

Biotechnology 2nd Ed
Volume 11c
Environmental Processes I

A Multi-Volume Comprehensive Treatise

Biotechnology

Second, Completely Revised Edition

Edited by
H.-J. Rehm and G. Reed
in cooperation with
A. Pühler and P. Stadler

Volume 11a

Environmental Processes I

Wastewater Treatment

Edited by
J. Winter

 **WILEY-VCH**

Weinheim · New York · Chichester · Brisbane · Singapore · Toronto

Series Editors:

Prof. Dr. H.-J. Rehm
Institut für Mikrobiologie
Universität Münster
Corrensstraße 3
D-48149 Münster
FRG

Prof. Dr. A. Pühler
Biologie VI (Genetik)
Universität Bielefeld
P.O. Box 100131
D-33501 Bielefeld
FRG

Dr. G. Reed

1029 N. Jackson St. #501-A
Milwaukee, WI 53202-3226
USA

Prof. Dr. P. I. W. Stadler

Artemis Pharmaceuticals
Geschäftsführung
Pharmazentrum Köln
Neurather Ring
D-51063 Köln
FRG

Volume Editor:

Prof. Dr. J. Winter
Universität Karlsruhe (TH)
Institut für Ingenieurbiologie und
Biotechnologie des Abwassers
Am Fasanengarten
Postfach 6980
D-76128 Karlsruhe

This book was carefully produced. Nevertheless, authors, editors and publisher do not warrant the information contained therein to be free of errors. Readers are advised to keep in mind that statements, data, illustrations, procedural details or other items may inadvertently be inaccurate.

Library of Congress Card No.: applied for

British Library Cataloguing-in-Publication Data:

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

Die Deutsche Bibliothek – CIP-Einheitsaufnahme

Biotechnology: a multi volume comprehensive
treatise / ed. by H.-J. Rehm and G. Reed.

In cooperation with A. Pühler and P. Stadler. –

2., completely rev. ed. - VCH.

ISBN 3-527-28310-2 (Weinheim ...)

NE: Rehm, Hans-J. [Hrsg.]

Vol. 11a: Environmental Processes / ed. by J. Winter

ISBN 3-527-28321-8

© WILEY-VCH Verlag GmbH, D-69469 Weinheim (Federal Republic of Germany), 1999

Printed on acid-free and chlorine-free paper.

All rights reserved (including those of translation into other languages). No part of this book may be reproduced in any form – by photoprinting, microfilm, or any other means – nor transmitted or translated into a machine language without written permission from the publishers. Registered names, trademarks, etc. used in this book, even when not specifically marked as such, are not to be considered unprotected by law.

Composition and Printing: Zechnersche Buchdruckerei, D-67330 Speyer.

Bookbinding: J. Schäffer, D-67269 Grünstadt.

Printed in the Federal Republic of Germany

Biotechnology

Second Edition

Volume 11a

Environmental Processes I



WILEY-VCH

Biotechnology

Second Edition

Fundamentals

Volume 1

Biological Fundamentals

Volume 2

Genetic Fundamentals and
Genetic Engineering

Volume 3

Bioprocessing

Volume 4

Measuring, Modelling and Control

Products

Volume 5a

Recombinant Proteins, Monoclonal
Antibodies and Therapeutic Genes

Volume 5b

Genomics

Volume 6

Products of Primary Metabolism

Volume 7

Products of Secondary Metabolism

Volumes 8a and b

Biotransformations I and II

Special Topics

Volume 9

Enzymes, Biomass, Food and Feed

Volume 10

Special Processes

Volumes 11a–c

Environmental Processes I–III

Volume 12

Legal, Economic and
Ethical Dimensions

All volumes are also displayed on our Biotech Website:

<http://www.wiley-vch.de/home/biotech>

Preface

In recognition of the enormous advances in biotechnology in recent years, we are pleased to present this Second Edition of "Biotechnology" relatively soon after the introduction of the First Edition of this multi-volume comprehensive treatise. Since this series was extremely well accepted by the scientific community, we have maintained the overall goal of creating a number of volumes, each devoted to a certain topic, which provide scientists in academia, industry, and public institutions with a well-balanced and comprehensive overview of this growing field. We have fully revised the Second Edition and expanded it from ten to twelve volumes in order to take all recent developments into account.

These twelve volumes are organized into three sections. The first four volumes consider the fundamentals of biotechnology from biological, biochemical, molecular biological, and chemical engineering perspectives. The next four volumes are devoted to products of industrial relevance. Special attention is given here to products derived from genetically engineered microorganisms and mammalian cells. The last four volumes are dedicated to the description of special topics.

The new "Biotechnology" is a reference work, a comprehensive description of the state-of-the-art, and a guide to the original literature. It is specifically directed to microbiologists, biochemists, molecular biologists, bioengineers, chemical engineers, and food and pharmaceutical chemists working in industry, at universities or at public institutions.

A carefully selected and distinguished Scientific Advisory Board stands behind the

series. Its members come from key institutions representing scientific input from about twenty countries.

The volume editors and the authors of the individual chapters have been chosen for their recognized expertise and their contributions to the various fields of biotechnology. Their willingness to impart this knowledge to their colleagues forms the basis of "Biotechnology" and is gratefully acknowledged. Moreover, this work could not have been brought to fruition without the foresight and the constant and diligent support of the publisher. We are grateful to VCH for publishing "Biotechnology" with their customary excellence. Special thanks are due to Dr. Hans-Joachim Kraus and Karin Dembowsky, without whose constant efforts the series could not be published. Finally, the editors wish to thank the members of the Scientific Advisory Board for their encouragement, their helpful suggestions, and their constructive criticism.

H.-J. Rehm
G. Reed
A. Pühler
P. Stadler

Scientific Advisory Board

Prof. Dr. M. J. Beker

August Kirichenstein Institute of Microbiology
Latvian Academy of Sciences
Riga, Latvia

Prof. Dr. I. Goldberg

Department of Applied Microbiology
The Hebrew University
Jerusalem, Israel

Prof. Dr. C. L. Cooney

Department of Chemical Engineering
Massachusetts Institute of Technology
Cambridge, MA, USA

Prof. Dr. G. Goma

Département de Génie Biochimique et
Alimentaire
Institut National des Sciences Appliquées
Toulouse, France

Prof. Dr. H. W. Doelle

Department of Microbiology
University of Queensland
St. Lucia, Australia

Sir D. A. Hopwood

Department of Genetics
John Innes Institute
Norwich, UK

Prof. Dr. J. Drews

F. Hoffmann-La Roche AG
Basel, Switzerland

Prof. Dr. E. H. Houwink

Organon International bv
Scientific Development Group
Oss, The Netherlands

Prof. Dr. A. Fiechter

Institut für Biotechnologie
Eidgenössische Technische Hochschule
Zürich, Switzerland

Prof. Dr. A. E. Humphrey

Center for Molecular Bioscience and
Biotechnology
Lehigh University
Bethlehem, PA, USA

Prof. Dr. T. K. Ghose

Biochemical Engineering Research Centre
Indian Institute of Technology
New Delhi, India

Prof. Dr. I. Karube

Research Center for Advanced Science
and Technology
University of Tokyo
Tokyo, Japan

Prof. Dr. M. A. Lachance
Department of Plant Sciences
University of Western Ontario
London, Ontario, Canada

Prof. Dr. K. Schügerl
Institut für Technische Chemie
Universität Hannover
Hannover, Germany

Prof. Dr. Y. Liu
China National Center for Biotechnology
Development
Beijing, China

Prof. Dr. P. Sensi
Chair of Fermentation Chemistry
and Industrial Microbiology
Lepetit Research Center
Gerenzano, Italy

Prof. Dr. J. F. Martín
Department of Microbiology
University of León
León, Spain

Prof. Dr. Y. H. Tan
Institute of Molecular and Cell Biology
National University of Singapore
Singapore

Prof. Dr. B. Mattiasson
Department of Biotechnology
Chemical Center
University of Lund
Lund, Sweden

Prof. Dr. D. Thomas
Laboratoire de Technologie Enzymatique
Université de Compiègne
Compiègne, France

Prof. Dr. M. Roehr
Institut für Biochemische Technologie
und Mikrobiologie
Technische Universität Wien
Wien, Austria

Prof. Dr. W. Verstraete
Laboratory of Microbial Ecology
Rijksuniversiteit Gent
Gent, Belgium

Prof. Dr. H. Sahl
Institut für Biotechnologie
Forschungszentrum Jülich
Jülich, Germany

Prof. Dr. E.-L. Winnacker
Institut für Biochemie
Universität München
München, Germany

Contributors

Dr. Rudolf Amann
MPI für Marine Mikrobiologie
Celsiusstraße 1
D-28359 Bremen
Germany
Chapter 5

Prof. Dr. Eberhard Bock
Institut für Allgemeine Botanik
Abteilung Mikrobiologie
Universität Hamburg
Ohnhorststraße 18
D-22609 Hamburg
Germany
Chapter 3

Dr. Ute Austermann-Haun
Institut für Siedlungswasserwirtschaft und
Abfalltechnik
Universität Hannover
Welfengarten 1
D-30167 Hannover
Germany
Chapter 10

Prof. Dr. Klaus Buchholz
Lehrstuhl für Technologie der Kohlenhydrate
Technische Universität Braunschweig
Langer Kamp 5
D-38106 Braunschweig
Germany
Chapter 24

Dr. Matthias Barjenbruch
Institut für Kulturtechnik und
Siedlungswasserwirtschaft
Universität Rostock
Satower Straße 48
D-18059 Rostock
Germany
Chapter 18

Prof. Dr. Rainer Buchholz
Institut für Biotechnologie
Technische Universität Berlin
Ackerstraße 71-76
D-13355 Berlin
Germany
Chapter 21

Dr.-Ing. Peter Baumann
Institut für Siedlungswasserbau, Wassergüte
und Abfallwirtschaft
Abt. Abwassertechnik
Bandtäte 2
D-70569 Stuttgart
Germany
Chapter 16

Dr. Gerald Bunke
Institut für Biotechnologie
Technische Universität Berlin
Ackerstraße 71-76
D-13355 Berlin
Germany
Chapter 21

Dr.-Ing. Bernd Dorias
Drees & Sommer GmbH
Obere Waldplätze 13
D-70569 Stuttgart
Chapter 16

Prof. Dr. Hans-Curt Flemming
Institut für Wasserchemie und
Wassertechnologie
Universität Duisburg
Moritzstraße 26
D-45476 Mülheim/Ruhr
Germany
Chapter 4

Dr. Claudia Gallert
Institut für Ingenieurbiologie und
Biotechnologie des Abwassers
Universität Karlsruhe (TH)
Am Fasanengarten
Postfach 6980
D-76128 Karlsruhe
Germany
Chapter 2

Dr. Peter Götz
Institut für Biotechnologie
Technische Universität Berlin
Ackerstraße 71-76
D-13355 Berlin
Germany
Chapter 21

Prof. Dr. Ludwig Hartmann
Am neuen Berg 10
D-86673 Unterstall
Germany
Chapter 1

Prof. Dr.-Ing. Winfried Hartmeier
Lehrstuhl für Biotechnologie
RWTH Aachen
Worringerweg 1
D-52056 Aachen
Germany
Chapter 7

Prof. Dr. Mogens Henze
Department of Environmental Science and
Engineering
Building 115
Technical University of Denmark
DK-2800 Lyngby
Denmark
Chapter 20

Dr. Look W. Hulshoff Pol
Department of Environmental Engineering
Agricultural University of Wageningen
P.O. Box 8129
NL-6700 EV Wageningen
The Netherlands
Chapter 25

Dr. Norbert Jardin
Ruhrverband Essen
Kronprinzenstr. 37
D-45128 Essen
Germany
Chapter 14

Dr. Hans-Joachim Jördening
Lehrstuhl für Technologie der Kohlenhydrate
Technische Universität Braunschweig
Langer Kamp 5
D-38106 Braunschweig
Germany
Chapter 24

Prof. Dr.-Ing. Rolf Kayser
Adolf-Bingel-Straße 2
D-38116 Braunschweig
Germany
Chapter 13

Prof. Dr. Paul Koppe
Obere Saarlandstraße 3
D-45470 Mülheim/Ruhr
Germany
Chapter 9

Prof. Dr. Helmut Kroiss
Institut für Wassergüte und
Landschaftswasserbau
Technische Universität Wien
Karlsplatz 13/226
A-1040 Wien
Austria
Chapters 6, 23

Dr. Peter Kuschik
UFZ – Umweltforschungszentrum
Leipzig-Halle GmbH
Sektion Sanierungsforschung
Permoserstraße 15
D-04318 Leipzig
Germany
Chapter 12

Prof. Dr. Gatze Lettinga
Department of Environmental Engineering
Agricultural University of Wageningen
P.O. Box 8129
NL-6700 EV Wageningen
The Netherlands
Chapter 25

Dr. Judy Libra
Institut für Verfahrenstechnik
Technische Universität Berlin
Straße des 17. Juni 135
D-10623 Berlin
Germany
Chapter 19

Prof. Dr.-Ing. Herbert Märkl
AB Bioprozeß- und Bioverfahrenstechnik
Technische Universität Hamburg-Harburg
Denickestraße 15
D-21071 Hamburg
Germany
Chapter 26

Dr. Michael J. McInerney
Department of Botany and Microbiology
University of Oklahoma
770 Van Vleet Oval
Norman, OK 73019-0245
USA
Chapter 22

Dipl.-Ing. Hartmut Meyer
Institut für Siedlungswasserwirtschaft und
Abfalltechnik
Universität Hannover
Welfengarten 1
D-30167 Hannover
Germany
Chapter 10

Dr. Eberhard Morgenroth
Department of Environmental Science and
Engineering
Technical University of Denmark
Building 115
DK-2800 Lyngby
Denmark
Chapter 15

Dr. Volkmar Neitzel
Ruhrverband
Kornprinzenstraße 37
D-45128 Essen
Germany
Chapter 9

Dr. Peter Nisipeanu
Ruhrverband
Kornprinzenstraße 37
D-45128 Essen
Germany
Chapter 8

Prof. Dr. Ing. Norbert Rübiger
Institut für Umweltverfahrenstechnik
Universität Bremen
Postfach 330440
D-28334 Bremen
Germany
Chapter 27

Dr. Monika Reiss
Lehrstuhl für Biotechnologie
RWTH Aachen
Worringerweg 1
D-52056 Aachen
Germany
Chapter 7

Prof. Dr.-Ing. Karl-Heinz Rosenwinkel
Institut für Siedlungswasserwirtschaft und
Abfalltechnik
Universität Hannover
Welfengarten 1
D-30167 Hannover
Germany
Chapter 10

Prof. Dr. Ulrich Stottmeister
UFZ – Umweltforschungszentrum
Leipzig-Halle GmbH
Sektion Sanierungsforschung
Permoserstraße 15
D-04318 Leipzig
Germany
Chapter 12

Prof. Dr. Georg Schön
Insitut für Biologie II
Universität Freiburg
Schänzlestraße
D-79104 Freiburg
Germany
Chapter 14

Chem.-Ing. Alfred Stozek
Auf dem Loh 7
D-45289 Essen
Chapter 9

Dr. Andreas Schramm
MPI für Marine Mikrobiologie
Celsiusstraße 1
D-28359 Bremen
Germany
Chapter 5

Dr. Ralf Stüven
Institut für Allgemeine Botanik
Abteilung Mikrobiologie
Universität Hamburg
Ohnhorststraße 18
D-22609 Hamburg
Germany
Chapter 3

Dr. Judith M. Schulz
genannt Menningmann
ENVICON Kläranlagen
Postfach 100637
D-46526 Dinslaken
Germany
Chapter 17

Dr. Karl Svardal
Institut für Wassergüte und
Landschaftswasserbau
Technische Universität Wien
Karlsplatz 13/226
A-1040 Wien
Austria
Chapters 6, 23

Dr. Carin Sieker
Berliner Wasserbetriebe
Neue Judenstraße 1
Postfach 021098
D-10122 Berlin
Germany
Chapter 18

Dr. Jules B. van Lier
Department of Environmental Engineering
Agricultural University of Wageningen
P.O. Box 8129
NL-6700 EV Wageningen
The Netherlands
Chapter 25

Prof. Dr.-Ing. Peter Weiland
 Bundesforschungsanstalt für Landwirtschaft
 Braunschweig-Völkenrode (FAL)
 Institut für Technologie
 Bundesallee 50
 D-38116 Braunschweig
 Germany
Chapter 11

Dr. Jost Wingender
 Institut für Wasserchemie und
 Wassertechnologie
 Universität Duisburg
 Moritzstraße 26
 D-45476 Mülheim/Ruhr
 Germany
Chapter 4

Prof. Dr.-Ing. Udo Wiesmann
 Institut für Verfahrenstechnik
 Technische Universität Berlin
 Straße des 17. Juni 135
 D-10623 Berlin
 Germany
Chapter 19

Prof. Dr. Josef Winter
 Institut für Ingenieurbiologie und
 Biotechnologie
 des Abwassers
 Universität Karlsruhe (TH)
 Am Fasanengarten
 Postfach 6980
 D-76128 Karlsruhe
 Germany
Chapter 2

Dr. Arndt Wießner
 UFZ – Umweltforschungszentrum
 Leipzig-Halle GmbH
 Sektion Sanierungsforschung
 Permoserstraße 15
 D-04318 Leipzig
 Germany
Chapter 12

Dr. Dirk Zart
 Institut für Allgemeine Botanik
 Abteilung Mikrobiologie
 Universität Hamburg
 Ohnhorststraße 18
 D-22609 Hamburg
 Germany
Chapter 3

Prof. Dr.-Ing. Peter A. Wilderer
 Lehrstuhl für Wassergüte und
 Abfallwirtschaft
 Technische Universität München
 Am Coulombwall
 D-85748 Garching
 Germany
Chapter 15

Dr. Grietje Zeemann
 Department of Environmental Engineering
 Agricultural University of Wageningen
 P.O. Box 8129
 NL-6700 EV Wageningen
 The Netherlands
Chapter 25

Contents

Introduction	1
<i>J. Winter</i>	

I General Aspects

1 Historical Development of Wastewater Treatment Processes	5
<i>L. Hartmann</i>	
2 Bacterial Metabolism in Wastewater Treatment Systems	17
<i>C. Gallert, J. Winter</i>	
3 Nitrification and Denitrification – Microbial Fundamentals and Consequences for Application	55
<i>D. Zart, R. Stüven, E. Bock</i>	
4 Autoaggregation of Microorganisms: Flocs and Biofilms	65
<i>J. Wingender, H.-C. Flemming</i>	
5 Nucleic Acid-Based Techniques for Analyzing the Diversity, Structure, and Dynamics of Microbial Communities in Wastewater Treatment	85
<i>A. Schramm, R. Amann</i>	
6 Analytical Parameters for Monitoring of Wastewater Treatment Processes	109
<i>H. Kroiss, K. Svardal</i>	
7 Monitoring of Environmental Processes with Biosensors	125
<i>M. Reiss, W. Hartmeier</i>	
8 Laws, Statutory Orders and Directives on Waste and Wastewater Treatment	141
<i>P. Nisipeanu</i>	

II Processes of Wastewater Treatment Waste Water Sources and Composition

9 Municipal Wastewater and Sewage Sludge	161
<i>P. Koppe, A. Stozek, V. Neitzel</i>	
10 Industrial Wastewater Sources and Treatment Strategies	191
<i>K.-H. Rosenwinkel, U. Austermann-Haun, H. Meyer</i>	
11 Agricultural Waste and Wastewater Sources and Management	217
<i>P. Weiland</i>	

Aerobic Carbon, Nitrogen, and Phosphate Removal

12 Biological Processes in Wetland Systems for Wastewater Treatment	241
<i>P. Kuschik, A. Wießner, U. Stottmeister</i>	
13 Activated Sludge Process	253
<i>R. Kayser</i>	
14 Biological and Chemical Phosphorus Removal	285
<i>G. Schön, N. Jardin</i>	
15 Continuous Flow and Sequential Processes in Municipal Wastewater Treatment	321
<i>E. Morgenroth, P. A. Wilderer</i>	

- 16 Trickling Filter Systems 335
P. Baumann, B. Dorias
- 17 Submerged Fixed-Bed Reactors 349
J. Schulz genannt Menningmann
- 18 Experience with Biofilters
in Wastewater Treatment 365
C. Sieker, M. Barjenbruch
- 19 Special Aerobic Wastewater
and Sludge Treatment Processes 373
U. Wiesmann, J. Libra
- 20 Modeling of Aerobic Wastewater
Treatment Processes 417
M. Henze

Metal Ion Removal

- 21 Metal Removal by Biomass:
Physico-Chemical Elimination
Methods 431
G. Bunke, P. Götz, R. Buchholz

Anaerobic Processes

- 22 Anaerobic Metabolism
and its Regulation 455
M. McInerney
- 23 CSTR-Reactors and Contact Processes
in Industrial Wastewater Treatment 479
H. Kroiss, K. Svardal
- 24 Fixed Film Stationary Bed
and Fluidized Bed Reactors 493
H.-J. Jördening, K. Buchholz
- 25 Possibilities and Potential of Anaerobic
Wastewater Treatment Using Anaerobic
Sludge Bed (ASB) Reactors 517
*G. Lettinga, L.W. Hulshoff Pol,
J.B. van Lieer, G. Zeemann*
- 26 Modeling of Biogas Reactors 527
H. Märkl
- 27 Future Aspects –
Cleaner Production 561
N. Rübiger

Index 579

Introduction

JOSEF WINTER

Karlsruhe, Germany

Except for soil sanitation environmental biotechnology, including air pollution, waste and wastewater treatment processes, surface and ground water pollution and many other topics was subsumed under the title *Microbial Degradations* in Volume 8 of the First Edition of *Biotechnology*, Urbanization and industrialization, especially in developing countries, is still in progress with all negative effects on the environment.

Resulting from the accumulation of huge masses of polluted water in human settlements or in industry the limits of self-purification of surface waters are often exceeded, leading to anaerobiosis with all its deteriorating consequences for life. In industrialized countries central wastewater treatment plants have been developed to reduce the pollution freight before disposing the wastewater into the next surface water.

In the First Edition of *Biotechnology* different wastewater treatment processes contribute a major part to Volume 8. Furthermore, the volume is devoted to different processes of solid waste composting, drinking water biofiltration, exhaust gas purification, removal of pathogens and several other environmental processes.

Now, some ten years later, the biological background of aerobic or anaerobic wastewater treatment processes and of most of the other processes in environmental biotechnology (e.g., soil sanitation, waste gas purification, compost preparation, drinking water purification, etc.) has increased tremendously and various new and differing processes are available to protect the environment. So it is the time to describe the present state of the art of environmental biotechnological processes in a comprehensive survey.

After bringing together the most important issues that had to be covered in the Second Edition of *Biotechnology*, the editors immediately realized that wastewater treatment, solid waste management (also including the broad field of municipal solids composting or anaerobic fermentation), off-gas purification, biological soil remediation processes, potable water denitrification and purification and many other selected environmental processes were too broad a field to be summarized with significance in a single book.

For this reason Volume 11 *Environmental Processes* of the Second Edition of *Biotechnology* is divided into three volumes, the first of which, Volume 11a, is devoted to *Wastewater*

Treatment Processes. This first volume on environmental biotechnology summarizes the biological principles and the technical limits of all those wastewater treatment processes that are operated by municipalities and industry up to the present state to meet the legal limits for carbon, nitrogen, and phosphorus disposal into surface waters.

In the first part of the book the present status of general biological and engineering aspects of wastewater purification procedures is summarized. What does environmental legislation require for wastewater disposal of municipalities or industry into surface waters? What can biology contribute together with chemistry, physics and engineering to wastewater purification from its organic and inorganic pollutants? How can the purification efficiency be measured analytically, either off-line or – even more important for monitoring of continuous processes – on-line?

In the second part of the book the different processes for wastewater treatment are described in more detail and under the aspect of full-scale application. At first wastewater sources and variations of wastewater composition are outlined, followed by specific aerobic carbon, nitrogen and phosphate removal processes, metal ion removal and, last but not least, anaerobic wastewater treatment processes.

The volume includes well-known and practiced technologies, as well as new and only recently developed processes. Especially in

the field of improved wastewater purification (N and P removal processes), which is a relatively young requirement within environmental legislation, new processes or process combinations had to be developed and applied.

It is hoped that the whole range of insights into biology and technology of wastewater treatment processes have been covered by the contributions of expert authors from Europe and America. The editors are well aware on the other hand, that not every individual system offered on the market could be described. Especially in the field of carrier-supported fixed or fluidized bed technologies not every single system could be mentioned, although carrier-supported processes may be a matter of choice for future high-rate wastewater treatment, e.g., in industry. Membrane technologies were not included, since the average lifetime of membranes is generally still too short due to membrane corrosion or biofouling.

This first volume on *Environmental Processes* should give the reader basic information on the biology of the degradation of pollutants, different processes for wastewater purification and process parameters for an optimal purification. It should be regarded as a source of overview information on frequently applied full-scale wastewater treatment processes with some more details presented for certain specific applications.

Karlsruhe, March 1999

J. Winter