ICE Handbook of Urban Drainage Practice

Other titles in the ICE Handbook series:

ICE Handbook of Concrete Durability, Second edition (2023)
Marios Nicou Soutsos. ISBN 978-0-7277-6375-4

ICE Handbook of Geosynthetic Engineering (2021)
Sanjay Kumar Shukla. ISBN 978-0-7277-6500-0

emerald PUBLISHING
ice Publishing

ICE Handbook of Urban Drainage Practice

Edited by Richard Ashley, Brian Smith, Paul Shaffer and Issy Caffoor

Published by Emerald Publishing Limited, Floor 5, Northspring, 21–23 Wellington Street, Leeds LS1 4DL.

ICE Publishing is an imprint of Emerald Publishing Limited

Other ICE Publishing titles:

ICE Manual of Blue-Green Infrastructure
Carla-Leanne Washbourne and Claire Wansbury. ISBN 978-0-7277-6542-0
Sustainable Water
Charles Ainger and Richard Fenner. ISBN 978-0-7277-5773-9
Land Drainage and Flood Defence Responsibilities, Fifth edition
Institution of Civil Engineers. ISBN 978-0-7277-6063-0

A catalogue record for this book is available from the British Library

ISBN 978-0-7277-4178-3

Cover photo: Susdrain

Commissioning Editor: Viktoria Hartl-Vida
Assistant Editor: Cathy Sellars
Production Editor: Rajachitra Suresh

Typeset by Manila Typesetting Company
Index created by Madelon Nanninga-Fransen

All editor royalties of this book are donated to Water Aid in support of the work they do. To learn more, visit wateraid.org.

Dedication

In memory of John Blanksby and Jamie Margetts, who both gave so much to the practice of urban drainage in the UK.

Contents

Foreword

I undertook my first design of a drainage system in the early 1970s. It was not an ambitious project, just modest lengths of surface water and foul sewers to drain a new housing development. The housing layout had already been determined and the roads designed. Any open space between building plots had been allocated and it only remained for me to set out the geometry and size of the drainage conduits for connection to the individual properties and highway gullies. I completed the work promptly with the aid of a slide rule and some simple design standards and formulae. The drainage was all below ground, out of sight and out of mind. As a colleague remarked at the time, there are no votes in drainage. Yet, as I write this, there are certainly many votes in drainage, with the public alarmed by the poor state of our rivers and the more frequent flooding of our major urban areas. The significant impact this has on the environment, the economy and quality of life has reached a stage in many countries where it is no longer acceptable.

In this book you will find a detailed description of how our drainage systems have developed over the years, the changes that are currently taking place, and what the future might look like. This development has not been a progressive evolution, but a series of step changes arising from crises (Bazalgette's development of the London sewerage system in response to the 'Great Stink' in the river Thames) or opportunities (the development of computers, simulation software and low-cost sensors). And as this has progressed, the skills and competences of drainage engineers and others connected with drainage procurement and operation have also had to progress. This has not been an easy task, as drainage systems become ever more complex, the bodies responsible for their development ever more diverse, and society ever more demanding.

Good drainage, together with the plentiful supply of clean water and effective wastewater treatment, are essential to the health and prosperity of society. The benefits of the original aims of drainage systems – to convey wastewater safely to a suitable point for treatment and disposal, to drain paved areas effectually and to safeguard receiving waters from pollution – have been immeasurable. And in recent years we have realised that we can do even more. A systematic and holistic approach to drainage shows us that managing surface water at source, improving the resilience of communities to flooding and harnessing the benefits of nature-based solutions can improve amenity and biodiversity, provide a much-needed alternative source of water and enhance the quality of life. Imagine a future where we all can benefit from surface water that is drained on the surface, creating natural water landscapes within our urban communities. Such landscapes bring with them all the benefits of natural watercourses by mimicking natural processes, supporting flora and fauna and compensating for the urban heat island effect against a background or rising temperatures. In this future, drainage drives new development rather than appearing as an afterthought.

To realise these benefits, we have to move beyond our technical portfolios. Good data and sound science alone will not achieve the very necessary future objectives. Future infrastructure needs the right technologies, but at the same time must align with the culture of the communities it serves and have a secure financial model and effective governance. All four elements must run together for success to be secured, and drainage professionals will need to be comfortable with working in all these areas. Such change will not always be welcome. Innovation brings with it uncertainty and may be resisted by those wedded to more familiar 'tried and tested' methods. This book is designed to challenge that reticence. Here you will find a detailed summary of all the essential elements of the different aspects of future drainage, written by leading experts in their field. It can be digested in the conventional way, from start to finish, or by dipping directly into individual chapters, which mostly are self-contained. It should also be of interest to those concerned with more general infrastructure provision, and its governance and finance. In each chapter, the evidence base is clearly referenced, and this provides a useful source of additional reading for those who wish to delve into specific topics in more detail. I recommend this book to you, not to sit on your bookshelf, but to be kept open on your desk as a day-to-day aid to your work.

David Balmforth, Visiting Professor, Imperial College London, and Past President of the Institution of Civil Engineers

About the editors

Richard Ashley MPhil, CEng, MICE, MCIWEM

Richard is a professional civil, water and environmental chartered UK civil engineer at the University of Sheffield. He is former managing director of EcoFutures Ltd; researcher in flood resilience at IHE in Delft, the Netherlands; and adjunct professor at Lulea Technical University, Sweden. He is recipient of the International Water Association/International Association for Hydro-Environment Engineering and Research (IWA/IAHR) Joint Committee on Urban Drainage 2014 triennial career achievement award, and co-recipient of the 2008 award for the biennial IWA prize for research excellence in support of sustainable urban water management. Richard originally worked in the sewers in London, but during a practice and research career spanning 50 years he has worked on urban drainage systems in many parts of the world. Most recently he has worked in cross-disciplinary activities covering governance, sustainability and resilience of urban water systems. With more than 600 publications, he is co-author of the *IWA Manual on Performance Indicators for Wastewater Services; main editor of Sustainable Water Services: A Procedural Guide* for IWA; and primary editor and contributor of the *IWA Scientific and Technical Report on Sewer Solids*. He has written reports for OECD on the global need for water infrastructure; flood risk management in the Loire Valley; Paris flood risks; and the future need and costs for water and wastewater assets across the EU. Richard has been a visiting professor for the Cooperative Research Centre for Water Sensitive Cities in Australia (led by Monash University). He was formerly a UK government designated UK representative for the EU COST action on urban flood management and a researcher in the EU PREPARED (for climate change) project, and was scientific adviser to the House of Lords inquiry into water management in England and Wales in 2006. Richard was also an adviser to Ofwat and Thames Water on the Thames Tideway Tunnel; Water UK's 21st Century Drainage Programme on economics of combined sewer overflows and retrofitting SuDS; and numerous UK Water Industry Research Ltd projects. Richard is a co-author of several Construction Industry Research and Information Association (CIRIA) guidance documents, including *Retrofit Surface Water Management; Exceedance Flood Management*; and *The SuDS Manual*. He was adviser to Welsh Water and the Welsh government for stormwater in Wales and for the implementation of Schedule 3 to the Flood and Water Management Act 2010. He is a former chairman of the Yorkshire region of the Institution of Civil Engineers (ICE) and former editor of the ICE journal *Engineering Sustainability* and is a trustee of the ICE Benevolent Fund.

Brian Smith I Eng, MICE

Before retiring in 2019, Brian was the drainage strategy manager for Yorkshire Water, one of the English water and wastewater utility companies. With a background in mechanical, electrical and civil engineering and a career spanning more than 47 years, Brian has a broad, diverse skill base and technical expertise across engineering disciplines relevant to the water industry, gained both in public and private sectors, in the UK, the Netherlands and Nigeria, the last 22 years of which were with Yorkshire Water. In 2011 he organised and led a joint UK water and sewerage company visit to Portland, Oregon and Seattle, Washington USA to learn about their approach, the costs and effectiveness of integrated and retrofit sustainable drainage measures and the benefits achieved from their implementation, and to understand the engineering, social engagement and socio-economic challenges to successful delivery and community acceptance. A consummate professional, committed to providing consistent high standards, Brian has an ability to maintain focus and identify issues and risks that are important to the sector. He provided strategic intelligence on matters relating to sewerage, the environment, and strategic planning and development, and established a clear direction and strategy for stormwater management and innovative, intelligence-driven solutions to help ensure Yorkshire Water was prepared to overcome future challenges in this area. He also developed a wider wastewater networks strategy to enable the company to achieve its vision and strategic objectives. Brian represented Yorkshire Water at a national level on technical, regulatory and legislative matters and was the national and international interface on policy and standards development, representing the UK on the development of an international standard for stormwater management. He formed the Water UK Surface Water Management Network and was chair for almost 8 years from its inception in 2012. He was a member of Water UK's 21st Century Drainage Programme board, chairing the workstream on 'enablers for progress'. Although retired, Brian maintains a working interest in the sector, keeps up to date with current thinking, particularly on integrated water management, and is an active member of the All-Party Parliamentary Water Group.

Paul Shaffer BSc, FCIWEM, C.WEM

Paul has worked in the water sector for over 25 years with a focus on delivering better approaches to the use and management of water. He has coordinated, fundraised for and developed dozens of guidance documents and initiatives to support SuDS, blue-green infrastructure (BGI), flood resilience and integrated water management. He is keen to promote the opportunities around water management and has developed numerous capacity-building programmes, fundraised and directed the delivery of two editions of *The SuDS Manual*, driven the development of tools to quantify the benefits of BGI and facilitated a variety of forums to share good practice. Paul is passionate about the opportunities to collaborate on urban water management and keen to create better places for people and wildlife. He strongly believes that water infrastructure should be multi-beneficial, and this can only be achieved with multiple disciplines working in concert to integrate the water cycle within our towns and cities.

Issy Caffoor BSc, PgDip Biom, PhD

Issy has worked within and alongside the water sector for over 49 years, 27 of which were at Yorkshire Water, where he worked as an R&D manager for over 17 years until he retired in 2006. While at Yorkshire Water, he was actively engaged in the management and peer review of national and international research programmes, including DTi LINK, EPSRC, NERC, BBSRC, European framework and COST actions. He has also been director and chairman of SWIG, a special interest group for sensors in the water industry. More recently Issy led the production of the environmental Knowledge Transfer Network (KTN) business cases: Energy Efficient Water and Wastewater Treatment; Towards Chemical-free Water and Wastewater Treatment; and Integrated Urban Water Management, and reports to NERC on mapping the water industry needs against NERC and Living with Environmental Change (LWEC) science priorities, and the business report to the Technology Strategy Board on a vision for a low-carbon water industry. Issy was formerly engaged as a knowledge transfer chair in water sustainability, based at the University of Sheffield Department of Civil and Structural Engineering. Issy has also held honorary visiting professorships at Imperial College London, Bradford University and Sheffield University. Most recently he was a member of the strategy and leadership boards of the high-profile and successful EPSRC funded TWENTY65 programme on water, which was coordinated by Sheffield University.

Acknowledgements

My career in urban drainage has spanned half a century, with a minor divergence into offshore structures. Starting in the sewers in London, under Norman Crane, I developed a passion for being underground and recently renewed my membership of Sewers Synonymous. Despite this, this book has been rather a long time in gestation. I had hoped that semi-retirement would expedite its production, but such forms of retirement incur full-time working and exciting new projects, with the book always in the background. Having inveigled the fourth editor, Issy Caffoor, into early involvement, his enormous early efforts were unrequited as the draft, in various forms, sat untouched for lengthy periods of time, even during the COVID-19 lockdowns. Nonetheless, Issy provided some excellent insights along the way, until the third editor, Paul Shaffer, was looking for something new and was also inducted into the editorial team, having been a chapter author. Almost as soon as Paul started to provide his long experience, the second editor, Brian Smith, having retired from Yorkshire Water, was recruited to provide the needed impetus in the form of kicks in the right places, to get the book writing process really moving. Brian brought valuable ‘real-world’ inputs into the book, offsetting the, at times, ‘academic’ perspective that perhaps is too pervasive in places, even in the final document.

Working with the many authors who have contributed chapters and contributed to chapters has been very rewarding, although many of the early drafts became superseded due to the length of time this book has taken to get to publication and some of the early sections no longer feature in this final version. Of the many contributors, we have lost both Jamie Margetts and John Blanksby, both of whom were significant players in the urban drainage world and who continue to leave their mark in the form of legacies that are affecting how urban drainage practice is carried out. Early contributors included Tony Poole, Mike Faram and Berry Gersonius.

Looking wider, the global urban drainage community has matured, especially since the millennium, with the domain becoming a discipline in its own right, albeit only to now be faced with absorption into the broader world of integrated water management and integrated infrastructure management. Personally, I have learnt so much from the members of this community over the years, including: the early pioneers in the UK, Bryan Ellis and others in academia, together with the real engineers Andy Eadon and John Tyson; Ian Clifforde at the Water Research centre, many of the research managers at CIRIA and former HR Wallingford staff Richard May and Martin Osborne; and those who are no longer with us, including Peter Ackers, Bob Crabtree and Chandra Nalluri.

Thanks also to the international leaders who defined and built the domain of urban drainage, including Bernard Chocat, Wolfgang Schilling, Jiri Marsalek, Geoff O'Loughlin, Thorkild Hvitved-Jacobsen, Larry Roesner and Rich Field; Tony Wong, who first created the water sensitivity ideas; and Wayne Huber, together with Roland Price and others, who did so much to create the computer models we now use routinely.

Richard Ashley

The editors of the book also owe much to the ICE editors Viktoria Hartl-Vida and Cathy Sellars, and the former editor Inês Pinheiro, who kept us on the straight and narrow. Also to our wives, Cate, Jo, Clare and Andrea, God bless them.

All editor royalties from this book are donated to Water Aid in support of the work they do. To learn more, visit wateraid.org.

Contributors

Andrew Bailey, HR Wallingford, UK

Peter Bide CGeol, CEng, FGS, MIMMM, CaBA Urban Water Group, London, UK

John Blanksby BSc, Dip CEng, MICE (†)

Jo Bradley, Stormwater Shepherds, Bamber Bridge, UK

Hannah Casswell, Sensors for Water Interest Group, UK

Dr Jacqueline Diaz-Nieto CWEM, MCIWEM, GMICE, Environmental Protection Group, Warrington, UK

Dr Glyn Everett, University of the West of England, Bristol, UK

Richard Kellagher, MSc, CEng, MICE, MCIWEM, HR Wallingford Ltd, UK

Professor Jeroen Langeveld, Delft University of Technology, the Netherlands, and Partners4UrbanWater, Nijmegen, the Netherlands

Jamie Margetts (†)

Dr Andy Nichols, University of Sheffield, UK

Nick Orman, Wastewater Networks, Water Research Centre, Swindon, UK

Adrian Saul, University of Sheffield, UK

Dr Alma Schellart, University of Sheffield, UK

Dr Will Shepherd, University of Sheffield, UK

Professor Simon Tait, University of Sheffield, UK

Dr Kieran Williams, Environmental Monitoring Solutions Limited, Sheffield, UK

Steve Wilson, Environmental Protection Group Ltd, Warrington, UK

Bridget Woods-Ballard MA, MICE, CEng, HR Wallingford, UK

Yiqi Wu, University of Sheffield, UK

Introduction

Purpose of the book

Who is this book for? It is for anyone with an interest in urban drainage or who thinks they might like to know what urban drainage is and how it is managed today. Although typically delivered by the civil engineering profession, 'urban drainage' is not exclusively 'engineering'. In fact, the term itself can be misleading in today's context, as a 'drain' is meant to transport water from surfaces and 'drainage' is the means of draining away. Urban drainage thus means the management of water or wastewater to 'flow away' from something or somewhere, specifically in built-up areas. Current thinking now sees water as a potential resource to be utilised where it falls as rainfall, even in towns and cities, placing this key part of the water cycle in a similar frame to the circular economy.

Water crises have consistently featured among the top-ranked global risks in the World Economic Forum's annual *Global Risks Report* (WEF, 2023). These risks are both highly likely and highly impactful and are the biggest threats facing life on earth over the coming decades. As the water cycle is intrinsically linked with climate change, ensuring there is sufficient water to support the needs of the world's increasing population will become ever more important.

There is a growing awareness and understanding among decision-makers that water is as important for cities as climate, energy or food, and there are risks and opportunities related to water that will affect economic development and prosperity, as well as life itself. 'Drainage' is still a useful term, but increasingly the value of water what was once automatically regarded as 'wastewater' to be drained away is being recognised. Even drainage from toilets, kitchens and other water use areas can provide opportunities for utilisation and resource recovery, as 'wastewater constitutes a valuable resource that, if sustainably managed, is set to become a central pillar of the circular economy' (UN, 2017).

This book provides an overview of the current state of the art that is the practice of urban drainage. It is a practice that has developed significantly over the past half a century, acknowledging the need to move away from a problem-centred perspective, where drainage is seen as a necessary way to remove water quickly and safely from areas where it may cause harm. The new perspective is adopting an approach that seeks to utilise rainfall near to where it lands and to apply the principles and practices whereby this resource can best be utilised.

Structure and contents

This book comprises fourteen chapters describing the development of drainage systems over the years, current challenges and what the future might look like. The contents of the chapters are as follows:

- Chapter 1 sets out the nature and context for urban drainage systems, briefly reviewing their development and limitations and introducing emerging ideas for managing water more appropriately in urban areas.
- Chapter 2 introduces the types of urban drainage systems in use and the most important aspects of the drivers and challenges faced today, focusing on sanitary systems.
- Chapter 3 deals with stormwater, including surface water, covering the origins and nature of stormwater and control to maximise value and minimise harm, and includes combined sewerage systems.
- Chapter 4 outlines the importance of stakeholder engagement in water management and how this is being carried out, including building capacity.
- Chapter 5 considers the complexities of the urban planning, political and regulatory landscapes in relation to urban drainage and their importance for integrated water management.
- Chapter 6 sets out the different ways in which rainfall can be measured and used to estimate the spatial and temporal patterns of rainfall. It explains the different concepts of rainfall estimation, prediction and design, and how these might be affected by climate change.
- Chapter 7 considers the key elements of urban hydrology used for urban drainage analysis and design.
- Chapter 8 outlines the current and increasing use of nature-based systems for drainage, the value of their utilisation and how they contrast with traditional buried piped systems.
- Chapter 9 explores the technologies used to sense and monitor flow properties and infrastructure conditions in urban drainage systems, including emerging technologies and sensor-driven control for water management in the future.
- Chapter 10 introduces asset management for urban drainage systems, with a focus on operation and maintenance, using an example of the UK approach to this for the water industry.
- Chapter 11 deals with the analysis and computational modelling of urban drainage systems, including the development history of these analysis techniques and a summary of their applications.
- Chapter 12 considers the frames being used for contextualising urban drainage analysis, planning and design, including sustainability, security, integrated water management and water sensitivity.

- Chapter 13 looks at how new thinking and alternative, more innovative ways to deliver a sustainable, affordable operating model for drainage services are required. It examines skills and capacity planning, and the need to futureproof the workforce of the sector. Advances in digitalisation and technological innovation to unlock the potential of data-driven decision-making are considered, as is the potential for artificial intelligence to transform sector efficiency.
- Chapter 14 provides a selection of case studies from across the UK and the USA detailing an extensive variety of approaches, practical applications and solutions to the many, and sometimes complex, issues faced and how urban drainage, and its practitioners, has and continues to evolve to provide a broader range of societal, environmental and economic benefits.

REFERENCES

WEF (World Economic Forum) (2023) *The Global Risks Report 2023*. WEF, Geneva, Switzerland.

UN (United Nations) (2017). *Wastewater: The untapped resource*. United Nations World Water development report. United Nations Educational, Scientific and Cultural Organization (UNESCO), Paris, France.

Ashley R, Smith B, Shaffer P and Caffoor I
ISBN 978-0-7277-4178-3
https://doi.org/10.1680/icehudp.41783.001

Chapter 1
Urban drainage

Richard Ashley and Brian Smith

1.1. Background and current perspectives

Just what is urban drainage? Like all definitions, the term should be seen as having a degree of fluidity. Although urban drainage has been provided for human settlements since time immemorial, urban drainage as a service and separate discipline seems to have emerged sometime in the nineteenth century, when engineered water supply and sewer systems were being designed and built using scientific knowledge. While it is arguable that water supplies came first, it can be seen in the left end of Figure 1.1 that drainage systems implicitly included the means to manage both the runoff from water falling onto towns and cities, now known as stormwater or surface water, and the emissions of human, animal, commercial and industrial wastes, which are termed sewage.

The scope of traditional urban drainage is also shown in Figure 1.1 and illustrated in Figure 1.2. In some urban areas, this scope extends also to point and diffuse water pollution management, but even in the first industrialised nations, diffuse pollution from runoff from urban surfaces is largely ignored, despite this

Figure 1.1 Evolution towards the water-sensitive city (Ashley *et al*., 2013; adapted from Brown *et al*., 2009)

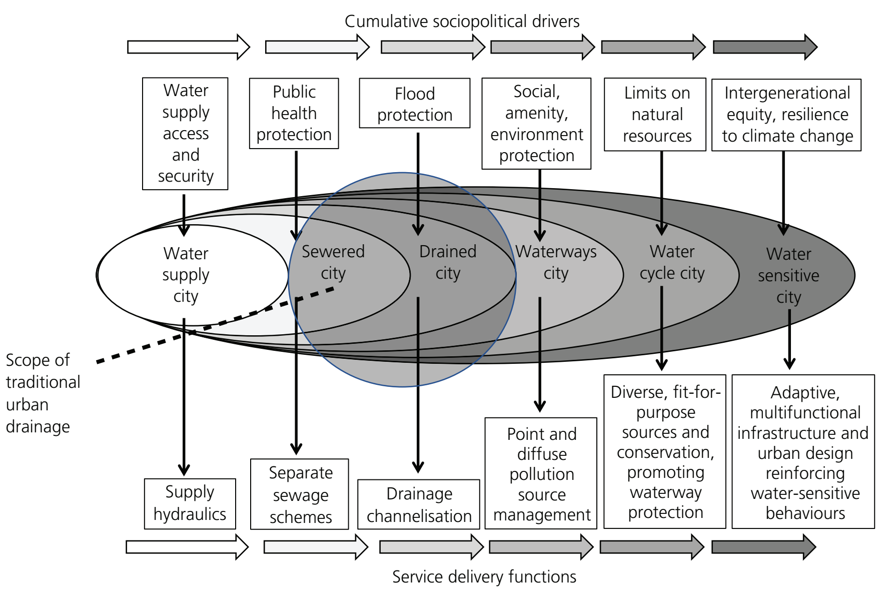


Figure 1.2 Urban drainage in Kolkata (Basu *et al*., 2013)

being a major factor in watercourse impacts (e.g. OECD, 2017). Figure 1.1 also illustrates that it is unwise to manage urban drainage systems separately from the other components of water cycle service and wider infrastructure provision.

1.1.1 The development of urban drainage

The history of how waterborne wastes have been managed in human settlements stretches back to several millennia BC (e.g. Angelakis *et al*., 2005; Burian and Edwards, 2002; De Feo *et al*., 2014; Lofrano and Brown, 2010). Effective wastewater management had emerged by at least the second millennium BC (as illustrated in Figure 1.3), or even before then, in Mesopotamia. The prehistoric settlement of Akrotiri on the island of Santorini (Thíra) had an elaborate drainage system and was made up of sophisticated multistorey buildings. The buildings had water closets with pipework between the walls and drains under the footpaths. In 4000 BC, the area had a better drainage system than much of modern-day Greece. The inhabitants of the town were forced to leave towards the end of the seventeenth century BC following a series of severe earthquakes and a volcanic eruption. Many of these lost early technologies have been 'rediscovered', especially in industrialised countries, where what are now considered to be normal technologies have been further developed (see Juuti and Katko, 2005). These modern developments in hygiene were initiated in Paris and London by engineers and others who travelled back and forth between France and England (Bertrand-Krajewski, 2005).

As well as protecting human settlements from flooding, much of the focus of industrial-era sanitation reforms was on improving standards of behaviour of the working population; originally even more so than for maintaining the health of the population (Allen, 2008). Formalised attempts at protecting the environment, and in particular the aquatic environment, can be traced in England to the reign of Richard II. In 1388, an ACT was passed to prevent the pollution of 'ditches, rivers and other waters' in

Figure 1.3 Drain in the Temple of Knossos, Crete, built during the Minoan period in the second millennium BC (Richard Ashley)

cities and towns by the dumping of animal remains and dung. Until the cessation of horse-drawn transport systems, animal dung had arguably been more of a problem in towns and cities than human waste. For example, in 1894, New York City experienced the 'great horse manure crisis' as more than 1000 t of manure were being deposited each day in the city. This caused chaos on the streets, where mountains of dung built up, disrupting transport, and resulted in acute and chronic pollution of the city's watercourses, into which the dung was conveyed when it rained.

1.1.1.1 Drainage is one part of how land is used, and towns planned

The integral relationship between drainage and the layout of streets and buildings and the way land is used in urban areas is an important aspect of urban drainage. For example, Figure 1.4 shows a street in Pompeii, illustrating the depth of the kerbs and the stepping-stones for crossing the road. The street is designed to convey surface water during rainfall, which would include various contaminants, while allowing pedestrians to cross safely. As contemporary city planning has evolved, the appropriate incorporation of drainage measures has also changed, much of this reflecting the prevailing modes of transport. Originally, drainage systems were on the surface, an obvious part of the urban landscape, with the polluted nature of wastewater being visible to everyone. Gradually, as urban streams and rivers became open sewers, these were covered over and hidden to enclose the evil-smelling and insanitary wastes they conveyed, many eventually becoming sewers that are still in use now in industrial-era towns and cities. Being 'out of sight, out of mind' has been a mixed blessing to humanity (Chocat *et al*., 2004). Modern developments invariably do not consider the 'drainage' aspects of the site layout until everything else has been decided, expecting that the drainage can be fitted in below ground, whatever the

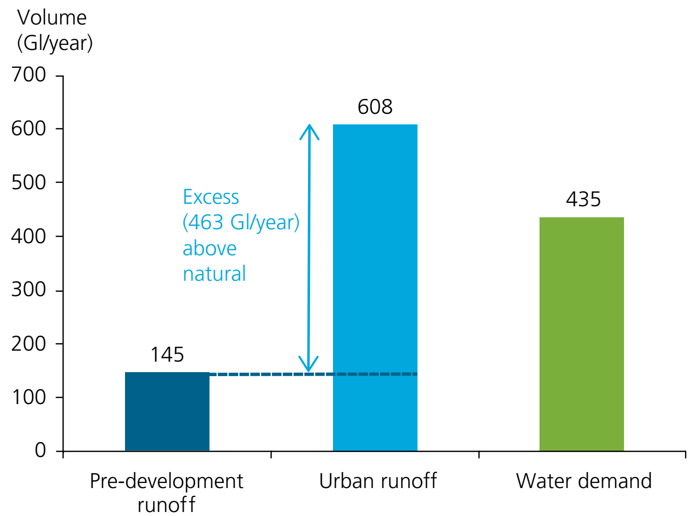
Figure 1.4 A road as a drain in the city of Pompeii (Chris Digman)

layout required. Breaking with this perspective and returning surface water drainage to the surface to make the most of what this water can provide is one of today's big challenges for engineers and practitioners. It is equally a challenge for politicians and the public, who will have to be comfortable with water being more visible and managed on the surface.

The other big challenge in changing mindsets, as in the seventeenth to nineteenth centuries, concerns what is conveyed in foul flows and that it can and should be utilised as a resource, using appropriate technologies (WWAP, 2017). Switching from a 'problem-centric' perspective, in which urban drainage deals with the threats to towns and cities from surface water and foul sewage, to an 'opportunity-centric' perspective, in which surface water and foul flows present opportunities to get the most from the rain and from the human and other wastes generated every day, is a theme of this book. Figure 1.5 shows the water supply needs of the City of Melbourne in Australia, together with volume of runoff from rainfall. The unutilised runoff matches the water demand. In view of this understanding, Australia commissioned a focused research and development programme known as 'Cities as Water Supply Catchments', which became a nationwide programme under the Cooperative Research Centre for Water Sensitive Cities (CRCWSC, 2023). This ongoing programme for water sensitivity aims to exploit all opportunities for water in cities and to do this by developing and integrating water management ideas with city planning processes.

How has urban drainage technology advanced? It is important for practitioners to understand that not all progress in the way in which drainage system technologies have evolved into what is now considered to be standard design and operational practice has been straightforward. For example, the original sewers in France were broader, flatter and, in many places, include cunettes or side walkway banquettes, and were of a different cross-sectional shape from the then commonly used egg-shaped sewers in London. These are legacies that both Paris and London have now, owing to the continuing longevity of the mainly brick sewers built in the sanitation revolution of the 1800s.

Figure 1.5 The water supply for Melbourne balances the rainfall on the city (Tony Wong, Personal communication)



1.1.1.2 The great sanitation reform

Engineers, or even scientists, did not lead many of the developments in sanitation. Much of the credit for the great sanitary reform in the UK that instituted the urban drains and sewers that are still used now is given to a London-based lawyer, Edwin Chadwick, who conducted an investigation between 1839 and 1841. The Sanitary Report of 1842 formed the basis of the Public Health Act 1848 – legislation that would improve the quality of public health in Britain's towns and cities by ensuring more effective provision for improving sanitary conditions. Many engineers in the eighteenth to nineteenth centuries were concerned with their business opportunities and not upsetting the status quo, rather than necessarily with the best way of arranging drainage.

> For Chadwick, mid [19th] century British civil engineers were part of the problems, not the solutions. He saw them as both loyal to a primitive laissez-faire and in cahoots with the most corrupt and irrational institutions of local government: [their works were] hyperexpensive, uninformed by science, even dangerous[…] they clung to obsolete doctrines and rejected truths from outsiders. (Hamlin, 1992)

Even Joseph Bazalgette, the great builder of London's interceptor sewerage system, among other prominent members of the Institution of Civil Engineers (ICE), opposed the reforms to bring in small-bored piped sewers into much of the sewer network on the grounds that these would not work.

Of course, controversies among engineers still prevail, although maybe not on such a significant topic as the sanitary conditions in England's capital city. Nevertheless, even in such an apparently straight-forward field of knowledge and practice as urban drainage, there are ongoing disagreements over innovations, and the risks and lack of certainty and security in not always doing what has always been done before and is 'known to work' (e.g. Palmer, 2000). Some of these controversies are highlighted in this book and what was formerly understood to be 'best practice' in urban drainage may no longer be so (e.g. Chocat *et al*., 2007). In a world of increasingly scarce resources, population growth and expectations of certain living standards, where the climate is changing at a rate that is noticeable in a single lifetime, the profligate use of materials and the waste of water implicit in the 'get the water away from the urban area as quickly as possible' approach are no longer tenable. A new model is required and needs to be implemented as quickly as possible, not only to provide for the millions of people without adequate water supplies and sanitation, but also to ensure that those who have these services can maintain them in an affordable way (Libey *et al*., 2020).

No longer can engineers focus on 'the engineering' as this was understood in the past. It is the interaction of different systems in urban areas, the need to engage with and work across disciplines and to understand as never before that 'the client' is society and it is the natural environment that is depended on, not the funder of a particular project (e.g. Dresp-Langley, 2008). Although, it is arguable that engineers have always done this; at least to some extent, and that the 'art' of engineering does in itself bring a many-disciplined perspective into engineers' work (e.g. Gaterell, 2012).

Policies, regulations and enforcement have always been key to ensuring the delivery of safe and effective drainage systems, forming the institutional arrangements for water services and sanitation (see Chapter 5). Service failures are usually due to policy, enforcement and fiscal issues rather than technical problems. For example, in 2021, Southern Water in England was fined a record £90 million for 6971 unauthorised sewer and wastewater treatment plant overflows over a prolonged period (Environment Agency, 2021a). This was not a technical failure, but a deliberate decision by the private company not to invest adequately in the assets needed. It was cheaper to break the law and pay any fines incurred. However, the company's decision should not be seen as anything but a logical product of the policy, regulatory and enforcement regime prevailing in England. From 2010 onwards, such companies were relieved of most of the performance oversight by the Environment Agency, whose budget was reduced, presuming self-reporting was sufficient (e.g. Hammond *et al*., 2021). The current regulatory regime might encourage some in the English private water companies to focus too much on shareholder dividends, rather than service, as illustrated in this example, in which the consequences of inadequate regulation and poor oversight should have been obvious. The failures in this case are clearly in governance and regulation, encouraging defective institutional arrangements and ineffective enforcement. Yet, most of the English media considered Southern Water as the criminal organisation, rather than the inadequate regulatory regime that allowed such behaviour (e.g. Monbiot, 2021).

The challenges that current needs and perspectives for societal water and sanitation bring now, whether it is the best response to climate change or balancing the many ways of 'seeing' water as an opportunity or a threat, may help to promote a return to engineering's roots, which are to serve society.

1.2. Contemporary urban drainage

Stormwater and wastewater are defined in BS ISO 24513:2019 (BSI, 2019): stormwater is 'water arising from precipitation and snowmelt[;] stormwater is associated with the entire range of rainfall events' and wastewater is 'water arising from any combination of domestic, institutional, commercial or industrial activities, surface runoff and any accidental sewer inflow/infiltration water and which can include collected stormwater, discharged to the environment or sewer'.

These 'waters' potentially impact the environment where they enter or are discharged into surface and groundwater bodies. High flows, erosion of riverbanks and polluted inflows can all damage natural habitats. However, where the assimilative capacity of the water body is high – that is, the drainage discharges are small (in volume or contaminants) compared with the size or flow of the water body, impacts can be small and may even in some cases be beneficial, provided the flow contains only organic materials. The nutrients conveyed in drainage flows can provide food for natural organisms, and provided these are not too concentrated, and the levels of toxic and bioaccumulative substances are low, drainage discharges can even help support industries such as fisheries. However, such clean discharges are rare, and in general pollutant discharges from urban runoff and even treated wastewater are likely to be damaging to water bodies and aquatic ecosystems and impact human health. Currently almost all wastewaters will convey persistent and 'forever' chemicals, including the ever-increasing number of poly- and perfluoroalkyl substances (PFASs) (e.g. Blum *et al*., 2015), as these are now ubiquitous in human and, increasingly, natural environments. Hence, without treatment, even the 'cleanest' wastewater is likely to be polluting.

Rainfall not only directly supports our water resource and supply systems, but it also delivers valuable environmental and amenity benefits, enhancing our urban environments by way of blue spaces in the form of water bodies. It also supports green spaces by providing essential water for plants, agriculture, irrigation and ecosystems as a whole. Thus, there is a wide range of potentially interested parties who should and do take an interest in drainage and the subsequent management of rainfall and runoff. Although public water supplies, health, sanitation and protection from the extremities of too much and too little water have traditionally been the province of engineers, contemporary understanding is that a far wider group of interested parties needs to be involved in water management (Chapter 4). It is not only relevant to professionals, but individual citizens, property owners and dwellers, private and commercial; all need to be much more engaged with how water is managed, especially in urban areas.

Why should many different people be interested in drainage? Well, the world is now more populous than ever before, resources are more stretched, and the pace of change is greater than ever before. Urbanisation has dramatically changed our environment, especially the built environment. In the developing world, citizens have always had to be intimately engaged with how they get their water, how wastes are dealt with and how best to cope when there is too much rainfall and flooding occurs, or indeed when there is too little water and there is water stress or drought. Hence the need for the worldwide initiative of the Sustainable Development Goals (SDGs), aiming to bring water supply and sanitation (WSS) to those without (Ashley and Horton, 2022), although it applies equally to those countries that already have functioning WSS, but possibly in need of improvement.

In the industrialised world, where provision has been a fact of life for at least a century, delegating responsibilities for secure water services, health protection and public safety to water service providers has become the norm. These services are provided by a variety of organisations, from local community groups through to multinational and multiutility corporations (Juuti and Katko, 2005). Many of these organisations make money from providing these services; other services are provided by the state as part of the community. There is no single management or operational model that appears to serve for all types of community or society. However, such services are provided within defined boundaries, and often those dealing with water supplies are not the same as those managing surface water or wastewater. Even in a single organisation there are many examples of different departments not communicating effectively together, a phenomenon termed 'silo thinking'. In addition, water and drainage system boundaries are typically defined by hydrological catchments, which may be natural or engineered by urbanisation, although boundaries may also be set within political or institutional frames. Disparities between boundaries for different types of service, such as catchment boundaries not matching management, political or policy boundaries, invariably lead to complexities in the provision of services and sometimes service provision gaps, where an expected service is ‘someone else’s job, not mine’.

This picture is complicated even further by the knowledge that urban drainage systems do not exist independently of the myriad of systems, infrastructure and services in urban areas. There are crucial interactions with land use, natural systems, transport systems, power supplies and telecommunications. Such interactions and the need to take them into account are changing the way in which urban systems and services are being planned, designed and operated, as ‘systems of systems’. These systems also need to include the people using and interacting with them. Importantly, the understanding that there is a need to get more from the systems by creating and operating them in a harmonised way for a range of functions – including how land is used – is growing. Urban drainage is, of course, a vital service, even if the traditional ideas as to how best to provide it are being challenged by such new understandings.

From this, it is possible to see that ‘drainage’ is a topic that concerns everyone. It can be problematic that it only concerns some of the key players for part of the time – for example, when flooding is prolonged, persistent and impacting vulnerable communities. It was only after months of flooding in 2014 in regions of the south and west of England that Prime Minister David Cameron began to take any real notice. Unfortunately, more flooding occurred in 2015. Despite decades of world-leading research, reports and recommendations, before and after the previous major flooding in 2007, there had been very little commitment by policymakers to address the growing flood risk in England, as is apparent from the UK’s recurrent Climate Change Committee reports (CCC, 2023). In England, more and more new houses are being built on known flood plains, despite these risks. It also appears that commitments to improve the quality of natural water bodies in England, formerly under the EU’s Water Framework Directive (WFD) have slipped, and the quality of waters is continuing to decline in England and Wales (Environment Agency, 2021b), with only 14% of UK rivers meeting good ecological status and not one meeting good chemical status in 2020. Systems thinking, a prerequisite to effective WFD implementation, is something in which the UK falls short. The exit of the UK from the EU has now seen the replacement of environmental directives with the Environment Act 2021, which sets out ambitious plans that should improve our natural water bodies, but only time will tell if this comes to fruition.

The situation is different in many countries around the world where water and drainage are seen as vitally important. This is usually because there are shortages of supply or too much water, with flooding being a regular occurrence. Globally the SDGs, through which water is a common thread, are providing the baseline for planning services and infrastructure within communities and include WSS (Hutton and Varughese, 2016). Urban drainage is frequently overlooked in the application of the SDGs. However, it is the ambition of the European Commission to realise the human right to water, and the implementation of SDG 6 – clean water and sanitation. Water and sanitation are human rights, recognised by the United Nations (EurEau, 2016) to be essential for living a life in dignity and the realisation of all human rights. Clearly, WSS services play a fundamental role in realising these basic human rights (EurEau, 2022). Often, though, the focus is on clean water supplies and basic sanitation, and some aspects of flooding. Surface water drainage is often subordinated, especially in urban areas. This may also happen to the important interactions between drainage and other services, as illustrated in Figure 1.6, where inadequate municipal solid waste systems impair effective drainage provision.

Although clearly relevant to developing countries where there is a lack of WSS, the SDGs are also being utilised in countries such as the UK. For example, the city of Bristol has a vision for 2050, developed in 2020, that is framed around the SDGs, including SDG 6 (Bristol, 2020).