

Chow's Handbook of Applied Hydrology

About the Author

Vijay P. Singh, Ph.D., D.Sc., D. Eng. (Hon.), Ph.D. (Hon.), D. Sc. (Hon.), P.E., P.H., Hon. D. WRE, Academician (GFA), is a Distinguished Professor and Caroline & William N. Lehrer Distinguished Chair in Water Engineering in the Department of Biological and Agricultural Engineering and Zachry Department of Civil Engineering at Texas A&M University. He holds a B.Tech degree from U.P. University of Agriculture and Technology, a Master's Degree from the University of Guelph, a Ph.D. from Colorado State University, and a D.Sc. from the University of the Witwatersrand. One of today's leading experts in the field of hydrology, Dr. Singh specializes in surface water hydrology, groundwater hydrology, hydraulics, irrigation engineering, environmental quality, and water resources. He has published 25 books and has edited over 58 books, and has published hundreds of journal articles. He has been the Editor-in-Chief of the Journal of Hydrologic Engineering, ASCE; is currently serving as Editor-in-Chief of Open Agriculture, and Journal of Agricultural research, and Journal of Groundwater Research and is on the editorial boards of numerous journals. He is also serving as Editor-in-Chief of Water Science and Technology Book Series as well as World Water Resources Book series. He has received more than 75 national and international awards.

Chow's Handbook of Applied Hydrology

VIJAY P. SINGH

Second Edition



New York Chicago San Francisco Athens London
Madrid Mexico City Milan New Delhi
Singapore Sydney Toronto

Cataloging-in-Publication Data is on file with the Library of Congress.
McGraw-Hill Education books are available at special quantity discounts to use as premiums and sales promotions, or for use in corporate training programs. To contact a representative please visit the Contact Us page at www.mhprofessional.com.

Chow's Handbook of Applied Hydrology, Second Edition

Copyright ©2016 by McGraw-Hill Education. All rights reserved. Printed in the United States of America.
Except as permitted under the United States Copyright Act of 1976, no part of this publication may be reproduced or distributed in any form or by any means, or stored in a data base or retrieval system, without the prior written permission of the publisher.

1 2 3 4 5 6 7 8 9 DOW 21 20 19 18 17 16

ISBN 978-0-07-183509-1
MHID 0-0-7183509-1

The pages within this book were printed on acid-free paper.

Sponsoring Editor
Lauren Poplawski

Copy Editor
Cenveo® Publisher Services

Editorial Supervisor
Donna M. Martone

Proofreader
Cenveo® Publisher Services

Acquisitions Coordinator
Lauren Rogers

Indexer
Ariel O. Tuplano

Project Manager
Raghavi Khullar, Cenveo®
Publisher Services

Production Supervisor
Pamela A. Pelton

Composition Art Director, Cover
Jeff Weeks

Information contained in this work has been obtained by McGraw-Hill Education from sources believed to be reliable. However, neither McGraw-Hill Education nor its authors guarantee the accuracy or completeness of any information published herein, and neither McGraw-Hill Education nor its authors shall be responsible for any errors, omissions, or damages arising out of use of this information. This work is published with the understanding that McGraw-Hill Education and its authors are supplying information but are not attempting to render engineering or other professional services. If such services are required, the assistance of an appropriate professional should be sought.

Contents in Brief

Part 1	Fundamentals	1.1
Part 2	Data Collection and Processing	4.1
Part 3	Methods	12.1
Part 4	Hydrologic Processes and Modeling	37.1
Part 5	Sediment and Pollutant Transport	63.1
Part 6	Hydrometeorologic and Hydrologic Extremes	73.1
Part 7	Systems Hydrology	81.1
Part 8	Hydrology of Large Riverand Lake Basins	93.1
Part 9	Applications and Design	127.1
Part 10	Future.....	151.1

For online supplements and color versions of images, please go to [www.mhprofessional.com/
handbookofappliedhydrology](http://www.mhprofessional.com/handbookofappliedhydrology)

Contents

Contributors xxxiii
International Advisory Board xlvi
Practitioner Advisory Board xlvi

Part 1. Fundamentals	1-1
Chapter 1. The Hydrologic Cycle.....	1-3
1.1 Characteristics of Water	1-3
1.2 Definition of Hydrology.....	1-4
1.3 Hydrologic Cycle	1-4
1.4 Components of the Hydrologic Cycle	1-5
1.5 Schematic Representation of the Hydrologic Cycle	1-5
1.6 Scales in Hydrologic Cycle	1-6
1.7 Impact of Climate Change on the Hydrologic cycle	1-6
1.8 Influence of Human Activities and Land Use Changes on Hydrologic Cycle	1-6
1.9 Relation between Hydrologic Cycle and Carbon and Nitrogen Cycles	1-7
References	1-9
Chapter 2. Watersheds, River Basins, and Land Use	2-1
2.1 Introduction	2-1
2.2 Components of Watersheds	2-1
2.3 Delineation of A Watershed	2-4
2.4 Watershed Hydrological Processes	2-4
2.5 Characteristics of a Watershed That Impact on Hydrological Processes.....	2-4
2.6 River Basin.....	2-6
2.7 River Basin Management	2-6
2.8 Major River Basins in the World	2-7
2.9 Land Use.....	2-7
2.10 Closing Remarks.....	2-8
References	2-8
Chapter 3. Water Balance	3-1
3.1 Introduction	3-1
3.2 Hydrologic Fluxes	3-1
3.3 Water on The Earth	3-1
3.4 Water Balance Modeling	3-4
3.5 Natural and Anthropogenic Effects on the Water Balance	3-7
3.6 Conclusions.....	3-9
References	3-9
PART 2. Data Collection and Processing.....	4.1
Chapter 4. Hydrometeors and Quantitative Precipitation Estimation	4-3
4.1 Introduction	4-3
4.2 Types of Hydrometeorological Data	4-3
4.3 Remote Sensing of Precipitation	4-3
4.4 Hydrometeorological Data Processing.....	4-4
4.5 Hydrometeorological Data Quality Assurance and Control	4-5
4.6 Quantitative Precipitation Estimate Data Use, Archiving, and Accessibility....	4-6
Chapter 5. Streamflow Data	5-1
5.1 Streamflow	5-1
5.2 Types of Streamflow Data.....	5-1

5.3 Streamgage Operation	5-1
5.4 Quality Assurance of Streamgage Data	5-6
5.5 Derived Streamflow Uncertainty	5-6
References	5-7
Chapter 6. Streamflow Ratings	6-1
6.1 Introduction	6-1
6.2 Rating Controls	6-1
6.3 Simple Ratings	6-4
6.4 Complex Ratings	6-6
6.5 Slope Ratings	6-8
6.6 Rate of Change of Stage Methods	6-8
6.7 Dynamic-Flow Model Methods	6-10
6.8 Index-Velocity Method	6-10
6.9 Shifting-Control Method for Dealing with Rating Complexities	6-11
6.10 Uncertainty in Ratings	6-13
References	6-13
Chapter 7. Hydrologic Information Systems	7-1
7.1 Introduction	7-1
7.2 Hydrologic Data Management	7-1
7.3 Service-Oriented Architectures for Integrating Distributed Hydrologic Data and Models	7-2
7.4 The CUAHSI Hydrologic Information System as an Example HIS	7-3
7.5 HydroShare as a Next-Generation HIS Software	7-5
7.6 Conclusion	7-8
References	7-8
Chapter 8. Remote Sensing Techniques and Data Assimilation for Hydrologic Modeling	8-1
8.1 Introduction	8-1
8.2 Remote Sensing Theory	8-1
8.3 Remote Sensing in Hydrological Sciences: A Historical Perspective	8-1
8.4 Remote Sensing: Methods and Techniques	8-2
8.5 Data Assimilation: Theory	8-3
8.6 Summary	8-4
References	8-4
Chapter 9. Geographic Information Systems	9-1
9.1 Introduction	9-1
9.2 Basic Principles of GIS	9-1
9.3 Data Sources and Characteristics	9-2
9.4 Representation of Model Inputs	9-5
9.5 Model/GIS Interfaces	9-7
9.6 Current Status and Future Directions	9-7
References	9-8
Chapter 10. Design of Hydrologic Networks	10-1
10.1 Introduction	10-1
10.2 Hydrologic Networks	10-1
10.3 Necessity of Hydrologic Network	10-1
10.4 Impact of Hydrologic Network Density on Streamflow Estimates	10-2
10.5 Design Considerations	10-2
10.6 Design of Hydrologic Networks: Methodologies	10-2
10.7 Conclusion	10-4
References	10-4
Part 3. Methods	11-1
Chapter 11. Artificial Neural Networks	11-3
11.1 Introduction	11-3
11.2 Historical Development	11-3
11.3 Artificial Neural Networks	11-4
11.4 ANN Training and Testing	11-4
11.5 Drawbacks of ANN Technique	11-5
11.6 Shortcomings in ANN Modeling	11-5

11.7 Future Direction	11-6
References	11-6
Chapter 12. Fuzzy Logic.....	12-1
12.1 Fuzzy Logic Basics.....	12-1
12.2 Function of Fuzzy Numbers	12-2
12.3 Fuzzy Rule-Based Modeling (Fuzzy Inference).....	12-3
Acknowledgement.....	12-5
References	12-5
Chapter 13. Evolutionary Computing: Genetic Algorithms	13-1
13.1 Introduction.....	13-1
13.2 Evolutionary Computing in Hydrology: An Overview	13-1
13.3 Genetic Algorithms.....	13-2
13.4 GA Applications in Hydrology.....	13-3
13.5 Conclusion and Future Directions	13-3
References	13-3
Chapter 14. Relevance Vector Machine	14-1
14.1 Introduction.....	14-1
14.2 Background	14-1
14.3 Mathematical formulation.....	14-2
14.4 Application of RVM.....	14-3
14.5 Examples from Hydrology and Future Scope.....	14-4
14.6 Miscellaneous Topics	14-5
References	14-6
Chapter 15. Harmonic Analysis and Wavelets.....	15-1
15.1 Introduction.....	15-1
15.2 The Continuous Wavelet Transform	15-1
15.3 Discrete Time Wavelet Transform and Multiresolution Analysis.....	15-3
15.4 Signal Energy Repartition in the Wavelet Frame.....	15-3
15.5 Wavelet Analysis of the Time-scale Relationship Between Two Signals.....	15-4
15.6 Wavelet Cross Spectrum and Coherence	15-4
15.7 Applications of Wavelet Transforms in Hydrology and Earth Sciences.....	15-5
15.8 Perspectives	15-5
References	15-5
Chapter 16. Outlier Analysis and Infilling of Missing Records in Hydrologic Data.....	16-1
16.1 Introduction	16-1
16.2 Concepts and Methods for Outliers Analysis	16-2
16.3 Concepts and Methods for Handling Missing Records	16-3
16.4 Discussion and Concluding Remarks on Methods for Outliers and Infilling of Missing Records	16-5
16.5 Future Research Directions	16-6
References	16-6
Chapter 17. Linear and Nonlinear Regression	17-1
17.1 Linear and Nonlinear Regression	17-1
17.2 Measures for Goodness of Fit	17-4
17.3 Multiple Linear Regression	17-5
17.4 Nonlinear Regression.....	17-6
References	17-9
Chapter 18. Time Series Analysis and Models.....	18-1
18.1 Introduction	18-1
18.2 Properties of Hydrological Time Series	18-1
18.3 Time-Series Modeling	18-2
18.4 Modeling of Continuous Time Processes.....	18-2
18.5 Univariate Modeling	18-2
18.6 Univariate Periodic Modeling	18-4
18.7 Multivariate Modeling	18-6
18.8 Disaggregation Models.....	18-7
18.9 Nonparametric Models	18-7
18.10 Stochastic Simulation, Forecasting, and Uncertainty	18-8

18.11 Conceptual Stochastic Modeling	18-8
18.12 Final Remarks and Future Challenges	18-9
References	18-9
Chapter 19. Statistical Detection of Nonstationarity: Issues and Needs.....	
19.1 Introduction	19-1
19.2 Exploratory Methods for Detection of Change	19-2
19.3 Statistical Exploration of Nonstationarity.....	19-2
19.4 Effect of Nonconstant Error Variation.....	19-3
19.5 Effect of <i>A Priori</i> Filtering of Time Series	19-4
19.6 Distribution of a Breakpoint	19-4
19.7 Conclusions.....	19-5
Chapter 20. Spatial Analysis and Geostatistical Methods.....	
20.1 Introduction	20-1
20.2 Data Types and Methods	20-1
20.3 Spatial analysis	20-1
20.4 Heterogeneous Field Estimation and Simulation	20-3
20.5 Summary	20-7
Acknowledgments	20-7
References	20-7
Chapter 21. Frequency Distributions	
21.1 Introduction	21-1
21.2 Discrete Frequency Distributions.....	21-1
21.3 Classification of Continuous Frequency Distributions.....	21-2
21.4 Continuous Frequency Distributions	21-2
21.5 Concluding Remarks	21-9
References	21-10
Chapter 22. Calibration, Parameter Estimation, Uncertainty, Data Assimilation, Sensitivity Analysis, and Validation.....	
22.1 Introduction	22-1
22.2 Parameter Uncertainty	22-1
22.3 Parameter Estimation	22-3
22.4 Data Assimilation	22-5
22.5 Sensitivity Analysis.....	22-10
22.6 Validation Techniques	22-11
References	22-15
Chapter 23. Bayesian Methods	
23.1 Introduction	23-1
23.2 The Bayesian Inference Framework.....	23-1
23.3 Computational Methods.....	23-4
23.4 Diagnostics to Scrutinize Model Assumptions.....	23-6
23.5 Applications in Hydrology	23-7
23.6 Conclusions.....	23-9
Acknowledgments	23-9
References	23-9
Chapter 24. Optimization Approaches for Integrated Water Resources Management.....	
24.1 Introduction	24-1
24.2 Trends.....	24-2
24.3 Challenges and Research Gaps	24-4
24.4 Conclusions.....	24-5
24.5 Acknowledgments	24-5
24.6 Appendix: Literature Trend Analysis.....	24-5
References	24-5
Chapter 25. Nonparametric Methods	
Introduction	25-1
25.1 Definitions.....	25-1
25.2 Methods.....	25-2
25.3 Applications	25-3
25.4 Discussion	25-4
References	25-5

Chapter 26. Predictive Uncertainty Assessment and Decision Making	26-1
26.1 Introduction	26-1
26.2 Forecasting in Hydrology	26-1
26.3 Motivations for Converting Deterministic to Stochastic Prediction	26-1
26.4 Predictive Uncertainty.....	26-2
26.5 Techniques Aimed at Assessing Predictive Uncertainty	26-4
26.6 Verification of the Estimated Predictive Density.....	26-9
26.7 Major Reasons Undermining the Operational use of Predictive Uncertainty	26-9
26.8 Examples of Proper use of Predictive Uncertainty to Improve Decisions	26-13
References	26-15
Chapter 27. Risk-Reliability Analysis.....	27-1
27.1 Introduction	27-1
27.2 Measures of Reliability	27-1
27.3 Performance Function and Reliability Index	27-2
27.4 Direct Integration Method	27-2
27.5 First-Order Second-Moment Reliability Methods.....	27-3
27.6 Time-Dependent (Dynamic) Reliability Models	27-5
27.7 Time-to-Failure Analysis	27-5
27.8 Monte Carlo Simulation	27-6
References	27-9
Chapter 28. Scaling And Fractals	28-1
28.1 Introduction	28-1
28.2 Scale-Invariant Sets and Functions	28-1
28.3 Some Properties of <i>H</i> - <i>SSS</i> / Processes and <i>MF</i> Cascades	28-2
28.4 Inference of Scaling for Stationary Multifractal Measures.....	28-4
28.5 Processes with Limited Scale Invariance	28-4
28.6 Conclusions.....	28-5
Acknowledgments	28-5
References	28-5
Chapter 29. Nonlinear Dynamics and Chaos.....	29-1
29.1 Introduction	29-1
29.2 Chaos Theory: A Brief History	29-2
29.3 Chaos Concepts and Identification Methods	29-2
29.4 Issues in Chaos Identification and Prediction	29-5
29.5 Hydrologic Applications	29-7
29.6 Final Remarks.....	29-7
Acknowledgments	29-8
References	29-8
Chapter 30. Copula Modeling in Hydrologic Frequency Analysis... .	30-1
30.1 Introduction	30-1
30.2 Description of Copula Models.....	30-1
30.3 Overview of Model Selection	30-2
30.4 Multivariate Quantile and Return Period.....	30-5
30.5 An illustration: the Fraser River at Hope	30-5
30.6 Extensions.....	30-7
30.7 Resources and Further Specific References.....	30-8
Acknowledgments	30-9
References	30-9
Chapter 31. Entropy Theory.....	31-1
31.1 Origin	31-1
31.2 Definition	31-1
31.3 Forms of Entropy	31-2
31.4 Directional Information Transfer Index	31-3
31.5 Entropy under Transformation of Variables	31-3
31.6 Informational Correlation Coefficient.....	31-3
31.7 Total Correlation	31-3
31.8 Theory of Entropy	31-4
31.9 Methodology for Application	31-4
31.10 Hydrologic Modeling Using Entropy Theory	31-7
References	31-8

Chapter 32. Entropy Production Extremum Principles	32-1
32.1 Introduction	32-1
32.2 Background and Review	32-1
32.3 Maximum Entropy Analysis	32-4
32.4 Review of Applications in Hydrology and Hydraulics	32-5
32.5 Closing Remarks	32-5
References	32-5
Chapter 33. Data-Based Mechanistic Modeling	33-1
33.1 Introduction	33-1
33.2 The Main Stages of DBM modeling	33-2
33.3 Linear DBM Models	33-3
33.4 Time Variable and State-Dependent Parameter Models.....	33-6
33.5 Hypothetico-Inductive DBM Modeling	33-7
33.6 DBM Emulation Modeling of High-Order Simulation Models	33-8
33.7 Conclusion.....	33-11
Reference	33-11
Chapter 34. Decomposition Methods	34-1
34.1 Introduction: Adomian's Decompositions Method.....	34-1
34.2 Regional Flow in an Unconfined Aquifer	34-2
34.3 Propagation of Nonlinear Kinematic Flood Waves in Rivers	34-2
34.4 Nonlinear Infiltration in Unsaturated Soils	34-4
34.5 Summary and Conclusions.....	34-4
References	34-5
Chapter 35. Network Theory	35-1
35.1 Introduction	35-1
35.2 Network Theory: Concept and History	35-2
35.3 Network Types.....	35-3
35.4 Network Measures	35-4
35.5 Applications in Hydrology	35-6
35.6 Closing Remarks	35-8
Acknowledgments	35-8
References	35-8
Chapter 36. Hydroeconomic Analysis	36-1
36.1 Introduction	36-1
36.2 Estimating the Economic Value of Water	36-1
36.3 Water Demand Functions	36-2
36.4 Considerations in the Design of Hydroeconomic Analysis Studies	36-3
36.5 Applications and Implementation of Hydroeconomic Analysis for Management and Decision Support	36-5
36.6 Discussion of Challenges, Limitations, and Future Directions	36-6
36.7 Conclusions.....	36-7
References	36-7
Part 4. Hydrologic Processes and Modeling	37-1
Chapter 37. Weather and Climate.....	37-3
37.1 Introduction	37-3
37.2 Hydrologic Engineering and Intersection with Weather and Climate	37-3
37.3 Weather	37-5
37.4 Observing Weather.....	37-7
37.5 Climate	37-7
37.6 Climate Change	37-8
References	37-10
Chapter 38. Hydroclimatology: Global Warming and Climate Change	38-1
38.1 Introduction: The Ambiguity of Climate	38-1
38.2 Natural and Human Influences on Present-Day Climate.....	38-1
38.3 Impacts of Climate Change on the Hydrological Cycle in the twentieth and Twenty-First Centuries.....	38-2
38.4 Global Climate Models	38-3
38.5 Working with Climate Model Projections	38-4
38.6 Concluding Remarks	38-6
References	38-6

Chapter 39. Spatial and Temporal Estimation and Analysis of Precipitation	39-1
39.1 Introduction	39-1
39.2 Estimates of Mean Areal Precipitation	39-1
39.3 Missing Precipitation Data Estimation Methods	39-4
39.4 Limitations of Estimation Methods	39-5
39.5 New Methods for Missing Data Estimation	39-5
39.6 Summary of Issues for Missing Precipitation Data Estimation	39-6
39.7 Conclusion.....	39-7
References	39-8
Chapter 40. Snow Distribution and Snowpack Characteristics	40-1
40.1 Introduction	40-1
40.2 Processes Controlling Snow Distribution	40-1
40.3 Spatial Patterns of Snow at Various Scales	40-2
40.4 Snowpack Characteristics	40-2
40.5 Discussion and Conclusion.....	40-3
Acknowledgement.....	40-4
References	40-4
Chapter 41. Time-Space Modeling of Precipitation	41-1
41.1 Introduction	41-1
41.2 Stochastic Modeling of Precipitation	41-1
41.3 Deterministic Numerical Modeling of Time-Space Precipitation	41-3
41.4 Remote Sensing for the Modeling of Time-Space Precipitation.....	41-7
References	41-10
Chapter 42. Evapotranspiration and Evaporative Demand	42-1
42.1 Introduction and History of Theory.....	42-1
42.2 Relevant Concepts and Methods	42-3
42.3 Outstanding Problems and Directions for Future Work	42-10
Acknowledgments	42-14
References	42-14
Chapter 43. Rainfall Interception, Detention, and Depression Storage	43-1
43.1 Canopy Interception Loss.....	43-1
43.2 Forest Floor Interception Loss.....	43-3
43.3 Detention and Depression Storage	43-3
43.4 Summary.....	43-3
References	43-3
Chapter 44. Watershed Geomorphological Characteristics	44-1
44.1 Introduction and Literature Review	44-1
44.2 Watersheds and Drainage Networks	44-2
44.3 Outstanding Problems and Directions for Future Work	44-10
References	44-11
Chapter 45. Infiltration Modeling.....	45-1
45.1 Introduction	45-1
45.2 Basic Equations For Vertical Infiltration	45-1
45.3 Classical Models For Point Infiltration Into Vertically Homogeneous Soils...	45-2
45.4 Modeling Of Point Infiltration Into Vertically Nonuniform Soils	45-4
45.5 Models for Rainfall Infiltration Over Heterogeneous Areas.....	45-5
45.6 Soil Conservation Service Runoff Curve Number Model.....	45-6
45.7 Open Problems	45-6
References	45-7
Chapter 46. Soil Moisture and Vadose Zone Modeling	46-1
46.1 Background	46-1
46.2 Continuum-Scale Models for Partially Saturated Flow in the Vadose Zone ..	46-2
46.3 Numerical Vadose Zone and Land Surface Models.....	46-3
46.4 Soil Moisture Across Spatial-Temporal Scales	46-5
46.5 Inverse Modeling—Soil Hydraulic Properties at the Model Grid Scale	46-8
46.6 Summary.....	46-10
References	46-11

Chapter 47. Hydrogeologic Characterization	47-1
47.1 Introduction	47-1
47.2 Borehole Samples and Groundwater Monitoring Wells	47-1
47.3 Investigation Borehole Drilling	47-1
47.4 Cone Penetrometry, Permeametry, and Electrical Conductivity Logging	47-2
47.5 Electrical Resistivity Survey	47-2
47.6 Hydraulic Methods for <i>in situ</i> Conductivity Measurement	47-2
47.7 Characterization of the Hydraulic Gradient and Flow Rates	47-3
47.8 Recharge Estimation	47-3
47.9 Summary	47-3
References	47-3
Chapter 48. Groundwater Modeling	48-1
48.1 Introduction	48-1
48.2 Groundwater Model Development	48-1
48.3 Grid Generation	48-2
48.4 Model Calibration	48-3
48.5 Case study: Groundwater Modeling in Baton Rouge, Southeastern Louisiana	48-3
48.6 Summary	48-5
Acknowledgments	48-7
References	48-7
Chapter 49. Watershed Runoff, Streamflow Generation, and Hydrologic Flow Regimes	49-1
49.1 Introduction	49-1
49.2 Dominant Runoff Generation Mechanisms	49-3
49.3 Infiltration Equations	49-6
49.4 Factors Affecting Runoff	49-6
49.5 Poorly Understood Factors Affecting Runoff Generation	49-7
Acknowledgments	49-11
References	49-11
Chapter 50. Snowmelt Runoff Generation and Modeling	50-1
50.1 Introduction	50-1
50.2 Snow Accumulation Processes	50-1
50.3 Energy Budget of Snow Pack and Snowmelt	50-2
50.4 Simulation of Snow Accumulation Processes	50-3
50.5 Heat and Water Transfer in Melting Snow Cover	50-3
50.6 Spatial Variability of Snow Cover	50-4
50.7 Constructing General Model of Snowmelt Runoff Generation	50-4
50.8 Case studies	50-6
References	50-9
Chapter 51. Glacial Melting and Runoff Modeling	51-1
51.1 Introduction	51-1
51.2 Remote Sensing	51-1
51.3 Application of Remote Sensing in Glacier Quantification	51-1
51.4 Glaciated versus Nonglaciated Watersheds	51-3
51.5 Application in Streamflow Measurement	51-3
51.6 Conclusion	51-4
References	51-4
Chapter 52. Reservoir and Channel Routing	52-1
52.1 Introduction	52-1
52.2 Reservoir Routing	52-1
52.3 River Routing	52-2
52.4 The Classical Muskingum Flood Routing Method	52-3
52.5 Nash Cascade Model for River Routing	52-4
52.6 Other Linear Storage Models	52-4
52.7 Linear Diffusion Analogy Routing Method	52-5
52.8 Nonlinear Routing Methods	52-5
52.9 Flow Routing Using Hydraulic Methods	52-6
52.10 Basis for The Development of Simplified Momentum Equations	52-7
52.11 Simplified Hydraulic Flood Routing Methods	52-7
52.12 Kalinin–Milyukov Method	52-9
52.13 Variable Parameter Muskingum Stage Routing Method	52-12

52.14 Conclusion.....	52-14
Acknowledgment.....	52-14
References	52-15
Chapter 53. Waterlogging and Salinization	53-1
53.1 Introduction	53-1
53.2 Salinity Features and Impacts.....	53-1
53.3 Irrigation Induced Rises of The Watertable.....	53-2
53.4 Irrigation Induced Land Salinization.....	53-3
53.5 Land Salinization Control.....	53-4
53.6 Salt Balance and Leaching Calculations.....	53-4
53.7 Monitoring and Mapping.....	53-5
53.8 Remedial Measures	53-5
53.9 New Challenges.....	53-6
53.10 Concluding Remarks	53-6
References	53-7
Chapter 54. Surface Water–Groundwater Interactions: Integrated Modeling of a Coupled System.....	54-1
54.1 Introduction	54-1
54.2 Surface Water Models	54-2
54.3 Subsurface Models.....	54-4
54.4 Soil Plant Models.....	54-5
54.5 Coupling Methods	54-6
54.6 Scale Issues.....	54-7
54.7 Data Requirements.....	54-9
54.8 Integrated Models and Watershed Applications	54-10
54.9 Conclusions.....	54-10
References	54-12
Chapter 55. Seawater Intrusion in Coastal Aquifers: Concepts, Mitigation, and Simulation	55-1
55.1 Introduction	55-1
55.2 Assumptions and Approaches for Modeling Seawater Intrusion.....	55-1
55.3 Mitigation of Seawater Intrusion	55-3
55.4 Case Study: The Nile Delta Aquifer	55-3
55.5 Conclusions.....	55-9
References	55-9
Chapter 56. Regional Land Subsidence Caused by the Compaction of Susceptible Aquifer Systems Accompanying Groundwater Extraction	56-1
56.1 Introduction	56-1
56.2 Detection and Assessment.....	56-2
56.3 Analysis and Simulation	56-7
Acknowledgments	56-9
References	56-9
Chapter 57. Hydraulic Fracturing and Hydrologic Impacts	57-1
57.1 Introduction	57-1
57.2 Hydraulic Fracturing Process	57-2
57.3 Risk of Groundwater Contamination	57-4
57.4 Potential for Induced Seismicity.....	57-6
57.5 Concluding Remarks	57-7
References	57-8
Chapter 58. Catchment Classification and Regionalization	58-1
58.1 Introduction.....	58-1
58.2 Catchment Classification: A Review.....	58-2
58.3 Classification Based on Chaos Theory	58-2
58.4 Classification Based on Network Theory	58-4
58.5 Closing Remarks	58-5
58.6 Acknowledgments	58-7
References	58-7

Chapter 59. Rainfall-Runoff Modeling	59-1
59.1 Introduction	59-1
59.2 A Brief History	59-1
59.3 Computation of Runoff Volume	59-1
59.4 Determination of Peak Discharge	59-3
59.5 Runoff Hydrograph	59-3
59.6 Computation of Runoff Hydrograph by Hydraulic Approaches	59-6
59.7 Conclusion.....	59-8
References	59-8
Chapter 60. Continuous Watershed Modeling	60-1
60.1 Introduction	60-1
60.2 Historical Development	60-2
60.3 Concepts and Methods	60-3
60.4 Outstanding Problems/Needs.....	60-7
60.5 Future Directions	60-8
References	60-10
Chapter 61. Calibration and Evaluation of Watershed Models	61-1
61.1 Introduction	61-1
61.2 Calibration and Evaluation	61-2
61.3 Elements of a Calibration/Evaluation Strategy	61-2
61.4 Historical Perspective	61-2
61.5 Model Calibration & Evaluation Protocol.....	61-3
61.6 Strategies for Calibration	61-3
61.7 Desirable Properties of a Successful Calibration.....	61-4
61.8 Preparation Phase.....	61-4
61.9 Calibration Phase	61-8
61.10 Evaluation Phase.....	61-8
61.11 Discussion and Conclusions.....	61-9
References	61-9
Chapter 62. Feasibility, Engineering, and Operations Models: Using the Decision Environment to Inform the Model Design	62-1
62.1 Introduction	62-1
62.2 The Decision Environment	62-1
62.3 USACE Decision Environment Schemas	62-2
62.4 Precision Dimensions of Decision Support.....	62-2
62.5 Process Representation.....	62-3
62.6 Information Content Scale.....	62-5
62.7 Case Study: Picayune Strand-Restoration Project.....	62-5
62.8 Future Research.....	62-6
62.9 Summary	62-6
References	62-7
Part 5. Sediment and Pollutant Transport	63-1
Chapter 63. Water Quality	63-3
63.1 Introduction	63-3
63.2 Water Pollution	63-3
63.3 Water Quality Standards and Water Use Designations	63-3
63.4 Restoration of Water Quality.....	63-5
63.5 Sensor-Based Water Quality Monitoring Technologies.....	63-8
References	63-9
Chapter 64. Soil Erosion	64-1
64.1 Introduction	64-1
64.2 Erosion by Wind.....	64-1
64.3 Erosion by Water	64-1
64.4 Gravity-Induced Erosion	64-2
64.5 Tillage Erosion	64-3
64.6 Snowmelt Erosion	64-3
64.7 Irrigation-Induced Erosion.....	64-3
64.8 Erosion by Wind-Driven Rain.....	64-3
64.9 Erosion Assessment	64-4
64.10 Erosion Assessment—Field and Laboratory Measurements	64-4

64.11 Erosion Assessment—Equations and Models	64-5
64.12 Erosion Impacts.....	64-5
64.13 Erosion Control and Soil Conservation	64-5
64.14 Conclusion	64-6
References	64-6
Chapter 65. Channel Erosion and Sediment Transport	65-1
65.1 Introduction	65-1
65.2 Sediment Production and Loads	65-1
65.3 Partitioning of Sediment Loads in Channels	65-2
65.4 Bank Profile and Erosional Modes.....	65-3
65.5 Modes of Sediment Transport.....	65-5
65.6 Conclusion.....	65-10
References	65-10
Chapter 66. Sedimentation of Floodplains, Lakes, and Reservoirs .	66-1
66.1 Floodplain	66-1
66.2 Lake	66-1
66.3 Reservoir	66-2
66.4 The Sedimentation Process	66-5
66.5 Prediction of Sediments in Floodplains.....	66-7
66.6 Reservoir Trap Efficiency	66-7
66.7 Estimation of Sediment in Lakes and Reservoirs.....	66-7
66.8 Protective Measure Against Sedimentation	66-9
66.9 Summary	66-9
Acknowledgment.....	66-10
References	66-10
Chapter 67. Pollutant Transport in Surface Water.....	67-1
67.1 Introduction	67-1
67.2 Fundamental Processes Controlling Pollutant Transport.....	67-1
67.3 Pollutant Transport in River and Streams	67-3
67.4 Pollutant Transport in Lakes and Reservoirs	67-4
67.5 Pollutant Transport in Coastal Waters	67-7
References	67-9
Chapter 68. Pollutant Transport in Vadose Zone.....	68-1
68.1 Introduction	68-1
68.2 Water Potential in the Unsaturated Zone	68-1
68.3 Governing Equation of Flow in Vadose Zone	68-1
68.4 Deterministic Approach to Solute Transport in the Vadose Zone	68-3
68.5 Codes for Numerical Solution of Vadose Zone Flow and Transport.....	68-5
References	68-6
Chapter 69. Pollutant Transport in Groundwater	69-1
69.1 Introduction	69-1
69.2 Learn from the Field Work—A case of Saltwater Intrusion Observation	69-3
69.3 Reactive Solute Transport Modeling	69-3
69.4 Dispersion Processes in Groundwater (Sato and Lwasa, 2003)	69-5
69.5 Conclusion.....	69-9
References	69-9
Chapter 70. Salinization and Salinity Management in Watersheds .	70-1
70.1 Introduction	70-1
70.2 Salinization.....	70-1
70.3 Salinity-Related Concerns	70-2
70.4 Salinity Management.....	70-2
70.5 Salinity Modeling	70-3
Acknowledgments	70-4
References	70-4
Chapter 71. Transport of Biochemicals and Microorganisms.....	71-1
71.1 Introduction	71-1
71.2 Biochemicals and Microorganisms	71-1

71.3 Mathematical Model Development.....	71-2
71.4 Conclusion.....	71-6
Acknowledgments	71-6
References	71-6
Part 6. Hydrometeorologic and Hydrologic Extremes	74.1
Chapter 72. Atmospheric Rivers	72-3
72.1 Introduction	72-3
72.2 Large-Scale Circulation and Moisture Sources and Pathways.....	72-4
72.3 Precipitation and Flooding Associated with ARs.....	72-4
72.4 Modeling of ARs and Associated Precipitation	72-5
72.5 Projection of Future Changes in ARs.....	72-6
72.6 Future Challenges.....	72-7
Acknowledgements.....	72-8
References	72-8
Chapter 73. Hydrometeorological Extremes (Hurricanes and Typhoons).....	73-1
73.1 Introduction	73-1
73.2 Climatology of Heavy Rainfall and Flooding from Tropical Cyclones	73-1
73.3 Remote Rainfall Associated with Tropical Cyclones: Predecessor Rain Events	73-2
73.4 Projected Increases in Rainfall Associated with Tropical Cyclones	73-2
References	73-3
Chapter 74. Extreme Rainfall: Global Perspective.....	74-1
74.1 Introduction: The Importance of Studying Extreme Rainfall and Related Difficulties	74-1
74.2 A Global Survey Of Record Rainfall Depths.....	74-3
74.3 Approaches in Estimating Extreme Rainfall	74-7
74.4 The Concept of Probable Maximum Precipitation	74-10
74.5 Probabilistic Approach to Extreme Rainfall	74-12
74.6 Ombrarian (Intensity-Duration-Frequency) Curves	74-13
74.7 Summary and Conclusions.....	74-15
Acknowledgments	74-15
References	74-16
Chapter 75. Floods	75-1
75.1 Introduction to Floods and Flooding	75-1
75.2 Flood Characteristics	75-1
75.3 Flood Processes	75-2
75.4 Estimation of Flood Magnitudes and Design Floods	75-4
References	75-5
Chapter 76. Flood Frequency Analysis	76-1
76.1 Introduction	76-1
76.2 Describing the Chance of Flood	76-1
76.3 Looking at the Data	76-3
76.4 Fitting Distributions.....	76-4
76.5 Index flood Method	76-5
76.6 Method of Moments, Bulletin 17B, and Bulletin 17C, with the LP3 Distribution	76-6
76.7 Uncertainty Analysis	76-6
76.8 Estimation at Ungaged Sites	76-7
76.9 Conclusions.....	76-7
References	76-7
Chapter 77. Regional Flood Frequency Modeling.....	77-1
77.1 Introduction: The Regional Framework	77-1
77.2 Regional Estimation Procedures	77-1
77.3 Delineation of Homogeneous Regions and Homogeneity Testing	77-1
77.4 Regional Transfer Methods	77-3
77.5 One-Step Regional Methods	77-4
77.6 Nonlinear Models in Regional Flood Frequency Modeling	77-4
77.7 Multivariate Regional Flood Frequency Modeling	77-5

77.8 Nonstationary Regional Flood Frequency Approaches.....	77-5
77.9 Regional Flood Frequency Analysis Based On Seasonality Measures.....	77-6
77.10 Combination of Local and Regional Approaches	77-6
77.11 Daily Streamflow Estimation at Ungauged Sites.....	77-6
77.12 Discussion and New Directions	77-7
References	77-7
Chapter 78. Risk, Reliability, and Return Periods and Hydrologic Design	78-1
78.1 Introduction	78-1
78.2 Probabilistic and Risk Based Approaches to Hydrologic Design	78-2
78.3 Multivariate Probabilistic and Risk-Based Approaches to Hydrologic Design	78-7
References	78-9
Chapter 79. Drought Characteristics.....	79-1
79.1 Introduction	79-1
79.2 Drought, Aridity, and Water Scarcity.....	79-2
79.3 Drought Occurrences in the World.....	79-3
79.4 Drought Properties Based on Statistical Techniques	79-3
79.5 Numerical Characterization of Drought Properties	79-4
79.6 Indices for Drought Characterization	79-6
79.7 Outstanding Problems and Direction of Future Work	79-8
Acknowledgments	79-10
References	79-10
Chapter 80. Low Flow and Drought Analysis	80-1
80.1 Introduction	80-1
80.2 Need for Low Flow Hydrology Research	80-1
80.3 Factors Affecting Low Flows	80-2
80.4 Low Flow Indices	80-2
80.5 Methods of Low Flow Estimation in Ungaged Catchments	80-4
80.6 Drought Analysis.....	80-4
80.7 Conclusion.....	80-9
References	80-9
Part 7. Systems Hydrology	81-1
Chapter 81. Isotope Hydrology	81-3
81.1 Introduction	81-3
81.2 Isotopes	81-3
81.3 Groundwater Dating	81-5
81.4 Sampling Methods and Isotope Measurements	81-7
81.5 Isotope Applications in Hydrology	81-8
References	81-12
Chapter 82. Lake Hydrology	82-1
82.1 Introduction	82-1
82.2 Origin of Lakes.....	82-1
82.3 Water Balance of Lakes	82-1
82.4 Thermal Regime of Lakes	82-2
82.5 Ice Growth on Lakes.....	82-4
82.6 Circulation Processes in Lakes.....	82-4
References	82-5
Chapter 83. Urban Hydrology	83-1
83.1 Introduction	83-1
83.2 The Effects of Urbanization	83-2
83.3 Other Aspects of Urban Hydrology	83-3
83.4 Conclusion.....	83-3
References	83-4
Chapter 84. Agricultural Hydrology.....	84-1
84.1 Introduction	84-1
84.2 Water Movement in the Root Zone	84-1
84.3 Evaporation and Transpiration.....	84-3
References	84-4

Chapter 85. Forest Hydrology	85-1
85.1 Introduction	85-1
85.2 Historical Development	85-1
85.3 Principles of Forest Hydrology	85-2
85.4 Research Methods	85-3
85.5 Key Findings in Forest-Stream Water Quantity and Quality Relationships	85-4
85.6 Future Directions	85-5
References	85-5
Chapter 86. Coastal Hydrology	86-1
86.1 Introduction	86-1
86.2 Overview of Coastal Processes	86-1
86.3 Movement of Water and Sediment in Coastal Areas	86-2
86.4 Mathematical Models of Water and Sediment Movement	86-6
86.5 Summary and Outlook	86-7
Acknowledgments	86-8
References	86-8
Chapter 87. Wetland Hydrology	87-1
87.1 Introduction	87-1
87.2 Importance of Hydrology on Wetland Functioning	87-1
87.3 Hydroperiod	87-2
87.4 Wetland Hydrologic Terms	87-2
87.5 Wetland Water Budget	87-3
87.6 Wetland Hydraulics	87-5
87.7 Modeling Groundwater-Surface Water Interactions	87-6
87.8 Wetland Hydrology at the Watershed Scale	87-7
87.9 Anthropogenic and Climate Change Impacts on Wetlands	87-7
Summary	87-7
References	87-8
Chapter 88. Arid Zone Hydrology.....	88-1
88.1 Introduction	88-1
88.2 Precipitation	88-1
88.3 Condensation	88-1
88.4 Infiltration	88-1
88.5 Runoff	88-2
88.6 Transmission Losses	88-3
88.7 Change in Storage (ΔS)-Groundwater Recharge	88-3
88.8 Evapotranspiration	88-4
88.9 Conclusion	88-6
References	88-6
Chapter 89. Karst.....	89-1
89.1 Introduction	89-1
89.2 Investigation and Characterization of Karst	89-4
89.3 Summary	89-10
Acknowledgements	89-11
References	89-11
Chapter 90. Cryospheric Hydrology: Mountainous Environment...	90-1
90.1 Introduction	90-1
90.2 Alpine Runoff	90-1
90.3 Monsoon Dominated Asian Mountain Ranges	90-1
90.4 Glacier Runoff as a Resource	90-1
90.5 Glacier Melting Processes	90-4
90.6 Glacier Melt Modeling	90-5
90.7 Drainage and Storage Characteristics	90-5
90.8 Diurnal and Seasonal Variations in Glacier Meltwater	90-6
90.9 Cryospheric Hydrology and Climate Change	90-7
90.10 Glacier Lake Outburst Floods	90-9
90.11 Summary	90-10
References	90-10

Chapter 91. Hydrology of Transportation Systems.....	91-1
91.1 Pathways in Nature.....	91-1
91.2 Scales of Movement and Accumulation Processes	91-2
91.3 Soil and Groundwater	91-3
91.4 Streams	91-4
91.5 Lakes.....	91-5
References	91-6
Chapter 92. Large-Scale and Global Hydrology.....	92-1
92.1 Introduction	92-1
92.2 The Distribution of Water on Earth	92-1
92.3 The Global Water Cycle	92-1
92.4 Numerical Modeling and Data Assimilation.....	92-2
92.5 Global Water Cycle Variability, Predictability, and Change	92-4
Acknowledgements	92-5
References	92-6
Part 8. Hydrology of Large Riverand Lake Basins.....	93.1
Chapter 93. Amazon River Basin.....	93-3
93.1 Main Geographical Features	93-3
93.2 Amazon Hydrological Processes.....	93-3
93.3 Environment, Economics and Potentialities of the Basin	93-5
93.4 Impact of <i>Anthropic Activities</i> in the Basin	93-6
93.5 Amazon Basin in the Context of its Water Footprint and Environmental Role	93-6
References	93-6
Chapter 94. Paraná (Rio de la Plata) River Basin	94-1
94.1 Introduction	94-1
94.2 Geographical Features and Main Regions	94-1
94.3 Climate.....	94-1
94.4 Hydrological Features and Water Use.....	94-2
94.5 Variability and Trends	94-2
References	94-4
Chapter 95. Orinoco River Basin.....	95-1
95.1 Introduction	95-1
95.2 Regional Geological and Topographical Setting.....	95-1
95.3 Hydroclimatic Conditions.....	95-1
95.4 The Main Stem and its Major Tributaries	95-2
95.5 Floodplains and Seasonal Sediment Regime	95-2
95.6 Delta	95-3
95.7 Regional Vegetation	95-4
95.8 Human Impacts	95-4
95.9 Concluding Remarks	95-4
References	95-4
Chapter 96. Nile River Basin.....	96-1
96.1 Introduction	96-1
96.2 Climate	96-3
96.3 Hydrology of the Nile Basin	96-4
References	96-9
Chapter 97. Congo River Basin	97-1
97.1 Introduction	97-1
97.2 The State of Hydrological Monitoring	97-1
97.3 Climate Regimes	97-2
97.4 Catchments Characteristics and Hydrological Similarities	97-2
97.5 Hydrogeochemical Processes and Sediment Transport	97-4
97.6 Hydrological Modeling	97-4
97.7 Climate and Land Use Change	97-5
97.8 Conclusion.....	97-5
Acknowledgment	97-5
References	97-5

Chapter 98. Zambezi River Basin.....	98-1
98.1 Introduction	98-1
98.2 Physical Characterization.....	98-1
98.3 Main Features.....	98-1
98.4 Climate.....	98-3
98.5 Runoff Regime.....	98-3
98.6 Past Hydrological Studies.....	98-4
98.7 Hydrological Data.....	98-5
98.8 Current Concerns and Future Challenges	98-6
Acknowledgments	98-6
References	98-6
Chapter 99. Euphrates and Tigris River Basin.....	99-1
99.1 General Characteristics of The Basin.....	99-1
99.2 Hydrology and Water Resources.....	99-1
99.3 Water Resources Developments in The Basin.....	99-3
99.4 Environmental Concerns.....	99-3
99.5 Climate Change Impacts on Basin Hydrology	99-3
Acknowledgment	99-3
References	99-4
Chapter 100. Yangtze River Basin.....	100-1
100.1 Introduction.....	100-1
100.2 Climate and Hydrology.....	100-2
100.3 Station Network and Water Conservancy Projects.....	100-4
100.4 Significant Water Issues	100-5
100.5 Research on the Yangtze River Basin	100-5
100.6 Concluding Remarks	100-5
References	100-6
Chapter 101. Yellow River Basin	101-1
101.1 Introduction.....	101-1
101.2 Climate and Hydrology.....	101-3
101.3 Station Network and Water Conservancy Projects.....	101-4
101.4 Significant Water Issues	101-5
101.5 Research on the Yellow River basin.....	101-5
101.6 Concluding Remarks	101-6
References	101-6
Chapter 102. Mekong River	102-1
102.1 Introduction.....	102-1
102.2 Upper Mekong River (Langcang Jiang)	102-3
102.3 Lower Mekong River	102-5
102.4 Floods and Flood Forecasting.....	102- 6
102.5 Mekong Delta	102- 8
102.6 Biodiversity	102- 8
102.7 Agriculture and Aquaculture.....	102- 8
102.8 Mekong River Commission	102- 9
102.9 Environmental Threats	102- 9
102.10 Closing Remarks.....	102- 9
References	102- 9
Chapter 103. Yenisei River Basin.....	103-1
103.1 Introduction.....	103-1
103.2 Central and Lower Sections of the Yenisei.....	103-1
103.3 Upper Section of the Yenisei.....	103-1
103.4 Fluvial System of the Angara River	103-1
References	103-4
Chapter 104. Lena River Basin.....	104-1
104.1 Introduction.....	104-1
References	104-4
Chapter 105. Brahmaputra River Basin	105-1
105.1 Introduction	105-1
105.2 Climate	105-1

105.3 Drainage Characteristics	105-2
105.4 Hydrology	105-4
105.5 Problems Faced, Projects Undertaken, and Future Scope	105-5
References	105-6
Chapter 106. Ganga River Basin	106-1
106.1 Ganga River Basin	106-1
106.2 Ganga River	106-1
106.3 Climate and Hydrology of the Ganga Basin	106-2
106.4 Floods and Droughts.....	106-2
106.5 GroundWater Resources	106-2
106.6 Hydropower	106-2
106.7 Sediments.....	106-3
106.8 Water Quality Aspects.....	106-3
106.9 Major Water Resources Development Projects	106-3
106.10 Social and Environmental Aspects	106-3
106.11 Future Perspectives.....	106-4
References	106-4
Chapter 107. Narmada Basin	107-1
107.1 Introduction.....	107-1
107.2 Population	107-2
107.3 Major Tributaries and Sub-basins	107-2
107.4 Climate in Narmada Basin	107-3
107.5 Soils and Land Use in Narmada Basin	107-4
107.6 Water Resources of Narmada Basin.....	107-4
107.7 Major Water Resources Projects in Narmada Basin	107-5
108.8 Closure.....	107-6
References	107-6
Chapter 108. Indus River Basin	108-1
108.1 Introduction to Indus River Basin	108-1
108.2 Physiography of Indus River Basin	108-1
108.3 River Network and Principal Hydrologic Units of Indus River Basin	108-1
108.4 Climate of Indus River Basin	108-2
108.5 Hydrological characteristics of Indus River Basin.....	108-3
108.6 Indus Water Treaty	108-5
108.7 Major Water Resources Development Projects in Indus River Basin.....	108-5
108.8 Groundwater Resources of Indus River Basin	108-9
108.9 Climate Change in Indus River Basin and its Hydrologic Consequences	108-9
108.10 Concluding Remarks on Hydrology of Indus Basin	108-10
References	108-10
Chapter 109. The Mississippi River Basin	109-1
109.1 Mississippi River Basin Physiography and Hydrology.....	109-1
109.2 Mississippi River Basin Climatology	109-1
109.3 Anthropogenic Changes in the River Basin	109-2
109.4 Future Critical Challenges in the Mississippi River Basin	109-4
Acknowledgments	109-4
References	109-5
Chapter 110. Colorado River Basin	110-1
110.1 Introduction and Basin Characteristics	110-1
110.2 History of Water Resources Allocation.....	110-1
110.3 Reservoirs and Other Water Management Facilities	110-2
110.4 Development and Use of the Colorado River Simulation System	110-3
110.5 Hydrologic Data	110-3
110.6 Generating Projected Future Flow Scenarios	110-4
110.7 Future Priorities	110-4
References	110-4
Chapter 111. Columbia River Basin	111-1
111.1 Introduction	111-1
111.2 Basin History	111-1
111.3 River Operations	111-2

111.4 Current and Future Concerns	111-4
111.5 Future Opportunities and Challenges	111-5
Acknowledgments	111-5
References	111-5
Chapter 112. St. Lawrence River Basin	112-1
112.1 Introduction	112-1
112.2 Characteristics of the St. Lawrence River and its Basin	112-1
112.3 Hydrological Characteristics of the River	112-4
Acknowledgments	112-5
References	112-5
Chapter 113. River Rhine Basin.....	113-1
113.1 Introduction	113-1
113.2 Climate.....	113-1
113.3 Water Balance in the Rhine Basin.....	113-4
113.4 Long-Term Variability of Hydrometeorological Variables in the Rhine Basin	113-4
113.5 Discharge Characteristics in Longitudinal Profile.....	113-5
113.6 The Runoff Regime of the Rhine.....	113-6
113.7 Changes in the Runoff Characteristics of Rhine Since the Beginning of the Twentieth Century	113-9
113.8 Changes in the Runoff Regime of the Upper Rhine	113-10
113.9 Changes in the Runoff Regime of the Middle and Lower Rhine	113-10
113.10 Development in Extreme Runoff Situations: Flood	113-10
113.11 Development in Extreme Runoff Situations: Low Water.....	113-10
Acknowledgment	113-10
References	113-10
Chapter 114. Danube River Basin.....	114-1
114.1 Introduction	114-1
114.2 History of the River System	114-1
114.3 Climate, Drainage Characteristics, and Hydrology.....	114-2
114.4 Problem faced	114-3
114.5 Scope of Future Development (2 pages)	114-5
References	114-5
Chapter 115. Ob River Basin	115-1
115.1 Introduction	115-1
115.2 Ob River Basin and Discharge Data	115-1
115.3 Streamflow Characteristics and Change	115-1
115.4 Water Temperature and Thermal Regime	115-4
References	115-5
Chapter 116. Po River Basin.....	116-1
116.1 River Basin Morphology and Geology, Geometry of The River Network....	116-1
116.2 Climate and Meteorology. Genesis of Extreme Events and Droughts	116-1
116.3 Monitoring Networks	116-3
116.4 Hydrological Balance in the Po River Basin. Exploitation of Water Resources and Sustainability.....	116-3
116.5 The River Regime. Variability, Seasonality, Long-Term Patterns	116-3
116.6 History of Po River Floods	116-3
116.7 Flood Hazard Mitigation Along the Course of the Po River.....	116-4
116.8 Conclusions	116-4
References	116-4
Chapter 117. River Thames Basin.....	117-1
117.1 Introduction	117-1
117.2 The Thames Basin	117-1
117.3 Hydrometric Measurement in the Thames Basin	117-1
117.4 Droughts and Alleviation Measures	117- 2
117.5 Floods and Flood Risk	117- 3
117.6 Research and Forecasting Initiatives	117-3
117.7 Trends in Runoff Patterns.....	117-4
117.8 Concluding Remarks	117-4
Acknowledgments	117-4

References	117-5
Useful Websites:	117-6
Chapter 118. Managing Water in an Arid land: The Murray Darling Basin, Australia	118-1
118.1 Introduction	118-1
118.2 The Murray Darling Basin	118-2
118.3 The changing hydrology of the Murray Darling Basin.....	118-3
118.4 Potential for Ecosystem Collapse	118-5
118.5 The Policy Response	118-5
118.6 What Future Do We Want for the Basin Anyway?	118-6
Conclusion	118-7
References	118-7
Websites	118-9
Chapter 119. The Great Lakes System.....	119-1
119.1 Introduction to the Great Lakes	
Hydrological system	119-1
119.2 The Great Lakes Water Budget	119-2
119.3 Great Lakes Water levels.....	119-5
Acknowledgments	119-5
Bibliography	119-5
Chapter 120. The East African Great Lakes	120.1
120.1 Introduction	120.1
120.2 Lake Victoria.....	120.1
120.3 Lake Tanganyika.....	120.3
120.4 Lake Malawi	120.4
120.5 Lake Albert.....	120.5
120.6 Lake Turkana	120.6
120.7 Lake Kivu.....	120.7
120.8 Lake Edward.....	120.8
References	120.9
Chapter 121. Aral Sea Basin	121-1
121.1 Introduction	121-1
121.2 Subsurface Flux Changes and Interactions with the Shrinking Sea	121-1
121.3 Surface Flux Changes and Interactions With Climate Change	121-2
121.4 Opportunities and Challenges for Water Quantity and Quality Management.....	121-3
121.5 Concluding Remarks	121-4
References	121-4
Chapter 122. Baltic Sea Basin	122-1
122.1 Introduction	122-1
122.2 Physiography and Hydroclimatology.....	122-1
122.3 Hydrology and Water Balance	122-4
122.4 Water Quality.....	122-6
122.5 Future Developments	122-8
122.6 Summary.....	122-9
Acknowledgments	122-9
References	122-9
Chapter 123. Black Sea Basin	123-1
123.1 Introduction	123-1
123.2 Geographical location and Basic Morphometric Characteristics	123-1
123.3 Hydrological Conditions.....	123-1
References	123-5
Chapter 124. The Caspian Sea Basin	124-1
124.1 Introduction.....	124-1
124.2 The Caspian Sea Watershed Area.....	124-1
124.3 The Volga River	124-1
124.4 Physicogeographical Conditions of the Caspian Sea.....	124-3
124.5 Hydrometeorology and Climate.....	124-3
124.6 Physical Oceanography.....	124-3
124.7 Sea Level Variability.....	124-4

124.8 Marine Chemistry.....	124-4
124.9 Marine Biology and Resources	124-5
124.10 Ecological Problems	124-5
124.11 Oil pollution of the Sea.....	124-6
124.12 Seismic Activity.....	124-7
124.13 Desertification.....	124-7
124.14 Conclusions	124-7
Acknowledgments	124-7
References	124-7
Chapter 125. Design Rainfall	125-1
125.1 Purpose of Design Rainfalls.....	125-1
125.2 Constructing Databases of Rainfall to Derive Design Rainfalls	125-2
125.3 AMS vs PDS.....	125-3
125.4 Appropriate Probability Distributions	125-3
125.5 Regionalization	125-4
125.6 Deriving Sub-Daily and Sub-Hourly IDF Relationships.....	125-5
125.7 Scaling Relationships in Design Rainfalls	125-5
125.8 Developing Design Rainfall Grids	125-6
125.9 Uncertainty in Design Rainfall Estimates	125-6
125.10 Design Temporal Patterns	125-6
125.11 Design spatial patterns.....	125-7
125.12 Implications of Temperature Linked Non-Stationarity on the Design Rain..	125-8
Acknowledgements	125-9
References	125-9
Chapter 126. Probable Maximum Precipitation.....	126-1
126.1 Introduction.....	126-1
126.2 Deterministic Method of Estimation of PMP	126-1
126.3 Probabilistic Method of Estimation of PMP	126-10
126.4 Generalized Versus Basin-Specific PMP Estimates	126-13
126.5 All-season Versus Seasonal PMP Estimates	126-13
126.6 Orographic Effects	126-13
126.7 Spatial Variation of PMP.....	126-13
126.8 Temporal Distribution of PMP—Development of PMS	126-14
126.9 Seasonal Variation of PMP.....	126-16
126.10 Cautionary notes on the Procedures for Estimation of New Set of PMP	126-16
References	126-17
PART 9. Applications and Design	127-1
Chapter 127. Runoff Prediction in Ungauged Basins	127-3
127.1 The Prediction in Ungauged Basins Problem	127-3
127.2 Best Practice Recommendations for Predicting Runoff in Ungauged Basins	127-3
127.3 Prediction of Floods in Ungauged Basins	127-4
127.4 Prediction of Low Flows in Ungauged Basins	127-5
127.5 Prediction of Runoff Hydrographs in Ungauged Basins	127-6
127.6 Where To Go From Here	127-7
Acknowledgements	127-9
References	127-9
Chapter 128. Stochastic Streamflow Simulation and Forecasting ..	128.1
128.1 Introduction.....	128. 1
128.2 Stochastic Simulation of Streamflow	128. 1
128.3 Nonparametric Time Series Models	128. 2
128.4 Multisite Streamflow Simulation.....	128. 3
128.5 Nonstationary Streamflow Simulation	128. 3
128.6 Streamflow Forecasting	128. 4
128.7 Stochastic Weather Generators	128. 4
128.8 Software and Resources	128. 5
References	128. 5

Chapter 129. Flood Forecasting and Flash Flood Forecasting— “Special Considerations in Hydrologic Modeling for the Expressed Purpose of Flood and Flash Flood Forecasting”	129-1
129.1 Introduction	129-1
129.2 Real-Time Data Requirements and Forecasts and Data Quality Control	129-1
129.3 Computational Efficiency and Latency Requirements	129-3
129.4 Data Assimilation and/or Adjusting Model Inputs, States, And Outcomes	129-3
129.5 Use of Future Weather	129-3
129.6 Requirements for Regulation Information	129-3
129.7 Flood-Control and Water-Supply Reservoirs	129-4
129.8 Reliability and Stability Requirements	129-4
129.9 Understanding and Conveying Uncertainty	129-4
129.10 Lead Time Considerations and Requirements	129-4
129.11 Temporal (Time Step) Requirements	129-4
129.12 Dissemination and Coordination with Customer, Partners, and the General Public	129-4
129.13 Applications Related to Flash Flooding	129-4
129.14 Special Temporal (Time Step) Requirements	129-4
129.15 Automated Data-Analysis Requirements.....	129-5
129.16 Automated Data Assimilation	129-5
129.17 Ungaged Watershed Application	129-5
129.18 Identification of Highly Vulnerable/at Risk Locations.....	129-5
References	129-5
Chapter 130. Reservoir Operation Design.....	130-1
130.1 Introduction	130-1
130.2 Reservoir Planning and Design	130-1
130.3 Reservoir Operation.....	130-3
130.4 Future Trends in Reservoir Operation Design	130-6
130.5 Conclusions	130-6
References	130-7
Chapter 131. Floodplain Management.....	131-1
131.1 Responses to Flood Risk.....	131-1
131.2 Evolution of Floodplain Management Practices.....	131-2
131.3 Concepts and Methods	131-2
131.4 Certification in Floodplain Management	131-3
131.5 Summary of Issues and Needed Advances	131-3
References	131-3
Chapter 132. Storm Water Management, Best Management Practices, and Low-Impact Development.....	132-1
132.1 Introduction	132-1
132.2 The Need for Stormwater Management.....	132-2
132.3 Specific BMPs.....	132-3
132.4 Analysis	132-4
132.5 Safety	132-4
References	132-4
Chapter 133. Flood Proofing and Infrastructure Development	133-1
133.1 Introduction to Flood Proofing and Infrastructure Development	133-1
Acknowledgement.....	133-9
References	133-9
Chapter 134. Environmental Flows	134-1
134.1 Introduction.....	134-1
134.2 Evolution of Environmental Flows Concept	134-2
134.3 Trade-offs in Development and Conservation.....	134-2
134.4 Estimation of Environmental Flows	134-2
134.5 Methodologies for Assessment of Environmental Flows Requirement	134-3
134.6 Implementation of EF	134-6
134.7 Environmental Flows in IWRM	134-7
134.8 Future Challenges.....	134-7
References	134-7

Chapter 135. Drainage and Culvert Design.....	135-1
135.1 introduction	135-1
135.2 Fundamentals of Design	135-1
135.3 Design Procedure.....	135-4
135.4 Potential Impact of Climate Change on Culvert Design and Operation	135-6
135.5 Sustainable Design	135-6
References	135-6
Chapter 136. Wetland and River Restoration	136-1
136.1 Introduction.....	136-1
136.2 Definitions	136-1
136.3 The Restoration Process	136-2
136.4 Approaches to Wetland And River Restoration.....	136-3
136.5 Advancing The Science and Practice of Stream and Wetland Restoration.....	136-6
Acknowledgement.....	136-7
References	136-7
Chapter 137. Institutional Framework for Water Management.....	137-1
137.1 Sustainable Integrated Water Management.....	137-1
137.2 Water Management in Texas: An Illustrative Case Study	137-1
137.3 Water Management Communities.....	137-1
137.4 Federal Agency Programs	137-3
137.5 State Water Resources Planning.....	137-4
137.6 Water Allocation	137-4
137.7 Environmental Management	137-5
137.8 Flood Mitigation.....	137-6
137.9 Institutional Aspects of Computer Modeling.....	137-6
137.10 Conclusions	137-7
References	137-7
Chapter 138. Peak Water, Virtual Water, and Water Footprints: New Definitions and Tools for Water Research and Policy.....	138-1
138.1 Introduction.....	138-1
138.2 Peak Water	138-2
138.3 Comparison of Peak Production in Oil and Water.....	138-3
138.4 Water Transfers and the Concept of Virtual Water	138-4
138.5 Water Footprints.....	138-6
138.6 Soft Water Paths	138-7
138.7 Conclusions	138-7
References	138-8
Chapter 139. Transboundary Water Management	139-1
139.1 Introduction.....	139-1
139.2 Water Conflict	139-1
139.3 Sources of Water Conflict.....	139-2
139.4 International Water Conflicts versus National Water Conflicts.....	139-2
139.5 Resolving Water Conflicts	139-2
139.6 The Importance of Institutional Capacity	139-3
139.7 Hydro-Hegemony.....	139-3
139.8 International Water Law	139-3
139.9 Third Party Involvement.....	139-3
139.10 Future Directions and Ways to Address New Problems	139-4
139.11 Conclusion	139-4
Acknowledgement.....	139-4
References	139-4
Chapter 140. Integrated River Basin Management.....	140-1
140.1 Integrated River Basin Management: A Framework and Process	140-1
140.2 Elements of IRBM	140-1
140.3 Historical Development	140-2
140.4 Institutional Arrangements for IRBM.....	140-2
140.5 Technical Concepts and Methods.....	140-4
140.6 Case Studies.....	140-5
140.7 Summary.....	140-6
References	140-7

Chapter 141. Conflict Resolution	141-1
141.1 Conflict Exists Everywhere.....	141-1
141.2 Game Theoretic Models for Conflict Analysis.....	141-1
141.3 Graph Model for Conflict Resolution	141-1
141.4 Fair Water Allocation	141-2
141.5 Compliance Models	141-4
141.6 Agent-Based Modeling and Simulation.....	141-5
141.7 Summary.....	141-5
References	141-5
Chapter 142. Long-distance Water Transfers	142-1
142.1 Introduction.....	142-1
142.2 Transfers Among Basins, Regions and Countries—Achievements and Concerns.....	142-1
Further Thoughts	142-6
References	142-6
Chapter 143. The Indian River-Linking Program	143-1
143.1 Introduction.....	143-1
143.2 India's Water Resources and the River-Linking Plan	143-1
143.3 Prognosis and Implication.....	143-5
143.4 Conclusions	143-8
Acknowledgment.....	143-8
Reference	143-8
Chapter 144. Irrigation Scheduling and Management	144-1
144.1 Introduction.....	144-1
144.2 Soil-Plant-Atmosphere Interaction	144-2
144.3 On-farm Irrigation Scheduling	144-2
144.4 Canal Irrigation Scheduling.....	144-7
144.5 Conclusions	144-8
144.6 Research Needs.....	144-8
References	144-8
Chapter 145. Rainwater Harvesting and Groundwater Recharge...	145-1
145.1 Introduction.....	145-1
145.2 Ancient Methods of Water Harvesting	145-1
145.3 Watershed Development	145-2
145.4 Rainwater-Harvesting Structures	145-3
145.5 Assessment of Rainwater Harvesting Using Remote Sensing and GIS.....	145-7
145.6 Rainwater Harvesting Studies a Global Perspective	145-7
References	145-9
Chapter 146. Reuse-Reclaimed Water in Managed Aquifer Recharge	146-1
146.1 Introduction	146-1
146.2 Treatment Mechanisms in Natural Systems	146-1
146.3 Managed Aquifer Recharge	146-2
146.4 Water Quality Considerations for Managed Aquifer Recharge.....	146-3
146.5 Surface Spreading	146-3
146.6 Injection Wells.....	146-4
146.7 Recovery of Reclaimed Water through Aquifer Storage and Recovery	146-5
146.8 Subsurface Geochemical Processes	146-6
146.9 Summary.....	146-6
References	146-6
Chapter 147. River Bank Filtration.....	147-1
147.1 Introduction	147-1
147.2 River Hydrology	147-1
147.3 Potential of River Bank Filtration.....	147-2
147.4 Simulating RBF Quality.....	147-3
147.5 Optimizing Distance of Well from the River	147-6
147.6 River Bank Filtration Sites	147-6
147.7 Summary.....	147-7
References	147-7

Chapter 148. Assessment of Climate Change Impacts on Water Resources	148-1
148.1 Introduction.....	148-1
148.2 Climate Change Observations and Model-Based Projections.....	148-1
148.3 Observations and Projections of Climate Change Impact on Water Resources	148-2
148.4 Aim Of Modeling of Climate Change Impact on Freshwater Resources	148-3
148.5 Methodology of Modeling Climate Change Impacts on Water Resources ..	148-3
148.6 Hydrological Models for Climate Change Impact Assessment	148-4
148.7 Model Selection, Calibration, and Validation	148-6
148.8 Examples of Applications of Hydrological Models for Climate Change Impact Assessment	148-7
148.9 Propagation of Uncertainty.....	148-7
148.10 Gaps and Challenges	148-9
Acknowledgments	148-10
References	148-10
Chapter 149. Human Impacts on Hydrology.....	149-1
149.1 Introduction.....	149-1
149.2 Methodology.....	149-2
149.3 Case Study	149-4
149.4 Future Outlook	149-7
Acknowledgement.....	149-8
References	149-8
Chapter 150. Climate Change and Its Impacts on Hydrologic Cycle	150-1
150.1 Climate Change: What Does it Mean?.....	150-1
150.2 Causes of Climate Change	150-1
150.3 Measure of Climate Change.....	150-3
150.4 Impacts of Climate Change	150-3
150.5 Impacts of Climate Change on The Hydrologic Cycle	150-3
150.6 Future.....	150-7
References	150-7
Part 10. Future	151-1
Chapter 151. Human-Hydrology Systems Modeling	151-3
151.1 Introduction.....	151-3
151.2 Evolution of Human-Hydrology Systems Modeling	151-3
151.3 Methods for Modeling Human-Hydrology Systems.....	151-4
151.4 Applications of Human-Hydrology Systems Modeling	151-6
151.5 Resources	151-9
151.6 Future Directions and Challenges	151-9
References	151-11
Chapter 152. Variability of Hydrological Processes and Systems in a Changing Environment	152-1
152.1 Climate Change and the Water Cycle	152-1
152.2 Human Activities and the Water Cycle	152-1
152.3 Intensification of the Hydrological Cycle in a Changing Environment.....	152-2
152.4 Sustainability, Hydrologic Risk, and Uncertainty	152-3
152.5 Tracking Hydrologic Change: Trend and Predictability.....	152-3
References	152-4

Chapter 153. Extraterrestrial Water.....	153-1
153.1 Introduction.....	153-1
153.2 The Origin of the Earth's Water.....	153-1
153.3 Water in our Solar System	153-1
153.4 Water Beyond our Solar System.....	153-3
153.5 Summary.....	153-4
References	153-4
Chapter 154. Water Security	154-1
154.1 Availability of Freshwater around the World	154-1
154.2 Current State of Water Affairs.....	154-1
154.3 Water Security—the Discourse.....	154-3
154.4 Global Availability of Groundwater	154-3
154.5 Water Security as Part of Economic Security	154-4
154.6 Managing Water in a Changing World	154-4
154.7 Meeting the Water Gap: Unlocking the Potential of Green Water	154-4
Conclusion	154-5
Acknowledgments.....	154-5
References	154-5
Chapter 155. Social Hydrology	155-1
155.1 Water and Human Beings.....	155-1
155.2 What is Social Hydrology?	155-3
155.3 Great Hydraulic Mission	155-4
155.4 Nature's Talk Back.....	155-4
155.5 Evolution of Social Hydrology as a New Discipline.....	155-6
155.6 Challenges Ahead in Water Management.....	155-7
155.7 Recent Trends and Developments in Social Hydrology	155-8
155.8 Climate Change and Future Issues in Social Hydrology	155-8
155.9 Future Direction in Social Hydrology	155-9
References	155-10
Chapter 156. Grand Challenges Facing the Hydrologic Sciences ...	156-1
156.1 Introduction.....	156-1
156.2 Quality-Differentiated Water Management	156-1
156.3 Conversion Strategy	156-2
156.4 Scoping the Greater Hydrologic System	156-2
156.5 Scoping Water Needs.....	156-3
156.6 Emerging Infrastructure Needs	156-3
156.7 Information Systems	156-4
156.8 Prioritization	156-4
156.9 Selected Priority Challenges.....	156-5
156.10 From Research to Reality.....	156-6
156.11 Summary and Conclusions	156-6
Acknowledgements	156-6
References	156-6

Contributors

Benjamin Abban

Department of Civil and Environmental Engineering
University of Tennessee
Knoxville, Tennessee

M. C. Acreman

Centre for Ecology and Hydrology
Crownmarsh Gifford
Wallingford, United Kingdom

Lauren Adams

Center for Watershed Sciences
University of California, Davis
Davis, California

Pradeep Aggarwal

Isotope Hydrology Section
Division of Physical and Chemical Sciences
Department of Nuclear Sciences and Applications
International Atomic Energy Agency (IAEA)
Vienna, Austria

Mohammad Z. Al-Hamdan

Universities Space Research Association
NASA/Marshall Space Flight Center
National Space Science Technology Center
Huntsville, Alabama

Doug Alsdorf

Byrd Polar and Climate Research Center
The Ohio State University
Columbus, Ohio

Devendra M. Amatya

USDA Forest Service Center for Forested Wetlands Research
Cordesville, South Carolina

Daniel P. Ames

Department of Civil and Environmental Engineering
Brigham Young University
Provo, Utah

Burakou Dmitry Anatolyevich

Department of Environmental Engineering
Krasnoyarsk State Agrarian University
Krasnoyarsk, Russia

Michael Anderson

California Department of Water Resources
Division of Flood Management
Hydrology and Flood Operations Office
Hydrology Branch
Sacramento, California

Mazdak Arabi

Department of Civil and Environmental Engineering
Colorado State University
Fort Collins, Colorado

Luis J. Aragunas-Aragunas

Isotope Hydrology Section
Division of Physical and Chemical Sciences
Department of Nuclear Sciences and Applications
International Atomic Energy Agency (IAEA)
Vienna, Austria

Mustafa M. Aral

School of Civil and Environmental Engineering
Georgia Institute of Technology
Atlanta, Georgia

Bhavna Arora

Earth Sciences Division
Lawrence Berkeley National Laboratory
Berkeley, California

M. Babbar-Sebens

School of Civil and Construction Engineering
Oregon State University
Corvallis, Oregon

Daniel W. Baker

Department of Civil and Environmental Engineering
Colorado State University
Fort Collins, Colorado

Emanuele Baratti

Department DICAM
University of Bologna
Bologna, Italy

Donald E. Barbe

Department of Civil and Environmental Engineering
University of New Orleans
New Orleans, Los Angeles

Henry Barousse

Louisiana Department of Transportation and Development (Retired)

Robert Bastian

U.S. Environmental Protection Agency
Washington, D.C.

Peter Bauer-Gottwein

Department of Environmental Engineering
Technical University of Denmark
Lyngby, Denmark

Hiroko Kato Beudoing

Earth System Science Interdisciplinary Center
University of Maryland
College Park, Maryland
Beijing Normal University
Research and Development Centre
Nippon Koei Co. Ltd.
(Consulting Engineers)
Tsukuba, Japan

Kati Bell

Global Practice Leader - Water Reuse
MWH Global
Brentwood, Tennessee

Joerg Uwe Belz

BIG - Federal Institute of Hydrology
Koblenz, Germany

Lars Bengtsson

Department of Water Resources Engineering
Lund Institute of Technology
Lund University
Lund, Sweden

Ronny Berndtsson

Department of Water Resources Engineering
and Center for Middle Eastern Studies
Lund University
Lund, Sweden

Daniela Biondi

Institute of Hydraulic Construction
University of Bologna
Bologna, Italy

Brian P. Bledsoe

Department of Civil and Environmental Engineering
Colorado State University
Fort Collins, Colorado

Günter Blöschl

Institute of Hydraulic Engineering
Centre for Water Resource Systems
Institut für Wasserbau und Ingenieurhydrologie
Technische Universität Wien
Wien, Austria

Istvan Bogardi

Department of Civil Engineering
Izmir Institute of Technology
Izmir, Turkey

D. Bolten

NASA/GSFC, Hydrological Sciences Branch
Greenbelt, Maryland

André Bouchard

Hydrology and Ecohydraulic Section
Meteorological Service of Canada
Environment Canada
Québec
Canada

Armando Brath

Department DICAM
University of Bologna
Bologna, Italy

Juan Martín Bravo

Instituto de Pesquisas Hidráulicas
Universidade Federal do Rio Grande do Sul
IPH-UFRGS
Porto Alegre, Brazil

Donald H. Burn

Department of Civil and Environmental Engineering
University of Waterloo
Waterloo, Canada

Aaron R. Byrd

Hydrologic Systems Branch
Coastal and Hydraulics Laboratory
Engineer Research Development Center
U.S. Army Corps of Engineers
Vicksburg, Mississippi

Ximing Cai

Department of Civil and Environmental Engineering
University of Illinois at Urbana-Champaign
Urbana, Illinois

Darryl Carlyle-Moses

Department of Geography and Environmental Studies
Thompson Rivers University
Kamloops, Canada

Attilio Castellarin

DICAM - Costruzioni Idrauliche, Università degli Studi di Bologna
Bologna, Italy

Serena Ceola

Department DICAM
University of Bologna
Bologna, Italy

C. P. Cetinkaya

Dokuz Eylül University
Water Resources Management Research and Application Center (SUMER)
İzmir, Turkey

Maria A. Charina

Water Problems Institute of the Russian Academy of Sciences
Moscow, Russia

Fateh Chebana

Institut national de la recherche scientifique
Centre Eau-Terre-Environnement
Québec, Canada

Ji Chen

Department of Civil Engineering
The University of Hong Kong
Hong Kong, People's Republic of China

Yang Cheng

Department of Civil and Environmental Engineering
Syracuse University
Syracuse, New York

Nannan Cheng

State Key Laboratory of Soil Erosion and Dryland Farming on the Loess Plateau
Institute of Soil and Water Conservation
Chinese Academy of Sciences and Ministry of Water Resources
Northwest Agriculture and Forest University
Yangling, People's Republic of China

Ekaterina V. Chuprina

Water Problems Institute of the Russian Academy of Sciences
Moscow, Russia

Theodore G. Cleveland

Associate Professor
Department of Civil, Environmental, and Construction Engineering
Texas Tech University
Lubbock, Texas

Walter Collischonn

Institute of Hydraulic Research
Universidade Federal do Rio Grande do Sul
IPH-UFRGS
Porto Alegre, Brazil

Zhentao Cong

Department of Hydraulic Engineering
Tsinghua University
Beijing, People's Republic of China

James Connauthon

Richmond, California

Corrado Corradini

Department of Civil and Environmental Engineering
Facoltà di Ingegneria
University of Perugia
Perugia, Italy

Alva Couch

Department of Computer Science
Tufts University
Medford, Massachusetts

Norman H. Crawford

Hydrocomp, Inc.
Menlo Park, California

James F. Cruise

Department of Civil and Environmental Engineering
University of Alabama in Huntsville
Huntsville, Alabama

Allegra da Silva

CDM Smith
Denver, Colorado

Baptiste Dafflon

Earth Sciences Division
Lawrence Berkeley National Laboratory
Berkeley, California

Kumer Pial Das

Department of Mathematics
Lamar University
Beaumont, Texas

Claus Davidsen

Department of Environmental Engineering
Technical University of Denmark
Lyngby, Denmark

Rodrigo Cauduro Dias de Paiva

Institute of Hydraulic Research
Federal University of Rio Grande do Sul
Porto Alegre, Brazil

Zhi-Qiang Deng

Department of Civil and Environmental Engineering
Louisiana State University
Baton Rouge, Los Angeles

Georgia Destouni

Department of Physical Geography and Quaternary Geology
Stockholm University
Stockholm, Sweden

Michael DeWeese
National Weather Service
North Central River Forecast Center
Chanhassen, Minnesota

Daniel H. Doctor
Eastern Geology and Paleoclimate Science Center
U.S. Geological Survey
Reston, Virginia

Alessio Domeneghetti
Department DICAM
University of Bologna
Bologna, Italy

A. S. Donigian, Jr.
AQUA TERRA Consultants
Mountain View, California

Charles W. Downer
CEERD-HFH
Coastal and Hydraulics Laboratory
Vicksburg, Mississippi

André Dozier
Department of Civil and Environmental Engineering
Colorado State University
Fort Collins, Colorado

Jim Dumont
Water Infrastructure Specialist
Salt Spring Island, Canada

Dipankar Dwivedi
Earth Sciences Division
Lawrence Berkeley National Laboratory
Berkeley, California

Walter L. Ellenburg
Department of Civil and Environmental Engineering
University of Alabama in Huntsville
Huntsville, Alabama

A. Ercan
Hydrologic Research Laboratory
Department of Civil and Environmental Engineering
University of California
Davis, California

Alvar Escrivá-Bou
Davis, California

James S. Famiglietti
NASA Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Koren Fang
School of Civil and Environmental Engineering
The University of New South Wales
Sydney, Australia

Liping Fang
Department of Mechanical and Industrial Engineering
Faculty of Engineering and Architectural Science
Ryerson University
Toronto, Canada

Bonifacio Fernandez and Jorge Gironás
P.U. Católica de Chile
Chile

Stefan Finsterle
Earth Sciences Division
Lawrence Berkeley National Laboratory
Berkeley, California

Faith A. Fitzpatrick
Fluvial Geomorphology
USGS WI Water Science Center
Middleton, Wisconsin

Darrell Fontane
Department of Civil and Environmental Engineering
Colorado State University
Fort Collins, Colorado

Donald K. Frevert
Retired Hydraulic Engineer and Team Leader
Bureau of Reclamation
Denver, Colorado

Devin L. Galloway
U.S. Geological Survey
Indianapolis, Indiana

Timothy S. Gambrell
Mississippi River Science and Technology Office and Mississippi River Commission
Mississippi Valley Division
U.S. Army Corps of Engineers
Vicksburg, Mississippi

Christian Genest
Department of Mathematics and Statistics
McGill University
Montréal, Canada

Timothy R. Ginn
Department of Civil and Environmental Engineering
University of California
Davis, California

Jorge Gironás
Departamento de Ingeniería Hidráulica y Ambiental
Centro de Investigación para la Gestión Integrada de Desastres Naturales (CIGIDEN)
Centro de Desarrollo Urbano Sustentable (CEDEUS)
Centro Multidisciplinario de Cambio Global
Pontificia Universidad Católica de Chile
Santiago, Chile

Peter H. Gleick
Pacific Institute
Oakland, California

Narendra Kumar Gontia
College of Agricultural Engineering and Technology
Junagadh Agricultural University
Junagadh, India

Jonathan L. Goodall
Department of Civil and Environmental Engineering
University of Virginia
Charlottesville, Virginia

David C. Goodrich
USDA-ARS
Southwest Watershed Research Center
Tucson, Arizona

R. S. Govindaraju
Delon and Elizabeth Hampton Hall of Civil Engineering
Purdue University
West Lafayette, Indiana

Robert E. Griffin
Atmospheric Science Department
Earth System Science Program
University of Alabama in Huntsville
Huntsville, Alabama

Neil S. Grigg
Department of Civil and Environmental Engineering
Colorado State University
Fort Collins, Colorado

Andrew D. Gronewold
NOAA (Great Lakes Environmental Research Laboratory)
University of Michigan (Civil and Environmental Engineering)
NOAA-GLERL
Ann Arbor, Michigan

Georges Gulemuya
Commission Internationale du bassin Congo-Oubangui-Sangha
Kinshasa-Gombe,
Democratic Republic of the Congo

Orhan Gunduz
Dokuz Eylül University
Department of Environmental Engineering
Izmir, Turkey

H. V. Gupta
Department of Hydrology and Water Resources
University of Arizona
Tucson, Arizona

Semyon M. Guzy
Institute "Krasnoyarskgidroproyekt"
Krasnoyarsk State Agricultural University
Krasnoyarsk branch of JSC "SibENTC"
Krasnoyarsk, Russia

Alan F. Hamlet
 Dept. of Civil and Environmental Engineering and Earth Sciences
 University of Notre Dame
 Notre Dame, Indiana

Cameron Handyside
 Earth System Science Center
 University of Alabama in Huntsville
 Huntsville, Alabama

Mohamed M. Hantush
 National Risk Management Research Laboratory
 U.S. Environmental Protection Agency
 Cincinnati, Ohio

Umesh Haritashya
 Department of Geology
 University of Dayton
 Dayton, Ohio

Bekki Ward Harjo
 Senior Hydrologist, National Weather Service
 Arkansas-Red Basin River Forecast Center
 Tulsa, Oklahoma

Nilgun Harmancioglu
 Water Resources Institute
 Dokuz Eylel University
 Izmir, Turkey

Julien J. Harou
 School of Mechanical, Aerospace and Civil Engineering
 The University of Manchester
 Manchester, United Kingdom

Robert Hartman
 HIC, NWS
 Sacramento, California

Hongming He
 Institute of Soil and Water Conservation
 Chinese Academy of Sciences and Ministry of Water Resources
 Yangling, People's Republic of China

Janet Herman
 University of Virginia
 Charlottesville, Virginia

Kith W. Hipel
 Department of Systems Design Engineering
 University of Waterloo
 Waterloo, Canada

Yoshinari Hiroshi
 Faculty of Engineering
 Department of Civil Engineering
 Kyushu University
 Fukuoka, Japan

Michael T. Hobbs
 National Integrated Drought Information System
 NOAA-Earth System Research Laboratory
 Boulder, Colorado

Robert R. Holmes, Jr.
 U.S. Geological Survey
 Rolla, Missouri

Jeffery S. Horsburgh
 Department of Civil and Environmental Engineering
 Utah State University
 Logan, Utah

Chi Hua Huang
 National Soil Erosion Research Laboratory
 West Lafayette, Indiana

Denis Arthur Hughes
 Institute for Water Research
 Rhodes University
 Grahamstown, South Africa

Rui Hui
 University of California, Davis
 Center for Watershed Sciences
 One Shields Avenue
 Davis, California

Justin Huntington
 Desert Research Institute
 Division of Hydrologic Sciences
 Western Regional Climate Center
 Reno, Nevada

John C. Imhoff
 AQUA TERRA Consultants
 Ouray, Colorado

K. Ishida
 Hydrologic Research Laboratory
 Department of Civil and Environmental Engineering
 University of California
 Davis, California

Sharad K. Jain
 Water Resources Systems Division
 National Institute of Hydrology
 Roorkee, India

L. Douglas James
 Fairfax, Virginia

A. W. Jayawardena
 Department of Civil Engineering
 The University of Hong Kong
 Hong Kong, People's Republic of China
 Research and Development Center
 Nippon Koei Co. Ltd. (Engineering Consultants)
 Tsukuba, Japan

Shanhu Jiang
 State Key Laboratory of Hydrology
 Water Resources and Hydraulic Engineering
 Hohai University
 Nanjing, People's Republic of China

Kenji Jinno
 Kyushu University
 Munakata City, Japan

Fiona Johnson
 School of Civil and Environmental Engineering
 The University of New South Wales
 Sydney, Australia

V. Jothiprakash
 Department of Civil Engineering
 Indian Institute of Technology Bombay
 Mumbai, India

Tijana Jovanovic
 Department of Civil and Environmental Engineering
 The Pennsylvania State University
 State College, Pennsylvania

Latif Kalin
 School of Forestry and Wildlife Sciences
 Auburn University
 Auburn, Alabama

Jagath Kaluarachchi
 College of Engineering
 Professor of Civil and Environmental Engineering
 Utah State University
 Logan, Utah

R. Karthikeyan
 Biological and Agricultural Engineering Department
 Texas A&M University
 College Station, Texas

Laila Kasuri
 Chevy Chase, Maryland

Dmitri Kavetski
 School of Engineering
 University of Newcastle
 Callaghan, Australia

M. Levent Kavas
 Department of Civil and Environmental Engineering
 University of California
 Davis, California

Akira Kawamura
 Department of Civil and Environmental Engineering
 Tokyo Metropolitan University
 Tokyo, Japan

Soksmannang Keo
State Key Laboratory of Soil Erosion and Dryland Farming on the Loess Plateau
Institute of Soil and Water Conservation
Chinese Academy of Sciences and Ministry of Water Resources
Northwest Agriculture and Forest University
Yangling, People's Republic of China

Greg Kerr
Office of Water Programs
University of Wyoming
Laramie, Wyoming

Martin Keulertz
Agricultural and Biological Engineering
Purdue University
West Lafayette, Indiana

Jongho Keum
Department of Civil Engineering
McMaster University
Hamilton, Canada

C. Prakash Khedun
Department of Biological and Agricultural Engineering
Texas A&M University
College Station, Texas

Max Kigobe
Department of Civil Engineering
College of Engineering, Design, Art and Technology (CEDAT)
Makerere University
Kampala, Uganda

Thomas R. Kjeldsen
Department of Architecture and Civil Engineering
University of Bath
Bath, United Kingdom

Barbara A. Kleiss
USACE Mississippi Valley Division
Vicksburg, Mississippi

Randal Koster
Global Modeling and Assimilation Office
NASA Goddard Space Flight Center
Greenbelt, Maryland

Andrey Kostianoy
P.P. Shirshov Institute of Oceanology
Russian Academy of Sciences
Moscow, Russia

Demetris Koutsoyiannis
Department of Water Resources and Environmental Engineering
National Technical University of Athens
Heroon Polytechniou
Zographou, Greece

Peter Krahe
BfG - Federal Institute of Hydrology
Koblenz, Germany

Valentina Krysanova
Potsdam Institute for Climate Impact Research
Potsdam
Germany

Lev Kuchment
Laboratory of Water Cycle
Water Problems Institute
Russian Academy of Sciences
Moscow, Russia

George Kuczera
School of Engineering
University of Newcastle
Callaghan, Australia

Bhishm Kumar
Ex Professional Staff
Isotope Hydrology Section
International Atomic Energy Agency (IAEA)
Vienna, Austria
Ex Head
Hydrological Investigations Division
National Institute of Hydrology
Roorkee, India

Zbigniew W. Kundzewicz
Institute of Agricultural and Forest Environment
Polish Academy of Sciences
Poznan, Poland

John Labadie
Department of Civil and Environmental Engineering
Colorado State University
Fort Collins, Colorado

David Labat
Géosciences Environnement Toulouse
Toulouse, France

Venkataraman (Venkat) Lakshmi
Department of Earth and Ocean Sciences
University of South Carolina
Columbia, South Carolina

Upmanu Lall
Department of Earth and Environmental Engineering
Department of Civil Engineering and Engineering Mechanics
Columbia Water Center
International Research Institute for Climate and Society
Columbia University
New York

Alain Laroque
Directeur de Recherche Hydrologie
GET - UMR CNRS / IRD / UPS - UMR 5563 du CNRS, UMR234 de l'IRD
Toulouse, France

Magnus Larson
Department of Water Resources Engineering
Lund Institute of Technology
Lund University
Lund, Sweden

Stanley A. Leake
U.S. Geological Survey
Tucson, Arizona

Chiara Lepore
Ocean and Climate Physics
Lamont-Doherty Earth Observatory
Palisades, New York

L. Ruby Leung
Atmospheric Sciences and Global Change Division
Pacific Northwest National Laboratory
Richland, Washington

Benjamin Lord
Raleigh, North Carolina

Yajie Lu
State Key Laboratory of Soil Erosion and Dryland Farming on the Loess Plateau
Institute of Soil and Water Conservation
Chinese Academy of Sciences and Ministry of Water Resources
Northwest Agriculture and Forest University
Yangling, People's Republic of China

Jay R. Lund
Center for Watershed Sciences
Department of Civil and Environmental Engineering
University of California
Davis, California

Gil Mahe
IRD, Laboratoire Hydro Sciences
Montpellier, France

D. R. Mailapalli
Agricultural and Food Engineering Department
Indian Institute of Technology Kharagpur
Kharagpur, India

Terry Marsh
Centre for Ecology & Hydrology
Wallingford, United Kingdom

Philip Marsh
Water Science Wilfrid Laurier University
Waterloo, Canada

José Pedro Matos
Laboratoire de constructions hydrauliques (LCH)
Ecole polytechnique fédérale de Lausanne (EPFL)
Lausanne, Switzerland

xxxviii CONTRIBUTORS

Larry W. Mays
Arizona State University
Tempe, Arizona

Richard H. McCuen
Civil and Environmental Engineering Department
University of Maryland
College Park, Maryland

Steven G. McNulty
Eastern Forest Environmental Threat Assessment Center
Southern Research Station, USDA Forest Service
Raleigh, North Carolina

Alfonso Mejia
Department of Civil and Environmental Engineering
The Pennsylvania State University
State College, Pennsylvania

Tarek Merabtene
Department of Civil and Environmental Engineering
College of Engineering
University of Sharjah
Sharjah, United Arab Emirates

Venkatesh Merwade
Lyles School of Civil Engineering
Purdue University
West Lafayette, Indiana

Guziy Semyon Mikhailovich
Institute "Krasnoyarskgidroproyekt"
Krasnoyarsk State Agricultural University
Krasnoyarsk branch of JSC "SibENTC"
Krasnoyarsk, Russia

Pavol Miklanek
Institute of Hydrology
Slovak Academy of Sciences
Bratislava, Slovakia

Srikanta Mishra
Energy & Environment
Battelle
Columbus, Ohio

Ashok K. Mishra
Glenn Department of Civil Engineering
Clemson University
Clemson, South Carolina

Natalia N. Mitina
Water Problems Institute of the Russian Academy of Sciences
Moscow, Russia

Iliana E. Mladenova
NASA/GSFC, Hydrological Sciences Branch
Greenbelt, Maryland

Binayak P. Mohanty
Biological and Agricultural Engineering
Texas A&M University
College Station, Texas

Rabi H. Mohtar
Biological and Agricultural Engineering and
Zachry Department of Civil Engineering
Texas A&M University
College Station, Texas

Kazuro Momii
Faculty of Agriculture
Kagoshima University
Korimoto, Japan

Alberto Montanari
Dipartimento di Ingegneria Civile, Chimica, Ambientale e dei Materiali
University of Bologna
Bologna, Italy

R. Morbidelli
Department of Civil and Environmental Engineering
Perugia University
Perugia, Italy

Biswajit Mukhopadhyay
National Practice Leader | Water Resources
North American Infrastructure
Jacobs Engineering Group, Inc.
Dallas, Texas

Dauren Mussabek
Department of Water Resources Engineering
Lund Institute of Technology
Lund University
Lund, Sweden

Kei Nakagawa
Nagasaki University
Graduate School of Fisheries Science and Environmental Studies
Nagasaki University
Nagasaki, Japan

Mohamed K. Nassar
Department of Civil and Environmental Engineering
University of California
Davis, California

Grey S. Nearing
NASA/GSFC
Hydrological Sciences Branch
Greenbelt, Maryland

W. W. Ng
Department of Civil Engineering
Lake Head University
Thunder Bay, Canada

John Nielsen-Gammon
Department of Atmospheric Sciences
Texas A&M University
College Station, Texas

Jun Niu
College of Water Resources and Civil Engineering
China Agricultural University
Beijing, People's Republic of China

Robert K. Niven
School of Engineering and Information Technology
The University of New South Wales
Canberra, Australia

P. E. O'Connell
School of Civil Engineering and Geosciences
Newcastle University
Newcastle upon Tyne, United Kingdom

Greg O'Donnell
School of Civil Engineering and Geosciences
Newcastle University
Newcastle upon Tyne, United Kingdom

Robert Occhipinti
United States Army Corps of Engineers (Retired)

Fred L. Ogden
Department of Civil and Architectural Engineering and
Haub School of Environment and Natural Resources
University of Wyoming
Laramie, Wyoming

N. Ohara
Department of Civil and Architectural Engineering
University of Wyoming
Laramie, Wyoming

C. S. P. Ojha
Department of Civil Engineering
Indian Institute of Technology Roorkee
Roorkee, India

Taha B. M. J. Ouarda
Institute Center for Water and Environment (iWATER)
Masdar Institute of Science and Technology
Abu Dhabi, United Arab Emirates

Hisashi Ozawa
Graduate School of Integrated Arts and Sciences
Hiroshima University
Higashi-Hiroshima, Japan

Umed S. Panu
Department of Civil Engineering
Lake Head University
Thunder Bay, Canada

Simon Michael Papalexiou
Department of Water Resources and Environmental Engineering
National Technical University of Athens
Heron Polytechnic
Zographou, Greece

- Thanos Papanicolaou**
Department of Civil and Environmental Engineering
University of Tennessee
Knoxville, Tennessee
- Sandra Pavlovic**
University Corporation for Atmospheric Research
Boulder, Colorado
- Pavla Pekarova**
Institute of Hydrology
Slovak Academy of Sciences
Bratislava, Slovakia
- Angela Pelle**
Department of Civil and Environmental Engineering
University of Alabama
Tuscaloosa, Alabama
- Mauri Pelto**
Department of Environmental Science
Nichols College
Dudley, Massachusetts
- Silvio J. Pereira-Cardenal**
COWI A/S
Lyngby, Denmark
- Magnus Persson**
Department of Water Resources Engineering
Lund Institute of Technology
Lund University
Lund, Sweden
- Muthiah Perumal**
Department of Hydrology
Indian Institute of Technology Roorkee
Roorkee, India
- Jacob Petersen-Perlman**
Oregon State University
Corvallis, Oregon
- Christa D. Peters-Lidard**
Hydrological Sciences Laboratory
NASA Goddard Space Flight Center
Greenbelt, Maryland
- Hai V. Pham**
Department of Civil and Environmental Engineering
Louisiana State University
Baton Rouge, Louisiana
- Mikolaj Piniewski**
Warsaw University of Life Sciences
Warsaw, Poland
- Paulo Rógenes Monteiro Pontes**
Instituto de Pesquisas Hidráulicas
Universidade Federal do Rio Grande do Sul
IPH-UFRGS
Porto Alegre, Brazil
- Erik C. Porse**
UCLA Institute of the Environment and Sustainability
Los Angeles, California
- Nawa Raj Pradhan**
CEERD-HFH
Coastal and Hydraulics Laboratory
Vicksburg, Mississippi
- James Prairie**
Hydrologic Engineer
Bureau of Reclamation
Upper Colorado Regional Office
Denver Federal Center
Denver, Colorado
- K. S. H. Prasad**
Department of Civil Engineering
Indian Institute of Technology Roorkee
Roorkee, India
- Roland K. Price**
UNESCO-IHE, Institute for Water Education
Delft, The Netherlands
- Fernando Falco Pruski**
Department of Agricultural Engineering
Federal University of Viçosa
Viçosa, Brazil
- Manuel Pulido-Velazquez**
Research Institute of Water and Environmental Engineering (IIAMA)
Universitat Politècnica de València
Valencia, Spain
- Narendra Singh Raghuvanshi**
Agricultural and Food Engineering Department
Indian Institute of Technology Kharagpur
Kharagpur, India
- Ataur Rahman**
Water and Environmental Engineering
School of Computing, Engineering and Mathematics
Western Sydney University
Penrith, Australia
- Balaji Rajagopalan**
Department of Civil, Environmental and Architectural Engineering
University of Colorado
Boulder, Colorado
- H. D. Rank**
Department of Soil and Water Engineering
College of Agricultural Engineering and Technology
Junagadh Agricultural University
Junagadh, India
- Liliang Ren**
International Office
Hohai University
Nanjing, People's Republic of China
- Ben Renard**
School of Engineering
University of Newcastle
Callaghan, Australia
- Pedro J. Respírepo**
National Weather Service
North Central River Forecast Center
Chanhassen, Minnesota
- Mehdi Rezaeianzadeh**
School of Forestry and Wildlife Sciences
Auburn University
Auburn, Alabama
- Niels Riegels**
DHI
Hørsholm, Denmark
- Matthew Rodell**
Hydrological Sciences Laboratory
NASA Goddard Space Flight Center
Greenbelt, Maryland
- Renata del Giudice Rodriguez**
CAPES Foundation
Ministry of Education of Brazil, Brasilia,
Distrito Federal, Brazil
- A. Charles Rowney**
Longwood, Florida
- Albert. I. Rugumayo**
Makerere University
College of Engineering, Design Art and Technology
Department of Civil and Environmental Engineering,
Kampala, Uganda
- Udisha Saklani**
Research Assistant at the Institute of Water Policy
Lee Kuan Yew School of Public Policy
National University of Singapore
Singapore
- Jose D. Salas**
Department of Civil and Environmental Engineering
Colorado State University
Fort Collins, Colorado
- Samuel Sandoval-Solis**
University of California Davis
Dept. LAWR
Davis, California
- Sankar Sarkar**
Physics and Applied Mathematics Unit
Indian Statistical Institute
Kolkata, India

Arup K. Sarma
Department of Civil Engineering
Indian Institute of Technology Guwahati
Guwahati, India

Shinji Sato
Department of Civil Engineering
University of Tokyo
Tokyo, Japan

John Schaake
Annapolis, Maryland

William A. Scharffenberg
CEIWR-HEC
Hydrologic Engineering Center
Davis, California

Anton Schleiss
Laboratoire de constructions hydrauliques (LCH)
Ecole polytechnique fédérale de Lausanne (EPFL)
LCH - ENAC - EPFL
Lausanne, Switzerland

Sergio E. Serrano
Department of Civil and Environmental Engineering
Temple University
Philadelphia, Pennsylvania

Yury V. Shar'ko
Candidate of Physics and Mathematics
Scientific Researcher of the Institute of Computational
Modeling of Siberian Branch of Russian Academy of Sciences, Krasnoyarsk

Ashish Sharma
School of Civil and Environmental Engineering
The University of New South Wales
Sydney, Australia

Jack Sharp
University of Texas
Austin, Texas

Mohsen Sherif
Civil and Environmental Engineering Department
College of Engineering
UAE University
United Arab Emirates

Haiyun Shi
State Key Laboratory of Hydroscience and Engineering
Tsinghua University
Beijing, People's Republic of China

Joel S. Sholtes
Department of Civil and Environmental Engineering
Colorado State University
Fort Collins, Colorado

Lucas Siegfried
Santa Cruz, California

Vijay P. Singh
Department of Biological and Agricultural Engineering &
Zachry Department of Civil Engineering
Texas A&M University
College Station, Texas

Bellie Sivakumar
School of Civil and Environmental Engineering
The University of New South Wales
Sydney, Australia

Brian E. Skahill
CEERD-HFH
Coastal and Hydraulics Laboratory
Vicksburg, Mississippi

Lambert K. Smedema
Independent Irrigation/Drainage Consultant
Arnhem, The Netherlands

S. Sorooshian
University of California
Irvine, California

Jery R. Stedinger
School of Civil and Environmental Engineering
Cornell University
Ithaca, New York

R. Subbaiah
Department of Soil and Water Engineering
College of Agricultural Engineering and Technology
Junagadh Agricultural University
Junagadh, India

Caroline A. Sullivan
School of Environment, Science and Engineering
Marine Ecology Research Centre
Southern Cross University
New South Wales, Australia

Ge Sun
Eastern Forest Environmental Threat Assessment Center
Southern Research Station, USDA Forest Service
Raleigh, North Carolina

Liqun Sun
Department of Civil Engineering
The University of Hong Kong
Hong Kong, People's Republic of China

Óli G. B. Sveinsson
Landsvirkjun (The National Power Company of Iceland)
Reykjavík, Iceland

David G. Tarboton
Department of Civil and Environmental Engineering
Utah State University
Logan, Utah

Gokmen Tayfur
Department of Civil Engineering
Izmir Institute of Technology
Urla, Turkey

Charles J. Taylor
Water Resources Section
Kentucky Geological Survey
University of Kentucky
Lexington, Kentucky

Ramesh S. V. Teegavarapu
Department of Civil Environmental and Geomatics Engineering
Hydrosystems Research Laboratory (HRL)
Boca Raton, Florida

A. K. Thakur
Darbhanga College of Engineering
Darbhanga, India

Reed Thayer
Center for Watershed Sciences
University of California
Davis, California

Mark Thyer
School of Engineering
University of Newcastle
Callaghan, Australia

Ezio Todini
Institute of Hydraulic Construction
University of Bologna
Bologna, Italy

Glenn Tootle
The University of Alabama
Department of Civil, Construction and Environmental Engineering (CCEE)
Tuscaloosa, Alabama

Cecilia Tortajada
Third World Centre for Water Management
Mexico

Shivam Tripathi
Department of Civil Engineering
Indian Institute of Technology Kanpur
Kanpur, India

Frank T.-C. Tsai
Louisiana State University
Department of Civil and Environmental Engineering
Baton Rouge, Los Angeles

Raphael M. Tshimanga
Department of Natural Resources Management & CB-HYDRONET
Faculty of Agronomic Sciences
University of Kinshasa
Kinshasa, Democratic Republic of the Congo

Yeou-Koung Tung
Taiwan, People's Republic of China

Kamshat Tussupova
Department of Water Resources Engineering
Lund University
Lund, Sweden

Julie A. Vano
Research Applications Laboratory
National Center for Atmospheric Research

Jennifer C. Veilleux
Oregon State University
Corvallis, Oregon

Daniele Veneziano
Department of Civil and Environmental Engineering
Massachusetts Institute of Technology
Cambridge, Massachusetts

R. Vignesh
Department of Civil Engineering
Indian Institute of Technology Bombay
Mumbai, India

Gabriele Villarini
IIHR-Hydroscience and Engineering
The University of Iowa
Civil and Environmental Engineering
Iowa City, Iowa

Richard M. Vogel
Department of Civil and Environmental Engineering
Tufts University
Medford, Massachusetts

Haruko M. Wainwright
Earth Sciences Division
Lawrence Berkeley National Laboratory
Berkeley, California

Glenn Warner
Department of Natural Resources and the Environment
The University of Connecticut
Storrs, Connecticut

Wallace A. Wilson
ASFPM Foundation

Fitsum M. Woldemeskel
School of Civil and Environmental Engineering
The University of New South Wales
Sydney, Australia

Aaron T. Wolf
Oregon State University
Corvallis, Oregon

Ming-ko Woo
School of Geography and Earth Sciences
McMaster University
Hamilton, Canada

Ralph A. Wurbs
Zachry Department of Civil Engineering
Texas A&M University
College Station, Texas

Yi Xiao
Department of Systems Design Engineering
University of Waterloo
Waterloo, Canada

Dawen Yang
Tsinghua University
Beijing, People's Republic of China

Daqing Yang
National Hydrology Research Center
Environment Canada
Saskatoon, Canada

Xiaoli Yang
State Key Laboratory of Hydrology
Water Resources and Hydraulic Engineering
Hohai University
Nanjing, People's Republic of China

Sooyeon Yi
University of California
Davis, California

Peter C. Young
Systems and Control Group
Lancaster Environment Centre
Lancaster University
Lancaster, United Kingdom

S. Yu
Witte Moscow University
Moscow, Russia

Fei Yuan
State Key Laboratory of Hydrology
Water Resources and Hydraulic Engineering
Hohai University
Nanjing, People's Republic of China

Edith Zagora
Research Professor
Department of Civil, Architectural and Environmental Engineering
University of Colorado
Boulder, Colorado

Kaveh Zamani
Research Professor
Department of Civil, Environmental and Architectural Engineering
University of Colorado
Boulder, Colorado

Ilya Zaslavsky
Spatial Information Systems Laboratory
San Diego Supercomputer Center
University of California, San Diego
La Jolla, California

Qiang Zhang
Department of Water Resources and Environment
Sun Yat-sen University
Guangzhou, People's Republic of China

Lan Zhang
Assistant Professor
Department of Civil Engineering
University of Akron
Akron, Ohio

Igor S. Zonn
Engineering Scientific-Production Center for Water Economy Reclamation & Ecology
Moscow, Russia

International Advisory Board

Chair: Richard H. McCuen
Department of Civil & Environmental Engineering
University of Maryland
Maryland

Andras Bardossy
Lehrstuhl für Hydrologie und Geohydrologie
Institute für Wasser- und Umwelt systemmodellierung
Universität Stuttgart
Stuttgart, Germany

Ronny Berndtsson
Department of Water Resources Engineering & Center for Middle Eastern Studies
Lund University
Lund, Sweden

Corrado Corradini
Department of Civil and Environmental Engineering
University of Perugia
Perugia, Italy

James F. Cruise
Department of Civil and Environmental Engineering, University of Alabama
Huntsville, Alabama

João Pedroso de Lima
Department of Civil Engineering
University of Coimbra
Coimbra, Portugal

M. Fiorentino
Department of Environmental Engineering and Physics
University of Basilicata
Potenza, Italy

R. S. Govindaraju
Delon and Elizabeth Hampton Hall of Civil Engineering
Purdue University
West Lafayette, Indiana

Nilgun B. Harmancioğlu
Dokuz Eylül University
Water Resources Management
Research & Application Center (SUMER)
Izmir, Turkey

Sharad Kumar Jain
Water Resources Systems Division
National Institute of Hydrology
Roorkee, India

M. Levent Kavvas
Department of Civil and Environmental Engineering
University of California
Davis, California

Lev Kuchment
Laboratory of Hydrological Cycle
Water Problems Institute of the Russian Academy of Sciences,
Moscow, Russia

Venkat Laxmi
Department of Earth and Ocean Sciences
University of South Carolina
Columbia, South Carolina

Upmanu Lall
Department of Earth and Environmental Engineering and Department of Civil Engineering and
Engineering Mechanics
Columbia Water Center
International Research Institute for Climate and Society
Columbia University
New York

P. E. O'Connell
School of Civil Engineering and Geosciences
Newcastle University
New Castle upon Tyne, United Kingdom

C. S. P. Ojha
Department of Civil Engineering
Indian Institute of Technology Roorkee
Roorkee, India

U. S. Panu
Department of Civil Engineering
Lakehead University
Ontario, Canada

Fernando Falco Pruski
Agricultural Engineering Department
Federal University of Viçosa
Viçosa, Minas Gerais State, Brazil

Liliang Ren
State Key Laboratory of Hydrology, Water Resources and Hydraulic Engineering
Hohai University
Nanjing, China

Dan Rosbjerg
Department of Environmental Engineering
Technical University of Denmark
Copenhagen, Denmark

Jose D. Salas
Department of Civil and Environmental Engineering
Colorado State University
Fort Collins, Colorado

Sergio E. Serrano
Department of Civil & Environmental Engineering
Temple University
Philadelphia, Pennsylvania

Ashish Sharma
School of Civil and Environmental Engineering
The University of New South Wales
Sydney, New South Wales, Australia

Bellie Sivakumar
School of Civil and Environmental Engineering
The University of New South Wales
Sydney, Australia

Witold Strupczewski
Water Resources Department
Institute of Geophysics
Polish Academy of Sciences
Warsaw, Poland

Ezio Todini
University of Bologna
Bologna, Italy

Dawen Yang
Department of Hydraulic Engineering
Tsinghua University
Beijing, China

Qiang Zhang
Department of Water Resources and Environment
Sun Yat-sen University
Guangzhou, China



Practitioner Advisory Board

Chair:6. R.D. Singh
National Institute of Hydrology
Roorkee
India

Aaron R. Byrd
Research Hydraulic Engineer & Branch Chief
Hydrologic Systems Branch
Coastal and Hydraulics Laboratory
Engineer Research Development Center
U.S. Army Corps of Engineers
Vicksburg, Mississippi

Anthony S. Donigian, Jr.
AQUA TERRA Consultants
Mountain View, California

Donald K. Frevert
Retired Hydraulic Engineer and Team Leader
Bureau of Reclamation
Denver, Colorado

Randall (Randy) W. Gentry
Argonne National Laboratory
Environmental Science Division
Argonne, Illinois

Mohamed M. Hantush
Research Hydrologist
National Risk Management Research Laboratory
U.S. Environmental Protection Agency
Cincinnati, Ohio

T. Moramarco
National Research Council, Institute for Hydrogeological Protection,
Perugia, Italy

John W. Mueller
State Conservation Engineer
USDA-NRCS
Temple, Texas

B. Mukhopadhyay
Richardson, Texas
J. Obeysekara
Hydrologic & Environmental Systems Modeling
South Florida Water Management District

