Modelling, Simulation and Control of Urban Wastewater Systems

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Manfred Schütze, David Butler and M. Bruce Beck

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With 81 Figures

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Πάντα ῥεῖ

Heraclitus

(c. 544 - 483 BC)

Foreword
by Professor Poul Harremoës

Environmental engineering has been a discipline dominated by empirical approaches to engineering. Historically speaking, the development of urban drainage structures was very successful on the basis of pure empiricism. Just think of the impressive structures built by the Romans long before the discipline of hydraulics came into being. The fact is that the Romans did not know much about the theories of hydraulics, which were discovered as late as the mid-1800s. However, with the Renaissance came a new era. Astronomy (Galileos) and basic physics (Newton) started the scientific revolution and in the mid-1800s Navier and Stokes developed the application of Newtons laws to hydrodynamics, and later, St. Venant the first basic physics description of the motion of water in open channels. The combination of basic physical understanding of the phenomena involved in the flow of water in pipes and the experience gained by "trial and error", the engineering approach to urban drainage improved the design and performance of the engineering drainage infrastructure. However, due to the mathematical complications of the basic equations, solutions were available only to quite simple cases of practical significance until the introduction of new principles of calculation made possible by computers and their ability to crunch numbers. Now even intricate hydraulic phenomena can be simulated with a reasonable degree of confidence that the simulations are in agreement with performance in practice, if the models are adequately calibrated with sample performance data. This development started in the 1970s and has the potential to significantly improve the design of urban drainage systems and structures.

On top of this development of the combination of theory and practice came the potential of optimising the performance in operation based on on-line data on the status of the system at any particular point of time. For this development to become effective the on-line provision of adequate performance data at selected points in the sewer system and tools for optimising performance on the basis of on-line data.

Since the mid-1800s European cities have been provided with infrastructures for water supply and sewerage, consistently separating the clean and dirty water. This is the basis for the fact that modern cities of the developed world are virtually without waterborne diseases. This infrastructure is a huge investment that is hidden under ground, more often than not taken for granted and ignored by the public and politicians. That investment has to be upgraded to modern demands for better environmental performance, on top of the ongoing demand for flood control. These indispensable infrastructures have to be maintained (refurbished when ignored for too long) and operated to get the most out of the investment. That problem will be with us for as far as we can look ahead. The challenge is to make the system and the investments sustainable. Advanced tolls for mathematical simulation of the systems, adequate data on performance and on-line measurements, in combination with advanced procedures for optimisation will be indispensable in the approach to drainage of urban cities with an established water infrastructure.

As an after-thought, it is important to realise that most cities, in fact almost all of the megatropolises of the world, are not in a similar position. The route for sustainable development may take a completely different direction. Copying the European approach does not provide the basis for development, due to lack of funds required for the huge investments. While appreciating, maintaining and optimising the drainage of cities in the developed world, the provision of alternatives for the growing megacities of the developing world has to be kept in sight.

Lyngby, July 2001

Poul Harremoës

Professor at Technical University of Denmark, Lyngby, Denmark

Foreword
by Professor Peter Vanrolleghem

This book, which originated from the comprehensive PhD work of Dr Manfred Schütze combined with the many years of related investigations of the co-authors Dr David Butler and Dr Bruce Beck, deals with the modelling and control of the entire urban wastewater system. I very much welcome its publication since it is an important step forward towards making the quantitative analysis and optimisation of the urban wastewater system an objective process in which design/optimisation options can be evaluated in a step-wise fashion. This does not mean, however, that the creativity, skill and challenging fun of designing/optimisation is to be lost. It does mean that engineers making choices can be inspired by the examples and procedures provided in this book and can be more confident that their solutions are thoroughly evaluated with respect to the needs and constraints which represent the ambitions of their potential customers and, indeed, any one that will come into contact with that (implemented) solution.

This book is all about integration. Foremost, it deals with the integration of the urban wastewater system. No longer can the sewer system be considered separate from the treatment plant, let alone the river system. The same holds for the treatment plant that needs to be regarded as an integral part of the urban wastewater system. The work reported here can be seen as an anticipation of what, for instance, the recently adopted European Water Framework Directive is imposing. From now on it is not the separate emissions from the subsystems that need to be looked after, but rather the integrated input of the different pollution sources must be looked at in terms of the effect on river quality (in all its aspects). The urban system is clearly one of the main pollutant sources into the river and should be tackled as a whole. The important contribution of the work reported in this book is that it is shown to be possible to make comprehensive models of the whole system that can be used within optimisation studies that focus on river water quality objectives. A number of hurdles that had to be taken were jumped, such as the problem of linking existing mathematical descriptions that use different state variables, the problem of model complexity and the necessity of having bi-directional information flow between the

subsystems for real-time control. This has led to what is probably the first simulator that can simultaneously solve a truly integrated urban wastewater system model.

The next aspect of integration pertinent to this book is the integration of disciplines. Going through the book the reader will be confronted with such widely varying disciplines as civil engineering, software engineering, (micro)biology, numerical analysis, control engineering, mathematical modelling, statistics, environmental and chemical engineering, and probably some more. It is remarkable that the authors have been able to master all of these disciplines and have brought them to synergy. This is quite an accomplishment and should set an example for any future work (not only in environmental issues!) that will increasingly rely on the multi-disciplinarity of individuals and teams.

Finally, an integration of backgrounds (schools of thought) was established in this work. In this era of globalisation, it is good to realise that this book is the result of a collaboration of a German PhD student with an English and an American supervisor. However, the effective supervision of this book is probably much wider. Dr Schütze started his research within MATECH, the European Centre for MAthematics and TECHnology of Urban Water Pollution, financed by the EC Human Capital and Mobility project. It links different research groups in Europe active in the field of Urban Water Pollution, concentrating on the modelling aspects. It goes without saying that tapping into such a network allows the efficient absorption of the necessary multi-disciplinary expertise to move forward quickly. In addition, it provides the necessary peer review options to (re)direct research. Consequently, through this comprehensive network, this book can also be seen as a result of an integrative effort within the profession.

At the time when I started my own research in the field of modelling and simulation, my then supervisor Dr Jan Spriet, introduced me to the methodological thinking of Dr Beck. Much of the fundamentals of my modelling work can still be traced back to his key publications. I feel fortunate to have the luck to discuss many of the methodological aspects with him, and to be able together, within the IWA Specialist Group on Systems Analysis and Computing in Water Quality Management, to highlight the methodological angle of quantitative thinking related to water quality problems. In view of my historical bias towards biological wastewater treatment, I feel very complementary to Dr Butler's background, particularly his work on sewer system processes and the characterisation of the dynamics of inhabitant equivalent inputs into the sewer system. These studies have had a major impact on my thinking of the sewer system as a part of the whole that can be manipulated to improve wastewater treatment.

I have been privileged to know Dr Schütze from the beginning of his PhD studies and have had many in-depth discussions with him on the different aspects of his work, in particular – to name a few – optimisation algorithms, the simultaneous integrated modelling approach, the real-time control options he proposed and the way they were evaluated. I have admired his multi-disciplinary knowledge base, his eagerness to learn and his sense of organisation. Also, having Manfred present in conferences or in EU COST (European Cooperation in the field of Scientific and Technical Research) Working Group meetings was always a pleasure. He was always driven to make progress in the convergence of thinking in the discipline. I feel that this book – to which he is the main contributor – is a reflection of this focus on common thinking and the efforts in this book to structure knowledge, work with clear terminology and methodology are illustrative of this. I am convinced the book will allow this terminology and methodology to further spread in the profession and will eliminate one of the main limitations to scientific progress, *i.e.,* the absence of common language and working procedures.

With this book the three authors share their significant contribution to the field of urban wastewater system modelling and control. They have much to tell us, and there is still more to come as they continue their research and apply it across the world.

Gent, July 2001

Peter A. Vanrolleghem

Professor at BIOMATH, Ghent University, Belgium

Acknowledgements

This book essentially presents the results of a PhD project, which I conducted at Imperial College of Science, Technology and Medicine (University of London) under the supervision of my coauthors, Professor Bruce Beck and Professor David Butler. Although the thesis work was carried out in the years 1994 to 1998, this book also includes some recent developments since then.

My special thanks are expressed to my coauthors for supervising this work. Without continuous interest and encouragement, numerous fruitful discussions and support this work would not have been possible.

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Manfred Schütze

Magdeburg, July 2001

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