Contents

1 Water Resources Planning and Management: An Overview ................................... 1
  1.1 Introduction ......................................................... 1
  1.2 Planning and Management Issues: Some Case Studies .................................... 2
    1.2.1 Kurds Seek Land, Turks Want Water ........................................... 3
    1.2.2 Sharing the Water of the Jordan River Basin: Is There a Way? ................ 5
    1.2.3 Mending the “Mighty and Muddy” Missouri ................................... 6
    1.2.4 The Endangered Salmon ....................................................... 8
    1.2.5 Wetland Preservation: A Groundswell of Support and Criticism .............. 10
    1.2.6 Lake Source Cooling: Aid to Environment, or Threat to Lake? ............... 10
    1.2.7 Managing Water in the Florida Everglades .................................... 12
    1.2.8 Restoration of Europe’s Rivers and Seas ...................................... 14
    1.2.9 Flood Management on the Senegal River .................................... 19
    1.2.10 Nile Basin Countries Striving to Share Its Benefits ......................... 20
    1.2.11 Shrinking Glaciers at Top of the World ..................................... 22
    1.2.12 China, a Thirsty Nation ..................................................... 22
    1.2.13 Managing Sediment in China’s Yellow River ................................ 23
    1.2.14 Damming the Mekong (S.E. Asia), the Amazon, and the Congo .......... 23
  1.3 So, Why Plan, Why Manage? ........................................... 28
    1.3.1 Too Little Water ....................................................... 30
    1.3.2 Too Much Water ......................................................... 31
    1.3.3 Too Polluted ........................................................... 31
    1.3.4 Too Expensive ........................................................ 32
    1.3.5 Ecosystem Too Degraded .................................................. 32
    1.3.6 Other Planning and Management Issues .................................... 33
  1.4 System Planning Scales ............................................... 33
    1.4.1 Spatial Scales for Planning and Management .................................. 33
    1.4.2 Temporal Scales for Planning and Management ................................. 34
1.5 Planning and Management Approaches .......................... 34
  1.5.1 Top-Down Planning and Management .................... 34
  1.5.2 Bottom-Up Planning and Management .................... 34
  1.5.3 Integrated Water Resources Management .................. 36
  1.5.4 Water Security and the Sustainable Development Goals (SDGs) .................. 36
  1.5.5 Planning and Management Aspects ....................... 37
1.6 Planning and Management Characteristics ..................... 40
  1.6.1 Integrated Policies and Development Plans ............... 40
  1.6.2 Sustainability ............................................. 42
1.7 Meeting the Planning and Management Challenges—A Summary ............... 43
References ................................................................. 45
Exercises ................................................................. 48

2 Water Resource Systems Modeling: Its Role in Planning and Management ............... 51
  2.1 Introduction ....................................................... 51
  2.2 Modeling Water Resource Systems ............................ 53
    2.2.1 An Example Modeling Approach .......................... 54
    2.2.2 Characteristics of Problems to be Modeled .......... 55
  2.3 Challenges Involving Modeling ................................ 57
    2.3.1 Challenges of Planners and Managers ................ 57
    2.3.2 Challenges of Modelers .................................. 58
    2.3.3 Challenges of Applying Models in Practice .......... 60
    2.3.4 Evaluating Modeling Success ......................... 61
  2.4 Developments in Modeling .................................... 62
    2.4.1 Technology ................................................. 62
    2.4.2 Algorithms .................................................. 63
    2.4.3 Interactive Model-Building Environments ............ 63
    2.4.4 Open Modeling Systems ................................. 68
  2.5 Conclusions ..................................................... 69
References ................................................................. 70
Exercises ................................................................. 71

3 Models for Identifying and Evaluating Alternatives ............... 73
  3.1 Introduction ....................................................... 73
  3.1.1 Model Components ....................................... 74
  3.2 Plan Formulation and Selection ................................ 75
    3.2.1 Plan Formulation ................................... 76
    3.2.2 Plan Selection ....................................... 78
  3.3 Conceptual Model Development ................................ 80
  3.4 Simulation and Optimization .................................. 81
    3.4.1 Simulating a Simple Water Resources System .......... 82
    3.4.2 Defining What to Simulate ............................. 84
    3.4.3 Simulation Versus Optimization ...................... 85
  3.5 Conclusions ..................................................... 86
Reference ................................................................. 87
Exercises ................................................................. 88
4 An Introduction to Optimization Models and Methods .......... 93
  4.1 Introduction ........................................... 93
  4.2 Comparing Time Streams of Economic Benefits and Costs ........................................... 94
    4.2.1 Interest Rates .................................. 95
    4.2.2 Equivalent Present Value ....................... 95
    4.2.3 Equivalent Annual Value ....................... 96
  4.3 Nonlinear Optimization Models and Solution Procedures ........................................... 97
    4.3.1 Solution Using Calculus ....................... 98
    4.3.2 Solution Using Hill Climbing .................. 98
    4.3.3 Solution Using Lagrange Multipliers ........ 99
  4.4 Dynamic Programming ................................ 105
    4.4.1 Dynamic Programming Networks and Recursive Equations ........................................... 105
    4.4.2 Backward-Moving Solution Procedure ........ 108
    4.4.3 Forward-Moving Solution Procedure .......... 112
    4.4.4 Numerical Solutions ............................ 113
    4.4.5 Dimensionality ................................. 115
    4.4.6 Principle of Optimality ....................... 115
    4.4.7 Additional Applications ....................... 115
    4.4.8 General Comments on Dynamic Programming ........................................... 137
  4.5 Linear Programming .................................. 137
    4.5.1 Reservoir Storage Capacity-Yield Models .... 138
    4.5.2 A Water Quality Management Problem .......... 142
    4.5.3 A Groundwater Supply Example ............... 151
    4.5.4 A Review of Linearization Methods ........... 158
  4.6 A Brief Review ....................................... 163
Reference ....................................................... 164
Exercises ....................................................... 165

5 Data-Fitting, Evolutionary, and Qualitative Modeling .......... 179
  5.1 Introduction ........................................... 179
  5.2 Artificial Neural Networks ............................ 181
    5.2.1 The Approach ................................... 181
    5.2.2 An Example ..................................... 184
  5.3 Evolutionary Algorithms ................................ 186
    5.3.1 Genetic Algorithms .............................. 187
    5.3.2 Example Iterations ............................. 190
    5.3.3 Differential Evolution ........................... 193
    5.3.4 Covariance Matrix Adaptation Evolution Strategy ........................................... 193
  5.4 Genetic Programming ................................... 193
  5.5 Qualitative Functions and Modeling ........................ 195
    5.5.1 Linguistic Functions .............................. 195
    5.5.2 Membership Functions ......................... 196
    5.5.3 Illustrations of Qualitative Modeling .......... 197
6 An Introduction to Probability, Statistics, and Uncertainty

6.1 Introduction

6.2 Probability Concepts and Methods
   6.2.1 Random Variables and Distributions
   6.2.2 Expected Values
   6.2.3 Quantiles, Moments, and Their Estimators
   6.2.4 L-Moments and Their Estimators

6.3 Distributions of Random Events
   6.3.1 Parameter Estimation
   6.3.2 Model Adequacy
   6.3.3 Normal and Lognormal Distributions
   6.3.4 Gamma Distributions
   6.3.5 Log-Pearson Type 3 Distribution
   6.3.6 Gumbel and GEV Distributions
   6.3.7 L-Moment Diagrams

6.4 Analysis of Censored Data

6.5 Regionalization and Index-Flood Method

6.6 Partial Duration Series

6.7 Stochastic Processes and Time Series
   6.7.1 Describing Stochastic Processes
   6.7.2 Markov Processes and Markov Chains
   6.7.3 Properties of Time Series Statistics

6.8 Synthetic Streamflow Generation
   6.8.1 Introduction
   6.8.2 Streamflow Generation Models
   6.8.3 A Simple Autoregressive Model
   6.8.4 Reproducing the Marginal Distribution
   6.8.5 Multivariate Models
   6.8.6 Multiseason, Multisite Models

6.9 Stochastic Simulation
   6.9.1 Generating Random Variables
   6.9.2 River Basin Simulation
   6.9.3 The Simulation Model
   6.9.4 Simulation of the Basin
   6.9.5 Interpreting Simulation Output

6.10 Conclusions

References
Exercises
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.4</td>
<td>Chance Constrained Models</td>
<td>306</td>
</tr>
<tr>
<td>7.5</td>
<td>Markov Processes and Transition Probabilities</td>
<td>308</td>
</tr>
<tr>
<td>7.6</td>
<td>Stochastic Optimization</td>
<td>311</td>
</tr>
<tr>
<td>7.6.1</td>
<td>Probabilities of Decisions</td>
<td>316</td>
</tr>
<tr>
<td>7.6.2</td>
<td>A Numerical Example</td>
<td>317</td>
</tr>
<tr>
<td>7.7</td>
<td>Summary</td>
<td>327</td>
</tr>
<tr>
<td>8</td>
<td>System Sensitivity and Uncertainty Analysis</td>
<td>331</td>
</tr>
<tr>
<td>8.1</td>
<td>Introduction</td>
<td>331</td>
</tr>
<tr>
<td>8.2</td>
<td>Issues, Concerns, and Terminology</td>
<td>332</td>
</tr>
<tr>
<td>8.3</td>
<td>Variability and Uncertainty in Model Output</td>
<td>334</td>
</tr>
<tr>
<td>8.3.1</td>
<td>Natural Variability</td>
<td>336</td>
</tr>
<tr>
<td>8.3.2</td>
<td>Knowledge Uncertainty</td>
<td>337</td>
</tr>
<tr>
<td>8.3.3</td>
<td>Decision Uncertainty</td>
<td>338</td>
</tr>
<tr>
<td>8.4</td>
<td>Sensitivity and Uncertainty Analyses</td>
<td>339</td>
</tr>
<tr>
<td>8.4.1</td>
<td>Uncertainty Analyses</td>
<td>339</td>
</tr>
<tr>
<td>8.4.2</td>
<td>Sensitivity Analyses</td>
<td>344</td>
</tr>
<tr>
<td>8.5</td>
<td>Performance Indicator Uncertainties</td>
<td>362</td>
</tr>
<tr>
<td>8.5.1</td>
<td>Performance Measure Target Uncertainty</td>
<td>362</td>
</tr>
<tr>
<td>8.5.2</td>
<td>Distinguishing Differences Between</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Performance Indicator Distributions</td>
<td>366</td>
</tr>
<tr>
<td>8.6</td>
<td>Communicating Model Output Uncertainty</td>
<td>367</td>
</tr>
<tr>
<td>8.7</td>
<td>Conclusions</td>
<td>370</td>
</tr>
<tr>
<td>8</td>
<td>References</td>
<td>371</td>
</tr>
<tr>
<td>8</td>
<td>Exercises</td>
<td>373</td>
</tr>
<tr>
<td>9</td>
<td>Performance Criteria</td>
<td>375</td>
</tr>
<tr>
<td>9.1</td>
<td>Introduction</td>
<td>375</td>
</tr>
<tr>
<td>9.2</td>
<td>Informed Decision-Making</td>
<td>376</td>
</tr>
<tr>
<td>9.3</td>
<td>Performance Criteria and General Alternatives</td>
<td>377</td>
</tr>
<tr>
<td>9.3.1</td>
<td>Constraints on Decisions</td>
<td>378</td>
</tr>
<tr>
<td>9.3.2</td>
<td>Tradeoffs Among Performance Criteria</td>
<td>379</td>
</tr>
<tr>
<td>9.4</td>
<td>Quantifying Performance Criteria</td>
<td>380</td>
</tr>
<tr>
<td>9.4.1</td>
<td>Economic Criteria</td>
<td>380</td>
</tr>
<tr>
<td>9.4.2</td>
<td>Environmental Criteria</td>
<td>389</td>
</tr>
<tr>
<td>9.4.3</td>
<td>Ecological Criteria</td>
<td>389</td>
</tr>
<tr>
<td>9.4.4</td>
<td>Social Criteria</td>
<td>392</td>
</tr>
<tr>
<td>9.5</td>
<td>Multicriteria Analyses</td>
<td>393</td>
</tr>
<tr>
<td>9.5.1</td>
<td>Dominance</td>
<td>394</td>
</tr>
<tr>
<td>9.5.2</td>
<td>The Weighting Method</td>
<td>395</td>
</tr>
<tr>
<td>9.5.3</td>
<td>The Constraint Method</td>
<td>396</td>
</tr>
<tr>
<td>9.5.4</td>
<td>Satisficing</td>
<td>398</td>
</tr>
<tr>
<td>9.5.5</td>
<td>Lexicography</td>
<td>398</td>
</tr>
<tr>
<td>9.5.6</td>
<td>Indifference Analysis</td>
<td>399</td>
</tr>
<tr>
<td>9.5.7</td>
<td>Goal Attainment</td>
<td>400</td>
</tr>
</tbody>
</table>
9.5.8 Goal Programming .......................... 401
9.5.9 Interactive Methods ...................... 402
9.5.10 Plan Simulation and Evaluation ......... 402
9.6 Statistical Summaries of Performance Criteria .... 407
  9.6.1 Reliability ............................... 409
  9.6.2 Resilience ............................... 409
  9.6.3 Vulnerability ............................. 409
9.7 Conclusions .................................. 410
References ..................................... 411
Exercises ........................................ 411

10 Water Quality Modeling and Prediction ............. 417
  10.1 Introduction .................................. 417
  10.2 Establishing Ambient Water Quality Standards .... 418
    10.2.1 Water Use Criteria ..................... 419
  10.3 Water Quality Model Use ..................... 420
    10.3.1 Model Selection Criteria ............... 421
    10.3.2 Model Chains ......................... 422
    10.3.3 Model Data ............................ 423
  10.4 Models of Water Quality Processes .......... 425
    10.4.1 Mass Balance Principles ............... 425
    10.4.2 Steady-State Models ................... 428
    10.4.3 Design Streamflows for Setting and Evaluating Quality Standards .... 430
    10.4.4 Temperature ......................... 432
    10.4.5 Sources and Sinks ..................... 433
    10.4.6 First-Order Constituents ............... 433
    10.4.7 Dissolved Oxygen ...................... 433
    10.4.8 Nutrients and Eutrophication .......... 437
    10.4.9 Toxic Chemicals ....................... 441
    10.4.10 Sediments ............................ 446
    10.4.11 Processes in Lakes and Reservoirs .... 446
  10.5 Simulation Methods .......................... 452
    10.5.1 Numerical Accuracy ..................... 452
    10.5.2 Traditional Approach ................... 453
    10.5.3 Backtracking Approach .................. 455
    10.5.4 Model Uncertainty ..................... 457
  10.6 Conclusions—Implementing a Water Quality Management Policy .................. 458
References ..................................... 459
Exercises ........................................ 462

11 River Basin Modeling ............................. 469
  11.1 Introduction .................................. 469
  11.2 Model Time Periods .......................... 470
  11.3 Streamflow Estimation ....................... 471
  11.4 Streamflow Routing .......................... 472
Water Resource Systems Planning and Management
An Introduction to Methods, Models, and Applications
Loucks, D.P.; van Beek, E.
2017, XX, 624 p. 363 illus., 356 illus. in color.,
Hardcover
ISBN: 978-3-319-44232-7