
URBAN WATER SUPPLY HANDBOOK

Larry W. Mays, Ph.D., P.E., P.H. Editor-in-Chief

*Department of Civil and Environmental Engineering
Arizona State University
Tempe, Arizona*

McGRAW-HILL

**New York Chicago San Francisco Lisbon London Madrid
Mexico City Milan New Delhi San Juan Seoul
Singapore Sydney Toronto**

CONTENTS

Contributors	xv
Preface	xvii
Acknowledgments	xxi

Part 1 History, Strategic Planning, and Outsourcing

Chapter 1. Urban Water Infrastructure: A Historical Perspective

Larry W. Mays

1.3

-
- 1.1 Cities and Water Knowledge / 1.3
 - 1.1.1 The Beginning / 1.3
 - 1.1.2 Contrast of Past and Present / 1.8
 - 1.2 Roman Predecessors / 1.9
 - 1.2.1 The Minoans / 1.9
 - 1.2.2 The Greeks / 1.13
 - 1.2.3 Anatolia / 1.23
 - 1.3 Roman Water Supply: Aqueducts and Aqueduct Bridges / 1.23
 - 1.3.1 Vitruvius and Frontinus / 1.27
 - 1.3.2 Aqueducts of Rome / 1.28
 - 1.3.3 Aqueduct of Nîmes (Ancient Nemausus) and the Pont du Gard / 1.33
 - 1.3.4 Aqueduct of Segovia / 1.38
 - 1.3.5 Aqueducts of Ephesus / 1.41
 - 1.3.6 Siphons / 1.48
 - 1.4 Roman Water Supply: Urban Distribution System /
 - 1.4.1 Pompeii / 1.48
 - 1.4.2 The *Castellum Divisorium* / 1.54
 - 1.4.3 Pipes and Fountains / 1.57
 - 1.5 After the Romans / 1.63
 - 1.6 References / 1.65
 - 1.7 Internet Sources / 1.66

Chapter 2. Strategic Planning Framework for Small Water Systems

Janice A. Beecher and Peter E. Shanaghan

2.1

-
- 2.1 Introduction / 2.1
 - 2.2 Strategic Planning / 2.2
 - 2.3 Planning Framework for Small Water Systems / 2.3
 - 2.3.1 Step 1: Specify Mission and Goals / 2.5
 - 2.3.2 Step 2: Assess Structure and Roles / 2.5
 - 2.3.3 Step 3: Identify Challenges and Opportunities / 2.7
 - 2.3.4 Step 4: Evaluate System Capacity / 2.8
 - 2.3.5 Step 5: Identify Strategic Options / 2.10

- 2.3.6 Step 6: Choose the Strategy / 2.11
- 2.3.7 Step 7: Implement and Monitor / 2.12
- 2.4 Conclusions / 2.13
- 2.5 Endnotes / 2.14

Chapter 3. Improving Urban Water Infrastructure through Public-Private Partnerships *Robin A. Johnson and Adrian T. Moore* **3.1**

- 3.1 Background of Water and Wastewater Partnerships / 3.2
- 3.2 Long-Term Contracts / 3.4
- 3.3 Extent of Privatization / 3.4
 - 3.3.1 Water / 3.6
 - 3.3.2 Wastewater / 3.6
 - 3.3.3 Trends / 3.6
- 3.4 Factors Causing Water and Wastewater Partnerships / 3.7
 - 3.4.1 Cost Savings / 3.7
 - 3.4.2 Infrastructure Needs / 3.9
 - 3.4.3 Unfunded Mandates / 3.10
 - 3.4.4 Improved Performance / 3.11
 - 3.4.5 Lack of Political Will / 3.11
- 3.5 Obstacles to Partnerships / 3.12
 - 3.5.1 Employee Opposition / 3.12
 - 3.5.2 Loss of Control / 3.13
- 3.6 The Selection Process / 3.14
 - 3.6.1 Performance-based Selection / 3.14
- 3.7 RFQs and RFPs / 3.15
 - 3.7.1 Contract Specifications / 3.16
- 3.8 Case Studies / 3.17
 - 3.8.1 Indianapolis / 3.17
 - 3.8.2 Milwaukee / 3.18
 - 3.8.3 Atlanta / 3.18
 - 3.8.4 Small Communities / 3.18
- 3.9 Summary / 3.19
- 3.10 References / 3.19

Chapter 4. Water-Use Management: Permit and Water-Transfer Systems *J. Wayland Eheart and Jay R. Lund* **4.1**

- 4.1 Introduction / 4.1
- 4.2 Foundations of Water-Withdrawal Regulations / 4.2
- 4.3 Water-Use Permit Systems / 4.3
 - 4.3.1 Water-Management Programs / 4.4
- 4.4 Permit Program Objectives / 4.6
 - 4.4.1 Ease of Implementation, Administration, and Enforcement / 4.6
 - 4.4.2 Equity / 4.6
 - 4.4.3 Effectiveness in Protecting Water Resources / 4.6
 - 4.4.4 Robustness and Flexibility / 4.6
 - 4.4.5 Economic Efficiency / 4.7
 - 4.4.6 Political and Legal Feasibility / 4.7
- 4.5 Permit Programs for Water-Withdrawal Control / 4.7
 - 4.5.1 Geographical and Temporal Configuration of Programs / 4.8
 - 4.5.2 Permit Definition Basis / 4.8
 - 4.5.3 Allocation Basis / 4.9
- 4.6 Technical Details of Permit Systems / 4.11
 - 4.6.1 Duration of Permits and Accommodation of Newcomers / 4.11

- 4.6.2 Averaging Periods / 4.12
- 4.6.3 Large-Scale Groundwater Restrictions / 4.12
- 4.6.4 Complexity of Surface-Water Programs Using the Flexible-Permit Basis / 4.13
- 4.6.5 Complexity of Surface-Water Programs Using Prioritized Permits / 4.15
- 4.6.6 Withdrawal versus Consumption and Accounting for Return Flows / 4.15
- 4.6.7 Interactions between Ground and Surface Waters / 4.16
- 4.7 Voluntary Water-Transfer Systems / 4.16
 - 4.7.1 Existing Examples of Water Transfers / 4.17
 - 4.7.2 Economic Theory of Water Transfers / 4.18
 - 4.7.3 Imperfect Markets / 4.19
 - 4.7.4 Third-Party and Environmental Impacts / 4.20
 - 4.7.5 Nonuser Market Players / 4.22
 - 4.7.6 Market Thinness / 4.22
 - 4.7.7 Multiple-Forum Origins of Transfers / 4.23
- 4.8 Types of Water-Transfer Arrangements / 4.23
 - 4.8.1 Permanent Transfers / 4.25
 - 4.8.2 Contingent Transfers/Dry-Year Options / 4.25
 - 4.8.3 Spot Market Transfers / 4.26
 - 4.8.4 Water Banks / 4.27
 - 4.8.5 Wheeling and Exchanges / 4.28
 - 4.8.6 Transfer of Reclaimed, Conserved, and Surplus Water / 4.29
- 4.9 Implementing Water Transfers / 4.30
 - 4.9.1 Legal Transferability of Water / 4.31
 - 4.9.2 Real versus Paper Water / 4.32
 - 4.9.3 Conveyance, Storage, and Treatment / 4.32
 - 4.9.4 Contracts and Agreements / 4.33
 - 4.9.5 Price, Transaction Costs, and Risks / 4.34
 - 4.9.6 Evaluation of Impacts to Third Parties / 4.34
 - 4.9.7 Roles for Government in Water Transfers / 4.35
- 4.10 Summary and Implications for Regulatory Programs and Water Transfers / 4.36
- 4.11 Acknowledgments / 4.38
- 4.12 References / 4.38

Part 2 Demand and Management Models

Chapter 5. Water Demand Analysis *Benedykt Dziegielewski and Eva Opitz*

5.3

-
- 5.1 Definition and Measurement of Water Use / 5.3
 - 5.2 Public-Supply Water Use / 5.5
 - 5.3 Sampling of Water Users / 5.5
 - 5.3.1 Types of Sampling Plans / 5.7
 - 5.3.2 Example of Sample Size Determination for Continuous and Proportional Data / 5.9
 - 5.4 Development of Data Sets / 5.11
 - 5.4.1 Data Scales / 5.12
 - 5.4.2 Data Arrangements / 5.13
 - 5.5 Water-Use and Service Area Data / 5.15
 - 5.5.1 Water-Use Data / 5.15
 - 5.5.2 Service Area Data / 5.17
 - 5.6 Components of Water Demand / 5.20
 - 5.6.1 Sectors of Water Users / 5.20
 - 5.6.2 Seasonal and Nonseasonal Components / 5.24
 - 5.6.3 End Uses of Water / 5.30
 - 5.7 Water-Use Relationships / 5.30
 - 5.7.1 Average Rates of Water Use / 5.32
 - 5.7.2 Modeling of Water Use / 5.33

- 5.8 Analysis of Water Savings / 5.45
 - 5.8.1 Statistical Estimation of Savings / 5.46
 - 5.8.2 Time Series Analysis of Conservation Effects / 5.49
 - 5.8.3 End-Use Accounting System / 5.50
- 5.9 Summary / 5.53
- 5.10 References / 5.54

Chapter 6. Water Pricing and Drought Management *Messele Z. Ejeta and Larry W. Mays*

6.1

- 6.1 Introduction / 6.1
- 6.2 Background of Water Conservation / 6.3
 - 6.2.1 Drought Management Options / 6.3
 - 6.2.2 Price Elasticity of Water Demand / 6.6
 - 6.2.3 Demand Models / 6.9
 - 6.2.4 The Need for a Risk-Based Approach / 6.10
 - 6.2.5 Drought Severity as Risk Indices / 6.13
- 6.3 Risk-Price Relationship / 6.15
 - 6.3.1 Developing Risk-Price Relationships / 6.15
- 6.4 Operation and Management Planning under Sustained Drought Conditions / 6.23
 - 6.4.1 Economic Aspects of Water Shortage / 6.24
 - 6.4.2 Damage Assessment / 6.26
 - 6.4.3 Operation and Management / 6.28
 - 6.4.4 The $\phi(\xi)$ Function / 6.30
 - 6.4.5 Uncertainty and Risk in Demand / 6.31
 - 6.4.6 Operation and Management Strategy / 6.34
 - 6.4.7 Risk Evaluation Procedure under Sustained Drought Conditions / 6.34
- 6.5 Summary and Conclusions / 6.40
- 6.6 References / 6.41

Chapter 7. Computer Programs for Integrated Management *Messele Z. Ejeta and Larry W. Mays*

7.1

- 7.1 Introduction / 7.1
- 7.2 Integrated Hydrosystems Management / 7.2
 - 7.2.1 Definition / 7.2
 - 7.2.2 History / 7.4
 - 7.2.3 Importance / 7.7
- 7.3 Computer Programs for Integrated Management / 7.8
 - 7.3.1 Development of Hydrosystems Simulation Computer Programs / 7.9
 - 7.3.2 Optimization Formulations / 7.11
 - 7.3.3 Interfacing Optimization and Simulation Computer Programs / 7.14
 - 7.3.4 Computer-Based Information Systems: Supervisory Control Automated Data Acquisition (SCADA) / 7.19
 - 7.3.5 Prospects of Computer Programs for Integrated Hydrosystems Management / 7.20
- 7.4 DSSs as Tools for Integrated Hydrosystems Management / 7.20
 - 7.4.1 Definition of DSSs / 7.20
 - 7.4.2 Basic Structure of DSSs / 7.20
 - 7.4.3 Examples of DSSs for Integrated Hydrosystems Management / 7.22
- 7.5 State of Practice and Prospects of Hydrosystems Computer Programs / 7.29
 - 7.5.1 State of Practice / 7.29
 - 7.5.2 Prospects / 7.30
- 7.6 Summary and Conclusions / 7.32
- 7.7 References / 7.33

Chapter 8. Regional Water Supply Planning and Capacity Expansion Models *Messele Z. Ejeta and Larry W. Mays*

8.1

-
- 8.1 Introduction / 8.1
 - 8.2 Model Formulations / 8.3
 - 8.2.1 Regional Water Supply Models / 8.3
 - 8.2.2 Capacity Expansion Model / 8.8
 - 8.3 Applications to the Rio Grande Project and the City of El Paso Water Supply / 8.13
 - 8.3.1 Overview of the Rio Grande Project / 8.13
 - 8.3.2 The City of El Paso Water Supply System / 8.15
 - 8.3.3 Static Model Application / 8.16
 - 8.3.4 Seasonal Model Application / 8.21
 - 8.3.5 Capacity Expansion Model Application / 8.24
 - 8.4 Model Results / 8.34
 - 8.4.1 Static Model / 8.34
 - 8.4.2 Seasonal Model / 8.36
 - 8.4.3 Capacity Expansion Model / 8.38
 - 8.5 References / 8.41

Part 2 Performance, Reliability, GIS, Operation, and Maintenance

Chapter 9. Performance Indicators as a Management Support Tool *Helena Alegre*

9.3

-
- 9.1 Introduction / 9.3
 - 9.2 Concept of Performance Indicator, Context Information, and Utility Information / 9.4
 - 9.3 Users, Benefits, and Scope of Application of Performance Indicators / 9.6
 - 9.4 State of the Art of Performance Assessment / 9.10
 - 9.4.1 Overview / 9.10
 - 9.4.2 Influence of the Growing Private Participation in Undertakings Management / 9.11
 - 9.4.3 Objective-Oriented Management and Benchmarking / 9.12
 - 9.4.4 Lessons Arising from the U.K. Privatization Process / 9.12
 - 9.4.5 The IWA PI System / 9.15
 - 9.4.6 The World Bank Benchmarking Toolkit / 9.16
 - 9.4.7 The Asian Development Bank Data Book / 9.17
 - 9.4.8 The Water Utility Partnership for Capacity Building in Africa / 9.18
 - 9.4.9 The Six Scandinavian Cities Group / 9.18
 - 9.4.10 The Dutch Contact Club for Water Companies / 9.20
 - 9.4.11 An Engineering Approach for Performance Assessment / 9.20
 - 9.4.12 Status of Performance Assessment in the United States / 9.21
 - 9.4.13 Other Initiatives / 9.22
 - 9.4.14 Summary of Performance Assessment Projects for Water Supply (WS) and Wastewater (WW) Services / 9.23
 - 9.5 The IWA PI System for Water Supply Services / 9.28
 - 9.5.1 Highlights of the IWA PI System / 9.28
 - 9.5.2 Listing of the IWA PIs and Guidance on Their Relative Importance / 9.28
 - 9.5.3 Data Reliability and Accuracy / 9.29
 - 9.5.4 Organization of the IWA PI Manual / 9.31
 - 9.5.5 A Partial In-depth Look into the IWA PI System / 9.36
 - 9.5.6 The SIGMA Lite Software / 9.43
 - 9.5.7 International Field Test of the IWA PI System (2000–2003) / 9.45
 - 9.6 Implementation of a PI System / 9.51
 - 9.6.1 Phases of Implementation / 9.51
 - 9.6.2 Definition of the Strategic Performance Assessment Policy / 9.51

- 9.6.3 Establishment of the PI System / 9.53
- 9.6.4 Data Collection, Validation, and Input / 9.55
- 9.6.5 PI Assessment and Global Reporting / 9.55
- 9.6.6 Results Interpretation / 9.55
- 9.6.7 Definition and Implementation of Improvement Measures / 9.56
- 9.7 Example of the Use of SIGMA Lite for Data Input and Indicators Assessment / 9.56
 - 9.7.1 Scope of the Example / 9.56
 - 9.7.2 Starting to Use SIGMA Lite / 9.57
 - 9.7.3 Context Information / 9.58
 - 9.7.4 PI Selection and Data Input / 9.58
 - 9.7.5 PI Assessment and Reporting / 9.58
- 9.8 Example of the Use of the IWA PI System for Water Losses Control / 9.66
 - 9.8.1 Scope of the Example / 9.66
 - 9.8.2 Objective Definition and Form of Use of the Indicators / 9.66
 - 9.8.3 Appointment of the PI Team and Definition of the Reference PI System / 9.66
 - 9.8.4 Selection of the Indicators / 9.66
 - 9.8.5 Assessment of the Water Balance / 9.68
 - 9.8.6 Assessment of the Indicators / 9.71
 - 9.8.7 Results Interpretation / 9.72
- 9.9 Final Remarks / 9.73
- 9.10 Acknowledgments / 9.74
- 9.11 References / 9.74
- 9.12 Endnotes / 9.76

Chapter 10. Reliability and Availability Analysis of Water Distribution Systems *Kevin Lansey, Larry W. Mays, and Y. K. Tung*

10.1

- 10.1 Failure Modes for Water Distribution Systems / 10.1
 - 10.1.1 Distribution Repair Definitions / 10.2
 - 10.1.2 Failure Modes / 10.4
 - 10.1.3 Reliability Indices / 10.6
- 10.2 Component (Mechanical) Reliability Analysis / 10.7
 - 10.2.1 Failure Density, Failure Rate, and Mean Time to Failure / 10.8
 - 10.2.2 Availability and Unavailability / 10.12
- 10.3 Methodology for Reliability and Availability Analysis for Water Distribution Networks / 10.14
 - 10.3.1 Reliability of a System / 10.14
 - 10.3.2 Methodology / 10.16
 - 10.3.3 Application of Methodology / 10.22
- 10.4 Other Approaches to Assessment of Reliability / 10.30
- 10.5 Reliability-based Design Optimization Models / 10.34
 - 10.5.1 Framework for Reliability-based Design Framework / 10.34
 - 10.5.2 Reliability-based Optimization Model for Operation Considering Uncertainties of Water Quality / 10.34
- 10.6 References / 10.37

Chapter 11. Geographic Information Systems Applied to Urban Water Supply Systems *Gonzalo López Patiño and Francisco Javier Martínez Solano*

11.1

- 11.1 Introduction / 11.1
- 11.2 Overview of Geographic Information Systems / 11.2
 - 11.2.1 Definition of a Geographic Information System / 11.2
 - 11.2.2 Spatial Data Representations / 11.3
 - 11.2.3 Structures of the Geographic Databases / 11.7
 - 11.2.4 Topologies / 11.9

- 11.3 The Use of GIS in Water Supply Systems: General Overview / 11.11
- 11.4 Planning, Design, and Project / 11.13
 - 11.4.1 Network Layout / 11.14
 - 11.4.2 Demand Pattern Prediction with the Help of a GIS / 11.14
 - 11.4.3 Projects / 11.16
- 11.5 Water Supply Network Operation / 11.17
 - 11.5.1 Remote Control and Telemetry / 11.18
 - 11.5.2 Mathematical Model Update / 11.19
 - 11.5.3 Network Management / 11.19
 - 11.5.4 Performance Indicators / 11.21
 - 11.5.5 System Maintenance and Rehabilitation / 11.21
- 11.6 Future Trends in the Development of the GIS / 11.23
- 11.7 References / 11.25.

Chapter 12. Optimal Operation of Water Systems *Fred E. Goldman, A. Burcu Altan Sakarya, and Larry W. Mays*

12.1

- 12.1 Introduction / 12.1
 - 12.1.1 Background / 12.1
 - 12.1.2 Previous Models for Water Distribution System Optimization / 12.3
- 12.2 Optimal Pump Operation—Mathematical Programming Approach / 12.4
 - 12.2.1 Model Formulation / 12.4
 - 12.2.2 Solution Methodology—Mathematical Programming Approach / 12.7
 - 12.2.3 North Marin Water District / 12.10
 - 12.2.4 Summary and Conclusions—Mathematical Programming Approach / 12.16
- 12.3 Optimal Pump Operation—Simulated Annealing Approach / 12.17
 - 12.3.1 Model Formulation / 12.17
 - 12.3.2 Solution Methodology—Simulated Annealing Approach / 12.17
 - 12.3.3 Applications—Simulated Annealing Approach / 12.22
 - 12.3.4 Summary and Conclusions—Simulated Annealing Approach / 12.29
- 12.4 Optimal Operation of Chlorine Booster Stations / 12.30
 - 12.4.1 Model Formulation / 12.30
 - 12.4.2 Application / 12.31
 - 12.4.3 Summary and Conclusions—Chlorine Booster Station Operation / 12.33
- 12.5 Challenges for the Future / 12.34
- 12.6 References / 12.35

Chapter 13. Optimal Maintenance, Rehabilitation, Replacement Scheduling *Caty Werey*

13.1

- 13.1 Introduction / 13.1
- 13.2 What Is a Planning Process for Renewal? / 13.1
- 13.3 Optimization of the Renewal Date / 13.2
- 13.4 A Little Study Network / 13.3
- 13.5 The RENCANA Model / 13.4
 - 13.5.1 Valuation of the Decision Tree / 13.5
- 13.6 Results Given by the Model / 13.7
 - 13.6.1 On the Example of Three Periods / 13.7
 - 13.6.2 On the Little Study Network / 13.7
- 13.7 Consideration of the Hydraulic Function of the Pipe in the Network / 13.10
- 13.8 Cost Valuation / 13.12
- 13.9 Testing on Real Data from Water Networks / 13.13
 - 13.9.1 Example 1: Urban Network / 13.13
 - 13.9.2 Example 2: Rural Network / 13.13
- 13.10 Conclusion / 13.17
- 13.11 References / 13.20

Chapter 14. Comparing Microbial and DBP Risk Tradeoffs in Drinking Water: Application of the CRFM *Robert M. Clark and Glenn Rice* **14.1**

- 14.1 Introduction / 14.1
- 14.2 The CRFM Concept / 14.2
- 14.3 Application of the CRFM to Water Supply / 14.3
 - 14.3.1 Outcome Measures / 14.5
 - 14.3.2 The QALY Concept / 14.6
- 14.4 Water Treatment Risk Tradeoff Example / 14.8
 - 14.4.1 Treatment Assumptions / 14.8
 - 14.4.2 DBP Risk Assumptions / 14.10
 - 14.4.3 Microbial Risk Assumptions / 14.10
 - 14.4.4 Cost Assumptions / 14.11
 - 14.4.5 Response Addition Model / 14.11
 - 14.4.6 Application of QALY Concept / 14.12
- 14.5 Summary and Conclusions / 14.13
- 14.6 Acknowledgments / 14.15
- 14.7 References / 14.15

Part 4 Case Studies

Chapter 15. Adaptive Management for Water Supply Planning: Sustaining Mexico City's Water Supply *Richard L. Skaggs, Lance W. Vail, and Steve Shankle* **15.3**

- 15.1 Introduction / 15.3
- 15.2 Adaptive Management / 15.4
 - 15.2.1 Plan / 15.5
 - 15.2.2 Act / 15.6
 - 15.2.3 Monitor / 15.6
 - 15.2.4 Evaluate / 15.7
- 15.3 Essential Elements for Application of Adaptive Management to Water Supply Planning / 15.7
 - 15.3.1 Economics Based / 15.8
 - 15.3.2 Robustness / 15.8
 - 15.3.3 Value of Information / 15.9
- 15.4 Case Study / 15.11
 - 15.4.1 Mexico City Water Challenge / 15.11
 - 15.4.2 The Problem / 15.12
 - 15.4.3 Problem Assessment / 15.13
- 15.5 Aquifer Enhancement through Wastewater Treatment and Injection / 15.17
- 15.6 Key Results / 15.20
 - 15.6.1 Economics Based / 15.20
 - 15.6.2 Robustness / 15.21
 - 15.6.3 Experiment / 15.22
 - 15.6.4 Value of Information / 15.23
- 15.7 Summary and Conclusions / 15.23
- 15.8 References / 15.24

Chapter 16. Water Infrastructure Management: An Overview of European Models and Databases *Patrick Eisenbeis, Pascal Le Gauffre, and Sveinung Saegrov* **16.1**

- 16.1 Introduction: Practices and Expectations in European Water Utilities / 16.2
- 16.2 Models for Failure Analysis, and Failure and/or Rehabilitation Forecasting / 16.3

- 16.2.1 Principles / 16.4
- 16.2.2 Requirements on Databases / 16.9
- 16.3 Availability and Management of Data: Some Case Studies / 16.12
 - 16.3.1 Some Case Studies Concerning European Cities / 16.12
 - 16.3.2 Improving Databases: A Need to Improve Failure Analysis and Forecasting / 16.14
- 16.4 Conclusion: Ongoing Research and Requirements on Urban Databases / 16.18
- 16.5 Acknowledgments / 16.19
- 16.6 References / 16.19

Chapter 17. Israel: Urban Water Infrastructure in the Desert **Hendrik J. Bruins**

17.1

- 17.1 Introduction / 17.1
- 17.2 Geography and Climate of Israel / 17.4
- 17.3 Aridity, Water Resources, and the Rainwater-Harvesting Civilizations in the Negev Desert in Antiquity / 17.5
- 17.4 Water Resources Developments in Israel in the Twentieth Century / 17.9
- 17.5 Urban Water Infrastructure in the Negev Desert / 17.14
- 17.6 Summarizing Comments and Conclusions / 17.19
- 17.7 Acknowledgments / 17.20
- 17.8 References / 17.20

Chapter 18. Using GIS and Hydraulic Modeling to Evaluate Susceptibility of Water Distribution Systems to Intrusions: A Case Study **Trevor R. Lindley and Steven G. Buchberger**

18.1

- 18.1 Introduction / 18.1
- 18.2 GIS and Hydraulic Modeling / 18.2
- 18.3 Data Needs Assessment / 18.5
- 18.4 Spatial Refinement of the Hydraulic Model / 18.7
- 18.5 Main Break and Structural Assessment / 18.8
- 18.6 Pressure Modeling and Pressure Susceptibility / 18.11
- 18.7 Contaminant Source Analysis / 18.14
- 18.8 Colocation of Susceptibility Conditions / 18.16
- 18.9 Sensitive Population Analysis / 18.16
- 18.10 Discussion / 18.20
- 18.11 Conclusion / 18.21
- 18.12 References / 18.21

Part 5 Security of Urban Water Supply Systems

Chapter 19. Protecting the Nation's Critical Infrastructure: The Vulnerability of U.S. Water Supply Systems **Robert M. Clark and Rolf A. Deininger**

19.3

- 19.1 Introduction / 19.3
- 19.2 Characteristics of Water Supply Systems in the United States / 19.4
- 19.3 Potential for Contamination of Water Supplies / 19.7
- 19.4 Countermeasures / 19.8
 - 19.4.1 Physical Countermeasures / 19.9
 - 19.4.2 Chemical Countermeasures / 19.10
- 19.5 Persistent Microbial Contaminants: The Rugose Variant / 19.10
 - 19.5.1 Chlorine Inactivation / 19.11

- 19.6 Contaminant Propagation in Drinking Water Systems / 19.11
- 19.7 Illness Propagation in a Water Distribution System / 19.12
- 19.8 Conclusions / 19.14
- 19.9 Notes / 19.15
- 19.10 References / 19.15

Chapter 20. Security Analysis and Response for Water Utilities
Nicholas L. Burns, Christine A. Cooper, David A. Dobbins,
Jessica C. Edwards, and Les K. Lampe

20.1

-
- 20.1 Overview / 20.1
 - 20.1.1 Hazard Assessment / 20.2
 - 20.1.2 Vulnerability Assessment / 20.2
 - 20.1.3 Mitigation / 20.2
 - 20.1.4 Development of a Response Plan / 20.3
 - 20.1.5 Crisis Communications / 20.3
 - 20.1.6 Summary / 20.3
 - 20.2 Hazard Assessment / 20.4
 - 20.2.1 Who Poses a Threat? / 20.5
 - 20.2.2 Types of Threats / 20.6
 - 20.3 Vulnerability Assessment / 20.10
 - 20.3.1 Step 1: Identify Major System Components / 20.10
 - 20.3.2 Step 2: Determine the Effects of Probable Disaster Hazards on System Components / 20.10
 - 20.3.3 Step 3: Establish Performance Goals and Acceptable Levels of Service for the System / 20.11
 - 20.3.4 Step 4: Identify Critical Components / 20.11
 - 20.3.5 Critical Review of Existing Security Systems / 20.12
 - 20.4 Mitigation / 20.12
 - 20.4.1 Mitigation at the Source / 20.12
 - 20.4.2 Preventing Access to Facilities / 20.12
 - 20.4.3 Distribution System Issues / 20.13
 - 20.4.4 Staff Role in Preventing Terrorism / 20.13
 - 20.5 Response Planning for Public Drinking Water Systems / 20.14
 - 20.5.1 Define Emergency Status / 20.15
 - 20.5.2 Developing an Emergency Response Plan / 20.16
 - 20.5.3 Threat Management / 20.19
 - 20.6 Crisis Communication / 20.20
 - 20.6.1 Preparing for a Crisis / 20.21
 - 20.7 References / 20.23

Index follows Chapter 20