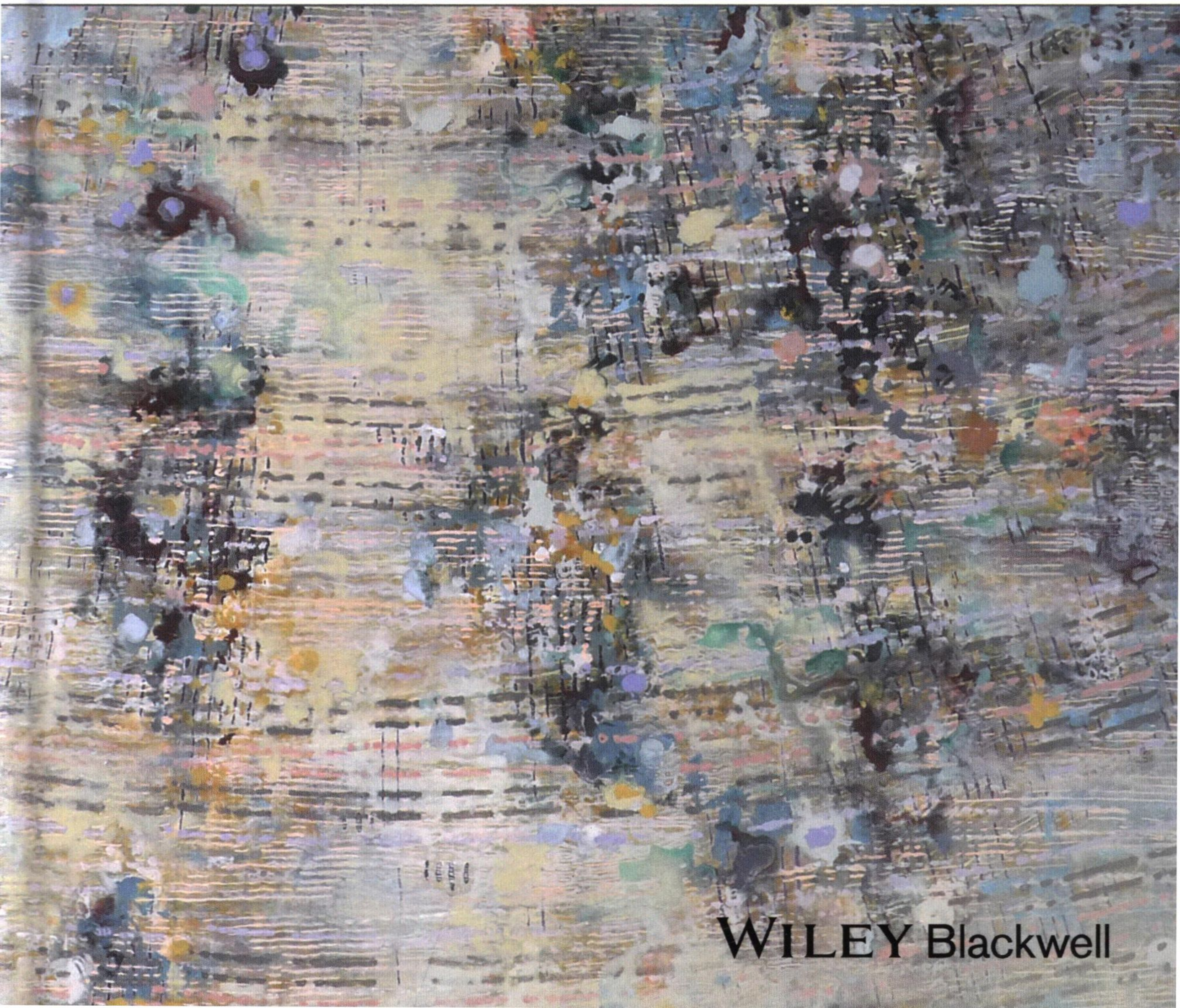
ANTIMICROBIAL RESISTANCE IN WASTEWATER TREATMENT PROCESSES

EDITED BY PATRICIA L. KEEN AND RAPHAËL FUGÈRE



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ANTIMICROBIAL RESISTANCE IN WASTEWATER TREATMENT PROCESSES

Antimicrobial resistance is arguably the greatest threat to worldwide human health. This book evaluates the roles of human water use, treatment and conservation in the development and spread of antimicrobial resistance. Designed as a companion volume to *Antimicrobial Resistance in the Environment* (Wiley-Blackwell, 2012), this book is a multi-disciplinary synthesis of topics related to antimicrobial resistance and wastewater treatment processes.

Antimicrobial Resistance in Wastewater Treatment Processes assembles detailed discussions written by many of the world's best-known experts in microbiology, civil engineering, chemistry, environmental science, public health and related fields. The book presents a collection of subjects that includes:

- Current knowledge of the role of the environment in development and spread of antimicrobial resistance
- Chemical analysis of antibiotics in environmental samples
- Molecular methods for analysis of antimicrobial resistance genes
- Advanced wastewater treatment processes and antimicrobial resistance effects
- Public perception of risk related to health consequences of antimicrobial resistance
- Public health implications of antimicrobial resistance with focus on wastewater treatment processes

Antimicrobial resistance has gained a foothold in the global consciousness as a serious public health threat. There is a much greater appreciation for the role of the environment in the dissemination of antimicrobial resistance and the effects of pollutants that can potentially promote development of resistance in bacteria. Contaminants released from wastewater treatment plants are a concern. In *Antimicrobial Resistance in Wastewater Treatment Processes,* readers will be guided through examinations of the current science related to this important health issue.

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Antimicrobial Resistance in Wastewater Treatment Processes

The editors dedicate this book to the memory of Fred Koch.

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Preface

Antimicrobial resistance is arguably the greatest threat to worldwide human health. This book evaluates the roles of human water use, treatment, and conservation in the development and spread of antimicrobial resistance.

The collection of wastewater dates back to the Roman Empire when sewage, surface runoff, and drainage water were received in the Cloaca Maxima and flushed into the Tiber River by water transported from a vast network of aqueducts. By the Middle Ages, several major urban centers developed throughout Europe that included systems of open ditches and wooden, lead, or clay pipes designed for the disposal of sewage. Rapid increases in population densities in major European cities since that time demanded considerable improvements in water distribution systems and wastewater management in order to protect the public health of citizens. However, it was not until the mid-nineteenth century that many of these improvements were, in fact, realized. Canals dedicated to the transport of wastewater for direct discharge into rivers were constructed, although frequently, drinking water pumps were installed in close proximity to the wastewater removal systems. In essentially all situations, wastewater was ultimately returned to the environment in an untreated form.

Since 1850, the increased frequency of disease outbreaks, such as cholera and typhus, has required dedicated engineering efforts for the treatment of wastewater. Early examples of sewage treatment were simply the application of lime to cesspools, intended to reduce foul odors. During the same period, infectious disease epidemics were still believed to be transmitted through the human population by exposure to filth and foul smells and via person-to-person contact. While major advancements in the disciplines of sanitary engineering and health sciences were being made, it became increasingly clear that water played a critical role in the spread of infectious disease among the human population and that the safety of drinking water was compromised by any possibility of exposure to sewage. Water flushed waste through vast networks of ditches and underground sewers, then discharged in major rivers such as the Thames, the Seine, and the Danube. This rapid growth of urban centers was associated with persistent objectionable smells emanating from water courses that bisected large cities. This, in turn, reinforced political will to improve environmental conditions and led to pioneering technologies in sanitary engineering.

The engineering of technologies specific to the treatment of wastewater experienced a period of unprecedented growth beginning in the mid-nineteenth century. Coincidentally, regulations intended to protect the environment from the impacts of discharge of sewage into receiving waters began to appear more frequently in many major urban centers throughout Europe (Cooper, 2001). The goal of wastewater treatment was to ensure that effluent was sufficiently free of disease-causing entities that it could be released without impacting the safety of drinking water that was being employed for the human population. The secondary objective for improvement in wastewater treatment was driven by the economic incentive linked to the production of artificial guano (Cooper, 2001). Fertility of agricultural lands was declining to such an extent that crop yields were diminishing while the human population in urban centers was constantly growing. To counter this threat to food security, bird droppings were being imported from South America to the United Kingdom for use as agricultural fertilizer. Although land application of domestic waste had been practiced since Roman times, large areas of land adjacent to major urban centers were purchased and designated as "sewage farms." These farms for the land treatment of sewage needed increasing allotments of valuable land. They were subject to a number of weather-related complications and failed to achieve adequate hygiene standards that would ensure the protection of the health of farm workers and citizens at large. In this way, the intimate link between engineered systems for wastewater treatment, agricultural food production, and public health was firmly rooted throughout history.

Antimicrobial resistance in pathogenic organisms is a health risk that has been increasing for the last half century. Domestic sewage contains microbes originating from microbiomes of the human population resident in any community. Wastewater treatment plants receive influent composed largely by domestic sewage and therefore concentrate a vast and diverse collection of microbes in one location. Discharge of effluent from wastewater treatment plants represents the most important source of environmental contaminants, including those that are associated with development of antimicrobial resistance in bacteria.

For some time, antibiotic compounds have been identified as emerging contaminants and included in the category of pharmaceuticals and personal care products. Antibiotics can retain their activity after excretion from human patients such that bacterial communities in biological wastewater treatment systems are impacted by exposure to such contaminants and this antibiotic activity could potentially persist if their removal is incomplete following wastewater treatment. Improvements in instrumentation and tools for the analyses of genes in complex environmental samples have enhanced the ability to track mobile genetic elements of antimicrobial resistance through the wastewater treatment process. Increasing evidence is being gathered to suggest that the dynamic chemical, biological, and ecological conditions of operations in wastewater treatment processes influence the abundance of antimicrobial resistance genes in the effluents discharged to the environment after treatment. Because wastewater treatment plants receive sewage composed of contributions from gut flora of healthy and sick individuals, bacteria that are highly resistant to antibiotic therapy are increasingly detected in wastewater treatment systems.

More than 50% of the world's populations live in cities. Developing nations are witnessing a trend of accelerated urbanization that, in some cases, is accompanied by increased health risks. Clean water, in terms of availability and safe quality, remains a key concern in urban centers. Urban water cycles are now recognized as subsystems where patterns of water use, wastewater treatment, and water reuse play major roles in protection of public health.

Designed as a companion volume to *Antimicrobial Resistance in the Environment* (Wiley-Blackwell, 2012), this book is a multidisciplinary synthesis of topics related to antimicrobial resistance and wastewater treatment processes. Building on the increasing understanding of the central role of the environment in the development and spread of antimicrobial resistance, the book begins with five chapters that describe key issues from a more general perspective before focusing specifically on issues related to wastewater treatment processes. Detailed discussions concerning chemical analyses of antibiotics are included as well as comprehensive examinations of the features of experimental design that are particularly important in studies related to antimicrobial resistance. Advanced treatment strategies for mitigating the effects of factors that influence development and dissemination of antimicrobial resistance in the receiving environment are examined in detail. Several chapters discuss the ever-growing improvements in metagenomics, molecular methods, culture-based analyses, and gene sequencing capabilities, which are becoming popular for the examination of antimicrobial resistance in environmental samples, including those derived from wastewater.

We thank our fantastic team of contributing authors whom we are extremely pleased to regard as both our professional colleagues and our friends. Each chapter of this book has been crafted by some of the world's leading authorities on the topic, in many cases together with early career researchers who continue to explore unanswered questions about risks linked to the development and spread of antimicrobial resistance. We thank the team at Wiley-Blackwell led by Mindy Okura-Marszycki and Kshitija Iyer for guiding us through the entire process of assembling this book from concept to completion. We extend our sincere gratitude to Philippe Raphanel for the use of the image from his wonderful painting on the cover of this book.

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Reference

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