand the mechanics of the physical assets.
- Instrumentation, control and automation (ICA) engineers who can understand the electronics and logic.
- Telemetry and telecommunications specialists who know how to get these data to the brain centre for processing.
- Data management and specialist architects who can design the software and systems to store data in retrievable and searchable formats.

Figure 13.3 The SWAN wastewater network management layered approach (SWAN, 2023)



Level 1: The physical layer made up of civils, mechanical and electrical assets.
Level 2: The sensor infrastructure (rain gauges, water quality sensors (WQS), level sensors (LS), flow meters (FL), etc.).
Level 3: Communications/telemetry/outstations infrastructure (remote terminal units (RTUs), cabled, wireless, IoT, radio, etc.).
Level 4: Data management and display (SCADA, GIS, dashboard, work management systems).
Level 5: Data fusion and analysis (high-value information, algorithms, automated responses, forecasts, decision-support systems, detection, optimisation).

- Data scientists and specialist programmers who can take incoming data and build algorithms that make sensible automated decisions.

The use of smart networks in the water sector will depend on active engagement and participation of stakeholders from inception through to implementation. A carefully planned and sensitive stakeholder engagement process should be in place for achieving system acceptance by users. Inclusion of operations and maintenance staff is critical at early stages and throughout implementation. The long-term maintenance needs of all control elements are critical, and the changed approach needs to be carefully planned with affected colleagues (Perciavalle *et al*., 2017).

Dilemmas and questions that service providers are currently faced with include the following.

- Should the sector develop in-house AI capabilities or use AI suppliers and frameworks?
- Is AI and data science a core function of the water industry and therefore will data scientists become just as essential as hydraulic modellers to the water industry?
- Can the digital transformation be delivered under current organisational structures (e.g. existing role descriptions and skills sets)?

There are different views of which type of operating model is best suited for a smart wastewater network, such as a ‘federated’ model, but with a centralised-expertise base or a centralised model. Federated architecture allows interoperability and information sharing between semi-autonomous decentralised organised lines of business, IT systems and applications. In this model, an integrated control centre houses experts that are capable of remotely operating workers who are ‘low skilled’. An example of this would be a farmer operating a pumping station on their property, using technologies such as augmented reality or Google Glass, but being directed from a central expert command. This would result in significantly fewer people being required to operate above-ground assets. It could provide quicker and more reliable data, enabling faster decision-making, all of which helps to improve the management of risk and ensure the continuity of the critical drainage service. A federated approach is more agile and flexible, allowing much more freedom of choice. However, a centralised model provides more comprehensive end-to-end transformation and is more scalable (up or down), but relies on strong leadership.

One key challenge is to unlock the potential of AI and data-driven technologies to optimise wastewater network performance and deliver operational efficiencies compared with the current ways of working. The digital transformation to a smart wastewater network will undoubtedly require dealing with what, until now, has been unknown territory, and testing various technologies. While it is important to consider scalability at an early stage, starting small with pilots can provide invaluable learning and insight. The journey will initially require technology selection that is compatible with the existing modus operandi. See Box 13.3.

AI and ML concepts are now being used to drive wastewater process improvements, which are helping reduce the number of pollution incidents, enable targeted NbSs, provide early detection of leaks and enhance energy efficiency and will ultimately, lead to optimised processes and efficient integrated water management. The development of smart networks is an evolving process. Ideally, this is about creating a fully connected network, topologically linked, that enables digital navigability across the assets. One of the main advantages is the ability to adapt to an uncertain future through operational changes rather than construction of new infrastructure. A phased approach that builds on what has already been achieved has a higher chance of success and is easier to manage than yet unknown innovation (Figure 13.2). Furthermore, an incremental staged transition will support evaluation of the benefits at each stage and ensure increased acceptance of the technology.

13.7. Outlook for urban drainage

Urban drainage as a service and as a discipline has matured, having gradually developed from ad hoc arrangements in ancient times into a more formalised discipline. Yet, many of the ancient and traditional practices are still used successfully now. The world has changed and is changing, perhaps faster than at any time since industrialisation. This includes the form and layout of urban areas, which potentially may change significantly within the lifetime of any drainage system. This raises questions as to whether

Box 13.3

Technology and smart networks – extract from WISER (EA, 2021)

‘Embracing technology and developing smart networks is essential to drive process efficiency and in achieving carbon reductions. Employing smart technology to inform drainage and wastewater planning and water resource planning will enable service providers to develop targeted solution delivery for more effective environmental outcomes, better service, and long-term efficiencies. It will also help achieve carbon reductions.’

traditional urban drainage practices are still fit for purpose. There are challenges in the immediate and longer term that need to be faced, but there are also opportunities to change what we do and how we do it.

13.7.1 Challenges

We face a multifaceted set of challenges and to meet future demands will need to consider every option to balance pressures on the drainage infrastructure. Over the past 100 years in the industrialised world the approach to managing wastewater through underground sewers, tanks and shafts has led to great benefits in public health, river and bathing water quality and flood control. However, there is a social and economic imperative to move from short-term delivery of service levels to longer-term sustainability of drainage infrastructure, or at least the services provided, for which building resilience is important to reduce vulnerability to natural hazards. In most places, significant investment in drainage capacity and storage has been provided to improve performance and meet ever-tightening regulatory obligations. Notwithstanding this, the ubiquitous use of combined sewer overflows (CSOs) for alleviating overloaded networks (and potential impacts on river and human health) has become seemingly untenable to the public. Dealing with these problems and the ageing buried infrastructure requires increasing investment in new assets and maintenance or replacement, but is adding mainly grey, buried infrastructure that is relatively inflexible to future pressures as well as costly the right course of action? In many countries the sewer networks are largely an inherited legacy of predominantly combined sewers that were not designed or envisaged to deal with the volumes of stormwater that they are now expected to convey or the range of substances being discharged. Problems from overloaded drainage systems will be worse in the future as surface water inputs increase due to climate change and urban development in most parts of the world. In addition, there is a legacy of flows entering drainage systems that may not have been designed or intended to be there, such as watercourses, highway drainage, inundation from stormwater runoff from fields and adjacent land (muddy flooding), incorrect connections and flows from informal sealing of surfaces. Continuing solely with an approach of using, maintaining and enhancing traditional drainage infrastructure is not sustainable. A point in time has been reached at which addressing future challenges requires a transformative change in approach. In the industrialised world it will be necessary to move towards one that maximises opportunities and resource efficiency, as opposed to traditional 'problem centred' urban drainage practices. As such, a phased approach to adaptation and mitigation is a more appropriate and sustainable response, rather than conventional solutions in which society 'builds its way out of a problem' by increasing conveyance or storage capacities.

However, given that it is impossible to control what is put into drainage systems by users, especially into underground piped systems, there will be a need to continue to expect a wide range of flows and an almost infinite variety of substances being discharged. Significant amounts of flows in sewers are due to groundwater ingress, in many cases most of the flow conveyed. Therefore, it is likely that there will always be a need for underground piped systems, mainly to deal with groundwater, but also to convey the most polluted flows (i.e. those with substances that cannot be managed locally, such as PAHs and microplastics) to centralised treatment plants where they can be dealt with more efficiently. However, these future sewers will, if systems are properly maintained, not be conveying surface water and the groundwater volumes will be better controlled. Much of the groundwater should be managed locally, with NbSs slowing flows and providing greater storage, and stormwater being used as a resource, either directly for non-potable use or supporting base flows in the ground.

In many parts of the world there are no or inadequate urban drainage systems. Despite the SDGs and worldwide efforts, there are still more than 5 billion people without adequate sanitation and more than

4 billion without safely managed water supplies. Although less than 50% of these live in urban areas, the main challenge in these countries, apart from financing, is to fulfil the SDG 6 aspirations by 2030. In many of these countries, such as India, drainage systems are usually malfunctioning, due to lack of prioritisation of investment and political neglect and because of abuse by other interacting infrastructure services and providers, especially highways and municipal wastes. The main challenges are in the policy sphere, and in acceptability of the many affordable technologies that could be used, other than 'western style' water and sanitation systems. For many, however, climate change is already bringing stresses to water resources and, in countries such as Bangladesh, increasing severity and durations of flooding. Dealing with urban drainage in such contexts is unlikely to be a priority for the foreseeable future.

Governance arrangements and institutions are the single most important factor in making cities water-sensitive. Worldwide there are more and more 'future of water and cities' initiatives and publications, but few actual shifts in established practice or the called-for institutional and governance reforms needed to make urban drainage fit for the future. The context for any new developments will inevitably remain within public policy and regulatory settings as these systems are public services. Neither policy nor regulations have been able to adapt to the speed of change we now experience. Despite worldwide exhortations by many respected agencies, governments worldwide are failing to manage water systems in an integrated way, let alone take whole-systems approaches. Yet, this will be essential to cope with the future pressures and impacts of water management. Policies and regulations will need to enable rather than constrain advances and innovations. However, how this can best be effected in a smart-city world is yet to be determined. Current approaches are simply 'tinkering at the edges' of the real-world systems. Yes, controlling a single CSO discharge is locally important, but it is the aggregation of the entirety of the diffuse polluting sources that needs to be controlled, aimed at specific outcomes in terms of societal benefits. Urban drainage is but one small part of the whole ecosystem of societal systems and services and prioritisation of resource allocation needs to balance the needs of all the sectors and everyone in society.

13.7.2 Opportunities

The four streams of the urban water cycle (potable water, wastewater, groundwater and stormwater) are intricately linked, with different technologies and strategies applying to each and several applying to more than one (Smith *et al.*, 2014). Improving the hydrological balance in catchments is needed for the protection of the environment and would also reduce risks of sewer, fluvial and surface water flooding. There is a need to move rapidly to some form of integrated water resource management using the optimal combination of above- and below-ground infrastructure (Chapter 12). The best approach is now more heavily influenced by the scale of intervention. NbSs are especially useful at the local and neighbourhood scale, bringing water into the public realm and providing local opportunities for direct and indirect use (Chapter 8). Management of runoff and rainfall at source like this will also provide some alleviation downstream, reducing system overload and consequent flooding and pollution. However, this will come at a price. NbSs, if not appropriately integrated into urban planning and design, can use more land. Making space to retrofit NbSs, particularly in existing developments, will become an increasing challenge into the future. Perhaps changing land uses and shared spaces can be an opportunity, in which new mobility initiatives, for example, can be utilised to implement local NbSs alongside other changes. This would also bring other benefits, including buffering the impacts from climate change.

Globally, there is evidence that wastewater 'reuse' is becoming more established, despite the 'yuck factor'. Decentralisation of water and wastewater assets for treatment and local provision is being more often considered and utilised in appropriate contexts. Onsite sanitation (Chapter 2) is therefore an option, but due to the ubiquitous problems of complex pollutants outlined above, it might not be a panacea for widespread use, at least in developed countries.

With strategic oversight, it is imperative to improve the certainty in understanding the nature of surface water threats in order to improve the robustness and resilience to responses to the risks. This may also improve preparedness for more extreme weather patterns and development pressures resulting from population movements and redistribution as well as growth. An integrated approach to stormwater management can provide opportunities to deliver innovative, intelligence-driven solutions to reduce stormwater discharges to sewers, control CSOs and help alleviate future challenges, thus contributing to economic development and growth (see Chapter 3).

Traditional urban drainage system design processes are undergoing change, perhaps more profound even than those following the advent of computational power in the twentieth century. The growing availability and ubiquity of sensors of all types, and their widespread use, and the accessible databases and real-time data streams made possible by the advancement of smart infrastructure and intelligence provide endless opportunities to track and understand the world. This, combined with agile decision-making (Chapter 9), will enable integration of stormwater networks, abstraction and discharge controls using dynamically controlled systems, which will deliver increased water supply security, river quality and environmental improvements, reduced flood risk and improved network robustness and resilience to future demands and impacts (Smith *et al*., 2014). This requires data in real time for agile decision-making (Chapter 9). Considering the dynamic interactions of minor/major systems and bidirectional interaction – that is, water in/water out – but this would require a flexible approach to managing environmental impacts. It is therefore essential to develop quickly an integrated approach to water resource management with a diversified/sustainable water supply system, and while this is a strategic necessity, it requires an agile, long-term, regulatory and policy environment to work.

The development of smart infrastructure and intelligence is mirrored by a variety of computational models. Most users of they models for all parts of the water cycle and beyond are presuming that the core science and algorithms on which they are based are robust and fit for purpose, or at least that the ‘trained’ relationships from the data streams are reliable. The innovative and attractive graphical user interface (GUI) for model users can disguise inaccuracies and inappropriate use of scientific relationships in the embedded analytical engines. Often, with tight deadlines to produce outputs, users are trained on how to produce outputs using the GUI, but are not trained or given the interfaces to question and challenge the embedded assumptions. The approach is to monitor a few storm events and the flows and loads using the new generation of sensors and then to compare the model results with the monitoring data, in the verification process. The model is then used to ‘predict’ future events, usually of a different scale to the monitored verification events, and then to design measures to handle flows or to improve performance.

Worrying as this is, the next step in the evolution of urban drainage practice will be even more profound and introduce much greater opacity to model use. This is the fruition of the development of ML and AI, which will transform how urban drainage systems are planned, designed and operated. In smart cities there will no longer be a need for human to input in each of these aspects of urban drainage. Planning, design and (once built by humans) operation will all be automated. Although, maintenance and management of local NbSs will require human expertise and intervention, as will physical asset management and renewal. The effectiveness of these changes will only be apparent when the outcomes can be seen in the performance.

A further complication will be that every system and service will also undergo this digital transformation as smart cities develop. Fortunately, AI systems will readily operate across a multisector domain, and readily assimilate and respond to changing circumstances, be they external to systems (e.g. climate) or internal (e.g. service demands), informed by smart sensing. The challenge then is to try to understand how to establish AI systems that will be able to make the decisions that we understand to be best for urban drainage practice and with no unintended consequences within smart urban systems. The current and future generations of infrastructure specialists will no longer consider only one domain, such as urban drainage, but will need to be cross-systems experts for smarter cities. How expert knowledge and capabilities will be assimilated into AI processes is not yet clear, but work is currently being carried out on this, so it will be. In the future, the primary challenges will not be in the physical water domain, but in the cyber world, where cybersecurity will be paramount in order to ensure sustainable system and service continuity.

There is and always will be a need for the physical infrastructure and assets required to manage wastewater safely. However, changes in need and possibilities, linked with advancing technologies, provide new opportunities to move away from the ‘dispose safely away from urban areas’ model to one where every drop of rainwater and runoff is utilised as a resource and every sanitary flow considered for utilisation. This may be for anthropogenic purposes or to support flora and fauna.

Current legislation in England, the Water Industry Act 1991 (HMG, 1991), states that water companies have the following general duty to provide a sewerage system.

> It shall be the duty of every sewerage undertaker to provide, improve and extend such a system of public sewers (whether inside its area or elsewhere) and so to cleanse and maintain those sewers as to ensure that that area is and continues to be effectually drained.

With the increasing use of SuDS, blue-green infrastructure (BGI) and NbSs, this then poses the question as to whether water utilities have a role to play in providing natural capital for society as a whole and, if so, what and how. As we know, SuDS, BGI and NbSs can perform a drainage function, so could potentially fall within the general duties of providing a sewerage system. This then leads on to the question of the role of water utilities in the public health arena. Water is essential for life, and the water environment has clear demonstrable benefits to wellbeing and mental health. Water professionals are health service providers. Should water regulation therefore be reformed as health policy, just as when the forerunners of the Chartered Institution of Water and Environmental Management (CIWEM, Chapter 1) were established with their principal aims about public health? And just as the first drainage engineers were in fact ‘public health engineers’, finding ways to prevent the public coming into contact with sewage. Embracing such a mindset may accelerate the advancing use of SuDS, BGI and NbSs.

In summary, the advancement of urban drainage practice, in categories of practice, people, and policy and institutions, with a need to do the following.

(*a*) Practice for the future

- Ensure urban drainage is appropriately integrated with both the water cycle and other urban infrastructure systems and services.

- Use and make the most of all types of water, at source, stored, harvested, conveyed, used and recycled.
- Treat 'wastewater' as a resource wherever possible.
- Encourage and develop sound hydrological cycle management through capture, treatment and use of rainwater.
- Make better use of water resources in response to long-term environmental, economic and social objectives.
- Endeavour to provide urban drainage systems that are as sustainable as possible, ensuring that the future and how it may change is appropriately considered in option selection, including who will manage the assets.
- Ensure the effective identification of pollutant sources, pathways and impacts (such as microbial source tracking) in order to control these.
- Minimise pollutant impacts, especially to groundwater.
- Use systems that are part of and mimic nature wherever and whenever possible.
- Identify and manage risk by acknowledging and making explicit the uncertainties in any analyses used in planning and designing urban drainage systems.
- Select urban drainage systems that can provide as many benefits as possible to society, especially for the most vulnerable.
- Utilise appropriately scaled urban drainage systems, from local to centralised, as best to suit the purposes for use and maximise opportunities.

(*b*) People

- Work with people; not only the key professionals, but also communities.
- Facilitate multidisciplinary dialogue with stakeholders and communities to co-design solutions.
- Establish robust partnerships and alliances with other significant players relevant to urban drainage practice.
- Promote social learning, improved awareness and understanding of the challenges faced (for everyone, including society).
- Adopt a multistakeholder approach and action plan to identify and address knowledge and skills gaps.
- Identify what current urban drainage specialists must prepare for and ensure professionals become more multidisciplinary, especially in the world of smart infrastructure and intelligence.
- Give proper consideration to how, by whom and when asset management will be ensured for any new or renovated urban drainage system.

(*c*) Policy and institutions

- Work within existing policy and institutional frameworks with contracting models, but highlight any shortcomings that are inhibiting integration, collaboration, innovation (particularly at scale) and the use of best practice.
- Highlight and seek to find ways of dealing with changes and constraints from policy, funding and regulatory processes that are inhibiting innovation.
- Identify how institutions' governance and systems can engage fully with relevant stakeholders.

Many of the bullet points above should already be in place. However, for various reasons, these are often not observed in current urban drainage practice. It is possible that ‘sewers’ as known now may no longer be required in the future. Local and source control measures will better utilise ‘wastes’ directly and homes and properties may become more self-contained. There will always be a need for exceedance drainage measures, but these would be expected, as far as practicable, to utilise NbSs. Otherwise, conveyance of excess flows will be to watercourses and storage systems above and below ground for utilisation. However, for the foreseeable future, existing assets need to remain in use in developed countries, due to the unaffordability of their abandonment, thus incurring the need for huge investments for refurbishment in the current widespread neglected and decaying systems. This will provide opportunities to use them differently for additional purposes, including for heat or energy recovery. Ideally, the developing world should not follow the practices of the developed world, but should learn from the resource intensity of traditional drainage and adopt appropriate systems and technologies. Many of the technologies used in the developing world will herald the future for how the developed world will need to change if it is to become more sustainable.

13.8. To conclude: *ça donne à réfléchir*!

The idiom ‘*la nourriture pour la pensée*’ or ‘food for thought’ literally translates as ‘*ça donne à réfléchir*’ – ‘it makes one think’. It is hoped that this book has, or will, make urban drainage professionals and others that interact with urban drainage consider water and the role it plays within each respective discipline and how water can be brought into designs and landscapes to reduce impacts to the natural environment from urban drainage systems and create social and natural capital.

The following quote from Victor Hugo, recognised as the most influential French romantic writer of the nineteenth century, who wrote one of the most famous books to immortalise sewers: *Les Misérables*, and is often identified as the greatest French poet, is perhaps quite apt to finish on: ‘*On résiste à l'invasion des armées; on ne résiste pas à l'invasion des idées*’ (Dicocitations, 2023). It translates as ‘An invasion of armies can be resisted, but not an idea whose time has come.’ Perhaps the time of integrated water management is here. As engineers, scientists, academics, architects, landscape architects and professionals, we have a duty to our communities and society to ‘integrate’ our disciplines and work together. It is incumbent on us to make it happen.

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