

Second Edition



Water,
Wastewater, and
Stormwater
Infrastructure
Management

Neil S. Grigg



Publishing



CRC Press
Taylor & Francis Group

Second Edition

Water, Wastewater, and Stormwater Infrastructure Management



CRC Press

Taylor & Francis Group

Boca Raton London New York

CRC Press is an imprint of the
Taylor & Francis Group, an **informa** business

Co-published by IWA Publishing

Alliance House, 12 Caxton Street, London SW1H 0QS, UK Tel. +44 (0)20 7654 5500, Fax +44 (0)20 7654 5555 publications@iwap.co.uk
www.iwapublishing.com

ISBN13 9781780400334

CRC Press
Taylor & Francis Group
6000 Broken Sound Parkway NW, Suite 300
Boca Raton, FL 33487-2742

© 2012 by Taylor & Francis Group, LLC
CRC Press is an imprint of Taylor & Francis Group, an Informa business

No claim to original U.S. Government works

Printed in the United States of America on acid-free paper
Version Date: 20120510

International Standard Book Number: 978-1-4398-8183-5 (Hardback)

This book contains information obtained from authentic and highly regarded sources. Reasonable efforts have been made to publish reliable data and information, but the author and publisher cannot assume responsibility for the validity of all materials or the consequences of their use. The authors and publishers have attempted to trace the copyright holders of all material reproduced in this publication and apologize to copyright holders if permission to publish in this form has not been obtained. If any copyright material has not been acknowledged please write and let us know so we may rectify in any future reprint.

Except as permitted under U.S. Copyright Law, no part of this book may be reprinted, reproduced, transmitted, or utilized in any form by any electronic, mechanical, or other means, now known or hereafter invented, including photocopying, microfilming, and recording, or in any information storage or retrieval system, without written permission from the publishers.

For permission to photocopy or use material electronically from this work, please access www.copyright.com (<http://www.copyright.com/>) or contact the Copyright Clearance Center, Inc. (CCC), 222 Rosewood Drive, Danvers, MA 01923, 978-750-8400. CCC is a not-for-profit organization that provides licenses and registration for a variety of users. For organizations that have been granted a photocopy license by the CCC, a separate system of payment has been arranged.

Trademark Notice: Product or corporate names may be trademarks or registered trademarks, and are used only for identification and explanation without intent to infringe.

Library of Congress Cataloging-in-Publication Data

Grigg, Neil S.

Water, wastewater, and stormwater infrastructure management / Neil S. Grigg. -- 2nd ed.
p. cm.

Summary: "The second edition of a bestseller, this book discusses details the latest research on management practices for water and sewer capital facilities with an emphasis on infrastructure. It explores recent advances and highlights the technique asset management, which has received international acceptance and applies across various infrastructure sectors. It covers the components of asset management systems, including computer platforms and software packages, methods for condition assessment and ratings, risk-based decision support systems, decision making protocols, triple bottom line business cases, and new options for repair, rehabilitation, and replacement of buried pipe assets"-- Provided by publisher.

Includes bibliographical references and index.

ISBN 978-1-4398-8183-5 (hardback)

1. Municipal engineering. 2. Municipal water supply. 3. Sewerage. 4. Infrastructure (Economics)--Management. I. Title.

TD159.G75 2012
628.1--dc23

2012013740

Visit the Taylor & Francis Web site at
<http://www.taylorandfrancis.com>

and the CRC Press Web site at
<http://www.crcpress.com>

Preface

Urban water services are building blocks for healthy cities, and they require complex and expensive infrastructure systems. Most of the infrastructure is out of sight and we tend to take the services for granted, but an infrastructure financing crisis looms because the systems are aging and we are behind on maintaining them.

This book aims to present clear and practical information for life-cycle management of these infrastructure systems, and it is my hope that the material will be useful to public works and utility professionals and provide a road map to valuable sources of information for all uses. Since the first edition was published in 2003, new thinking about the future of urban water infrastructure systems has emerged, and I have tried to describe it. Part of it is due to learning about what other nations are doing, and part has resulted from research and experience in the United States.

The evolution of this book begins with opportunities in the 1970s to work with the ASCE Urban Water Resources Research Program and, in particular, with Murray McPherson and Scott Tucker. In that period, my consulting partner, Dave Sellards, always kept my eye on the practical side of things as we formed Sellards & Grigg, Inc., in Denver, Colorado. As a result of those experiences, I published two books in the 1980s with John Wiley & Sons, one titled *Urban Water Infrastructure* and the other *Infrastructure Engineering and Management*.

Along the way, many other people have helped me learn about urban water infrastructure. In particular, I am indebted to Frank Blaha, who got me involved with an advisory committee of the Water Research Foundation, and Mike Woodcock of the Washington Suburban Sanitary Commission, who mentored me about managing water supply pipelines.

I thank Joe Clements, Acquisitions Editor for CRC Press, who made the publishing arrangements for this current book, and Frances Weeks of CRC Press in Boca Raton, Florida, who oversaw the production process. Both handled their duties with skill and care.

As always, I am grateful to Colorado State University for providing me with a good place to work on this research.

Neil S. Grigg
Fort Collins, Colorado

Author

Neil S. Grigg is a professor of civil and environmental engineering at Colorado State University, where he focuses on water resources and infrastructure management. At Colorado State, he has been the head of the Department of Civil and Environmental Engineering and director of the Colorado Water Resources Research Institute and Water Center. He is a graduate of the U.S. Military Academy, Auburn University, and Colorado State University and is a registered professional engineer in three states.

In addition to university work, he has been a consulting engineer and state environmental official, and he has worked on a number of government policy and advisory panels. His current research is concentrated on urban water infrastructure, especially distribution systems management. He publishes widely on topics that range across water resources and infrastructure. In addition to *Water, Wastewater, and Stormwater Infrastructure Management*, other recent books are *Water Finance: Public Responsibilities and Private Opportunities*; *Infrastructure Finance: The Business of Infrastructure for a Sustainable Future*; *Economics and Finance for Engineers and Planners*; *Total Water Management: Leadership Practices for a Sustainable Future*; *Colorado's Water: Science & Management, History & Politics*; and *The Water Manager's Handbook: A Guide to the Water Industry*.

Neil has been honored in selection for a number of important responsibilities. He is a life member of the American Society of Civil Engineers and the American Water Works Association. He is a diplomate of the American Academy of Water Resources Engineers and a charter member of the Pan American Academy of Engineering. He serves the U.S. Supreme Court as River Master of the Pecos River, and in 2011 he chaired two national flood control panels, one for the U.S. Army Corps of Engineers and the other for the National Institute of Building Sciences.

Contents

List of Figures	xi
List of Tables	xv
Preface.....	xix
Author.....	xxi
1. Urban Water Infrastructure for Healthy Cities	1
Water Supply, Wastewater, and Stormwater Systems.....	2
Managing the Infrastructure Life Cycle.....	4
Data-Centered Infrastructure Management.....	6
Elements of Infrastructure Management Systems	7
Measuring Infrastructure Integrity.....	8
Condition and Investment Needs of Urban Water Systems	10
Classification System for Infrastructure Systems and Components	11
Program Management within Organizational Units	11
Best Practices in Infrastructure Management	12
Conclusion	16
References	16
2. Managing Water Systems and Services	17
Water, Wastewater, and Stormwater Systems.....	17
Evolution of Urban Water Systems.....	18
Water Supply Infrastructure Systems	20
Configuration and Functions of Water Supply Systems	20
Water Quality and Health.....	22
Sources of Water.....	22
Peak Rate Operations of Water Supply Systems.....	23
Drinking Water Treatment	23
Transmission and Distribution System Infrastructure	25
Water Supply Statistics	30
Management Organizations for Water Supply	38
Interest Groups	39
Trends and Issues in Water Supply Systems.....	39
Wastewater Infrastructure Systems	41
Configuration and Functions of Wastewater Systems.....	41
Collection and Transmission Systems	43
Wastewater Treatment Systems	44
Reclaimed Water Systems.....	45
Wastewater Statistics	46
Management Structures.....	48

- Interest Groups 49
- Trends and Issues in Wastewater Systems 49
- Stormwater Infrastructure Systems 50
 - Configuration and Functions of Stormwater Systems..... 50
 - Stormwater Needs..... 53
 - Stormwater Planning..... 53
 - Management Structure..... 55
 - Trends and Issues in Stormwater Systems 56
- Future Water Management Issues 57
- References 58

- 3. Asset Management for Urban Water Systems 61**
 - Concept of Asset Management 62
 - Organizing Asset Management Programs 65
 - Guidance from the International Infrastructure Management Manual 67
 - Asset Management Functions..... 69
 - Coordination of Asset Management Functions..... 69
 - Planning Section 70
 - Engineering and Construction 70
 - Operations and Maintenance (O&M) 71
 - Financial Management..... 72
 - Risk Management 72
 - Information Systems and Data Management 72
 - Asset Management for Water Systems 73
 - Implementation of Asset Management for Water Systems 75
 - References 77

- 4. Capital Improvement Planning and Programming 79**
 - Planning–Programming–Budgeting Systems 79
 - Planning Process: Multistage, Rational, and Political 82
 - From Integrated Plans to Capital Improvement Programs 84
 - Capital Improvement Programs 85
 - Water Supply Capital Planning..... 86
 - Wastewater System Planning..... 87
 - Stormwater System Planning..... 88
 - Evaluation Techniques and Priority Setting..... 89
 - How to Develop a Capital Improvement Program 91
 - Example of a CIP 92
 - References 93

- 5. Engineering and Construction for the Infrastructure Life Cycle 95**
 - Stages of Design and Construction 96
 - Achieving Quality and Value in Infrastructure Projects..... 97

Project Roles.....	100
Project Delivery Methods	101
Planning for Water, Wastewater, and Stormwater Projects	103
Project Design.....	103
Management of Engineering Services	106
Construction Phase.....	111
Design Guides for Water, Wastewater, and Stormwater Systems.....	117
References	120
6. Financial Management for Urban Water Systems	123
Financial Knowledge for Water Systems Management.....	124
Deferred Investment in Water, Wastewater, and Stormwater Systems	125
Financial Tools in Utility Management	128
Field of Public Finance	128
Financial Planning.....	130
Budget Processes.....	131
Accounting and Reporting Infrastructure Condition and Needs.....	134
Basic Principles of Accounting.....	134
Government Accounting Principles.....	136
Accounting for Fixed Assets	138
Financial Statements.....	139
Audits.....	139
Triple Bottom-Line Accounting	140
Revenue Generation	140
Rate Setting	145
Water Supply Rates	145
Wastewater Rates.....	146
Stormwater Rates.....	147
Capital Financing.....	148
Tax Revenues	152
Privatization and Public-Private Partnerships.....	153
Further Guidance for Water, Wastewater, and Stormwater Finance	154
Appendix: Fort Collins Financial Data.....	154
Information Sources	154
Budget Document	154
Comprehensive Annual Financial Report.....	157
Rate Structure	165
User Charges.....	165
Plant Investment Fees for Wastewater	169
Other Fees and Charges	169
Enforcement	169
References	170

- 7. High-Performance Operation of Water Systems**..... 173
 - Operations Management as a Discipline 174
 - Elements of Operations Management..... 176
 - Water, Wastewater, and Stormwater System Operations..... 179
 - Water Supply..... 181
 - Wastewater..... 182
 - Reclaimed Water Systems..... 183
 - Stormwater Systems..... 183
 - SCADA Systems 183
 - Performance Assessment, Optimization, and Quality Control 185
 - Workforce Issues and Operators..... 190
 - Trends in Water, Wastewater, and Stormwater Operations..... 196
 - References 199

- 8. Risk Management and Disaster Preparedness** 203
 - How Risk Is Increasing 204
 - Examples of Failures..... 205
 - Risk Management Terminology..... 207
 - Natural and Human-Caused Threats to Water Systems..... 211
 - Risk and Vulnerability Assessment 214
 - Mitigation Measures 218
 - Security and Emergency Management 221
 - Lessons Learned 225
 - References 227

- 9. Maintenance and Renewal of Water Infrastructure**..... 229
 - Maintenance Management Systems..... 230
 - Maintenance and Facility Management 231
 - Benefits of Maintenance Programs..... 232
 - Preventive and Corrective Maintenance 233
 - Decision Making for Maintenance Levels..... 233
 - Maintenance of Water, Wastewater, and Stormwater Systems 234
 - Condition Assessment of Infrastructure and Equipment 240
 - Planning and Managing the Renewal of Infrastructure 243
 - Materials..... 247
 - Future Issues and Needed Research..... 248
 - References 248

- 10. Information Technology for Water Infrastructure** 251
 - IT across Organizations 252
 - IT Applications..... 255
 - Databases, Models, and Decision Support..... 256
 - Models and Decision Support..... 265
 - Models 265
 - Engineering and Planning Support 267

GIS	268
Design Platforms	270
BIM	270
Document Management	270
Design and e-Construction	271
O&M Support	271
SCADA	271
Telecommunications	271
Enterprise Systems	272
Cyber Security	274
Future IT Directions for Water Utilities	275
New Info Sources	275
Change Organization	275
Integration	275
Security	275
References	276
11. Legal and Regulatory Controls on Urban Water Systems	279
Examples of Legal Scenarios in the Infrastructure Life Cycle	280
Types of Laws and Regulations	281
Agencies and Roles	284
United States Code (U.S.C.) and Code of Federal Regulations (CFR)	285
Regulation of Water, Wastewater, and Stormwater Systems	286
Safe Drinking Water Act	287
Clean Water Act and Wastewater Regulation	289
Drainage and Flood Laws, Regulations, and Codes	291
Enforcement of Regulations	293
Financial and Service Quality Regulation	294
Politics of Regulation	295
References	295
12. Managing Infrastructure in the Water Industry	297
Management in the Public Works and Utility Environment	298
The Big Picture	300
Business Practices Affecting Infrastructure	301
Human Resources Management	302
Strategic Planning	304
Project Management	304
Risk Management and Loss Prevention	304
Decision Making	304
Program Assessment and Management Audits	305
Quality Management	305
Public Involvement, Marketing, and Customer Relationship Management	305

Management in a Government Environment..... 307
Leadership Issues for Infrastructure Managers..... 311
References 314

Appendix A: List of Acronyms 315

Appendix B: Urban Water Infrastructure Research 321

Index 325

List of Figures

Figure 1.1	The integrated urban water system.....	3
Figure 1.2	Water, wastewater, and stormwater within integrated systems.	4
Figure 1.3	Phases of life-cycle management.....	5
Figure 1.4	Data-centered infrastructure organization.....	7
Figure 1.5	Inputs to infrastructure integrity.	9
Figure 1.6	Infrastructure condition curve.	9
Figure 1.7	Levels and activities of infrastructure work.....	12
Figure 2.1	Subsystems of water supply service.....	20
Figure 2.2	Los Angeles Filter Plant.....	24
Figure 2.3	Aeration basins, Los Angeles Filter Plant.....	25
Figure 2.4	Water transmission line: 42 in. steel pipe.....	27
Figure 2.5	Water line in a tunnel: 36 in. raw-water pipe.....	27
Figure 2.6	Water line under construction.....	28
Figure 2.7	Water supply networks.....	29
Figure 2.8	Fire hydrant.....	31
Figure 2.9	Water tank for a distribution system.....	31
Figure 2.10	Investment in pipeline installation in 20 cities.....	38
Figure 2.11	Wastewater system.....	41
Figure 2.12	Lift station in Florida.....	42
Figure 2.13	Stormwater system.....	50
Figure 2.14	Pipe awaiting installation.....	51
Figure 2.15	Stormwater pipe near outfall.....	52
Figure 3.1	Data-centered management of physical assets.....	65
Figure 3.2	Asset management tasks across the utility organization.....	66
Figure 3.3	Asset management plan in the organizational planning system.....	68

Figure 3.4	Asset management steps from a USEPA (2008) best practices guide.....	74
Figure 3.5	Asset management triangle.....	76
Figure 3.6	Functional view of asset management system.	76
Figure 4.1	The planning–programming–budgeting system.....	81
Figure 4.2	The infrastructure life cycle.	81
Figure 4.3	Steps in a rational planning process with stakeholder involvement.....	82
Figure 4.4	Financial planning as part of a capital improvement process.	87
Figure 5.1	Pipe under construction.....	96
Figure 5.2	Engineer designing pipe rehabilitation projects.	105
Figure 5.3	Elements of high-quality constructed project.	111
Figure 5.4	Project management for stormwater pipeline installation.	113
Figure 5.5	Publications display at convention of American Water Works Association.	115
Figure 5.6	Canal construction using hand labor.....	119
Figure 6.1	Hierarchy of plans, programs, and capital budget.	131
Figure 6.2	Budget schedule and process.	132
Figure 6.3	Utility financial flows.....	142
Figure 7.1	Operations, maintenance, and the workforce.	174
Figure 7.2	General model of facility operations.	175
Figure 7.3	Requirements of operations management by organization level.	176
Figure 7.4	Levels of operations for water systems.	180
Figure 8.1	Buildup of risk to water utilities.	204
Figure 8.2	1989 Loma Prieta San Francisco Bay quake.	205
Figure 8.3	Flooded water treatment plant in Grand Forks, North Dakota.....	206
Figure 8.4	Elba, Alabama, pumping plant to dewater from behind a levee.....	206
Figure 8.5	Chemical storage area.	207

Figure 8.6 Utility risk management programs..... 210

Figure 8.7 Risk triangle..... 214

Figure 8.8 Risk matrix..... 215

Figure 8.9 Installation of EBMUD flexpipe..... 221

Figure 8.10 Meeting of emergency managers..... 224

Figure 9.1 Maintenance and renewal in the facility life cycle..... 230

Figure 9.2 Work tasks of a maintenance management system..... 231

Figure 9.3 Excavated water line showing a torn wrap and external corrosion..... 236

Figure 9.4 A facility condition curve compared to depreciation schedules..... 243

Figure 9.5 Demonstration of pipe bursting..... 245

Figure 9.6 Pipeline sliplining project in a high-density urban environment..... 245

Figure 10.1 Information support for infrastructure management tasks..... 256

Figure 10.2 Decision support system..... 266

Figure 11.1 Trench construction..... 282

Figure 11.2 A stormwater planning model..... 284

Figure 11.3 How lead gets into drinking water..... 288

Figure 11.4 Ozone towers at the Los Angeles Filter Plant..... 289

Figure 12.1 Customer service outlet of the Washington Suburban Sanitary Commission..... 301

Figure 12.2 Sculpture of utility workers opening a water gate..... 303

Figure 12.3 Iron triangle of water utility decisions..... 310

Figure 12.4 Memorial to Dr. Abel Wolman..... 313

List of Tables

Table 1.1	Outline of Book	8
Table 1.2	Programs and Relevant Departments	13
Table 1.3	Best Practices in Infrastructure Management	14
Table 2.1	Inventory of Pipeline in U.S. Systems	33
Table 2.2	Numbers of U.S. Community Water Systems.....	35
Table 2.3	Pipe Length in Miles (km) by Diameter and System Size	36
Table 2.4	Estimate of National Pipe Replacement Costs.....	37
Table 2.5	Number of Wastewater Treatment Facilities in 2008 by Flow Range	48
Table 3.1	Linking of Functional Management Areas with Asset Management Activities	67
Table 3.2	Coordination of Asset Management Plan	70
Table 4.1	Template for a Basic MCDA Display	90
Table 4.2	Steps in CIP Preparation.....	92
Table 5.1	Stages of Planning, Design, and Construction.....	97
Table 5.2	Main Roles in Design and Construction	100
Table 5.3	Outline for an Engineering Report for a Water, Wastewater, or Stormwater Project	104
Table 5.4	Best Practices for Design Review.....	110
Table 5.5	In-House Engineering Responsibilities.....	114
Table 6.1	Sample Water Bill from Fort Collins, Colorado	146
Table 6.2	Rates Based on Water Budget in Boulder, Colorado	146
Table 6A.1	Comparative Budget Statement	158
Table 6A.2	City of Fort Collins, Colorado, Debt Outstanding at Year End: Actual 2010 and Projected 2011 and 2012	160
Table 6A.3	Pledged Revenues Relating to Water, Wastewater, and Stormwater	162
Table 6A.4	Water Fund Bond Issues	162

Table 6A.5 Wastewater Fund: Schedule of Revenues, Expenses, and Changes in Net Assets—Actual and Budget (Non-GAAP Budgetary Basis) for the Year Ended December 31, 2010	164
Table 6A.6 Reconciliation to GAAP Basis.....	165
Table 6A.7 Proprietary Funds Statement of Net Assets, December 31, 2010.....	166
Table 6A.8 Storm Drainage Revenue Bonds.....	168
Table 6A.9 Monthly User Charges for Wastewater	168
Table 6A.10 Plant Investment Fees.....	170
Table 7.1 Five Main Functions of the Equipment and Infrastructure in Water, Wastewater, and Stormwater Systems.....	181
Table 7.2 Some SCADA Applications to Water, Wastewater, and Stormwater Systems.....	185
Table 7.3 Examples of Operational Requirements.....	194
Table 7.4 List of Skill Levels for Operations	195
Table 7.5 Courses and Training Aids at the Maryland Center	196
Table 8.1 Terminology for Risk Management	209
Table 8.2 Threats to Water Systems.....	211
Table 8.3 Classification of Human-Caused Threats	213
Table 8.4 Quantification of Risk	215
Table 8.5 Critical Support Systems and Lifelines	217
Table 8.6 Range of Risks	218
Table 8.7 Risk Mitigation Measures.....	219
Table 10.1 Application of IT in Different Units of Utilities.....	254
Table 10.2 Utility Applications in Various IT Categories	254
Table 10.3 Applications of Enterprise Software Systems.....	255
Table 10.4 Identification of Utility Assets Using Real Property, Fixed Assets, and Equipment.....	260
Table 10.5 Identification of Utility Assets Using Inventories for Water, Wastewater, and Stormwater.....	261
Table 10.6 Data Elements for Typical System Inventories	262
Table 10.7 Decision Support System	266