

WATER RESOURCES SYSTEMS PLANNING AND MANAGEMENT

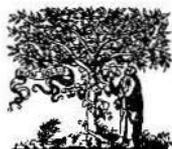


S.K. Jain

*National Institute of Hydrology,
Roorkee 247 667, Uttaranchal,
India*

V.P. Singh

*Department of Civil and Environmental Engineering,
Louisiana State University,
Baton Rouge, LA 70803-6405,
USA*



2003

ELSEVIER

Amsterdam - Boston - Heidelberg - London - New York - Oxford
Paris - San Diego - San Francisco - Singapore - Sydney - Tokyo

CONTENTS

Preface	vii
Acknowledgments	x
Part I Preliminaries	1
Chapter 1 Introduction to Water Resources Systems	3
1.1 Need for Water	6
1.1.1 Likely Future Trends of Water Demands	10
1.1.2 Water and Ecosystems	11
1.2 Availability of Water	12
1.2.1 Water Resources Assessment	14
1.3 Technology for Meeting Water Needs	18
1.4 Water Resources Planning	19
1.5 Water Resources Development	20
1.6 Water Resources Management	21
1.7 Water Resources Systems	26
1.7.1 Concept of a System	26
1.7.2 Systems Analysis Techniques	29
1.7.3 Characteristics of Water Resources Systems	30
1.8 Issues in Systems Approach	31
1.8.1 Potential of Systems Analysis Approach	32
1.8.2 Economics in Systems Engineering	33
1.9 Advantages and Limitations of Systems Approach	34
1.10 Challenges in Water Sector	36
1.11 An Example Water Resources System – Sabarmati System	40
1.11.1 Regulation of Sabarmati System	43
1.12 Closure	43
1.13 References	44
Chapter 2 Acquisition and Processing of Water Resources Data	47
2.1 Types of Water Resources Data	48
2.1.1 Time-Oriented Data	50
2.1.2 Space-Oriented Data	50
2.1.3 Relation-Oriented Data	50
2.1.4 Techniques for Observation of Water Resources Data	51
2.1.5 Sources of Data	52
2.2 Design of Hydrometeorological Networks	52
2.2.1 Precipitation Networks	53

	2.2.2 Streamflow Networks	54
2.3	Data Validation	55
	2.3.1 Primary Validation	58
	2.3.2 Secondary Validation	58
	2.3.3 Hydrological Validation	58
	2.3.4 Data Fill-in	59
2.4	Acquisition and Processing of Precipitation Data	59
	2.4.1 Precipitation Gages	59
	2.4.2 Processing of Precipitation Data	64
	2.4.3 Spatial Interpolation of Precipitation Data	67
	2.4.4 Disaggregation of Rainfall Data	75
	2.4.5 Rain Storm Analysis	75
2.5	Acquisition and Processing of other Meteorological Data	76
	2.5.1 Pan Evaporation Data	76
	2.5.2 Temperature and Humidity Data	78
	2.5.3 Wind Speed and Direction	79
	2.5.4 Sunshine Duration	80
	2.5.5 Automatic Hydrologic Stations	80
2.6	Acquisition and Processing of Streamflow Data	81
	2.6.1 Selection of Gauging Sites	82
	2.6.2 Measurement of Stage	83
	2.6.3 Measurement of Discharge	85
	2.6.4 Processing of Streamflow Data	94
2.7	Water Quality Data	99
	2.7.1 Physical Parameters	99
	2.7.2 Chemical Parameters	101
	2.7.3 Biological Parameters	103
	2.7.4 Sediment Data	104
	2.7.5 Processing of Water Quality Data	106
2.8	Other Data	107
	2.8.1 Ground Water Data	107
	2.8.2 Reservoir and Lake Data	108
	2.8.3 Spatial Data	108
	2.8.4 Socio-economic and Agriculture Data	109
	2.8.5 Water Use and Demand Data	111
	2.8.6 Data Gathered during System Operation	112
2.9	Water Resource Information System	114
	2.9.1 Data Transmission	115
	2.9.2 Data Storage and Retrieval	116
	2.9.3 Data Dissemination	118
2.10	Closure	119
2.11	References	119
Chapter 3 Emerging Techniques for Data Acquisition and Systems Modeling . 123		
3.1	Remote Sensing	123
	3.1.1 Basic Components of Remote Sensing Data Collection	126

3.1.2	Remote Sensing Sensors	127
3.1.3	Remote Sensing Platforms	128
3.1.4	Resolution of Remote Sensing Data	131
3.1.5	Reflectance Characteristics of Earth Features	132
3.1.6	Remote Sensing Data Analysis	135
3.1.7	Digital Image Processing	135
3.1.8	Applications of Remote Sensing to Water Resources Problems ...	141
3.1.9	Cost of Remote Sensing Analysis	146
3.2	Geographic Information Systems	146
3.2.1	Geographic Data Types	148
3.2.2	GIS Data Structure	151
3.2.3	Geographic Coordinate Systems	157
3.2.4	GIS-User Interface	160
3.2.5	Steps of GIS Based Analysis	160
3.2.6	Analysis of Geographic Data using a GIS	162
3.2.7	Digital Terrain Model (DTM)	167
3.2.8	GIS Applications in Water Resources	169
3.2.9	Conclusions	171
3.3	Artificial Neural Networks	171
3.3.1	Structure and Classification of ANNs	173
3.3.2	Feed-forward ANNs	173
3.3.3	Designing an ANN	176
3.3.4	Training of ANN	176
3.3.5	Error Back Propagation Algorithm	178
3.3.6	Cascade Correlation Algorithm	182
3.3.7	Modular Neural Network	183
3.3.8	Radial-Basis Function Networks	184
3.3.9	Applications	186
3.3.10	Issues in ANN Applications	187
3.4	Expert Systems	189
3.4.1	Expert Systems Architecture	191
3.4.2	ES Development	192
3.4.3	ES Techniques	193
3.4.4	ES Tools	193
3.4.5	Knowledge Base	194
3.4.6	Inference Engine	195
3.4.7	Applications in Water Resources	196
3.5	Closure	198
3.6	References	199
Chapter 4	Statistical Techniques for Data Analysis	207
4.1	Basic Concepts	208
4.1.1	Distribution Characteristics	210
4.2	Probability Distributions	215
4.2.1	Continuous Probability Distributions	217
4.2.2	Discrete Probability Distributions	221

4.3	Methods of Parameter Estimation	222
4.3.1	Method of Moments for Continuous Systems	223
4.3.2	Method of Moments for Discrete Systems	224
4.3.3	Method of Probability Weighted Moments	226
4.3.4	Methods of Mixed Moments	227
4.3.5	Method of L-Moments	227
4.3.6	Method of Maximum Likelihood Estimation (MLE)	229
4.3.7	Method of Least Squares	230
4.4	Concept of Entropy	230
4.4.1	Principle of Maximum Entropy	231
4.4.2	Entropy-Based Parameter Estimation	232
4.5	Problems of Parameter Estimation	232
4.6	Hypothesis Testing	235
4.6.1	The t-test	238
4.6.2	Chi-square Distribution	239
4.7	Linear Regression	240
4.7.1	Parameter Estimation	241
4.7.2	Goodness of Regression	241
4.7.3	Inferences on Regression Coefficients	243
4.7.4	Confidence Intervals	243
4.7.5	Extrapolation	247
4.8	Multiple Linear Regression	248
4.8.1	Estimation of Regression Coefficients	249
4.8.2	Inferences on Regression Coefficients	249
4.8.3	Stepwise Regression	250
4.9	Correlation Analysis	251
4.9.1	Cross-Correlation	251
4.9.2	Serial or Auto-Correlation	252
4.9.3	Inferences on Correlation Coefficients	253
4.10	Frequency Analysis	254
4.10.1	Point Frequency Analysis	255
4.10.2	Frequency-Factor Method	256
4.10.3	Confidence Limits	258
4.10.4	Regional Frequency Analysis	259
4.10.5	Index Flood Method	259
4.10.6	Multiple Regression Method	262
4.11	Time Series Analysis	262
4.11.1	Stationary Stochastic Processes	264
4.11.2	Time Series Models	264
4.11.3	Partial Autocorrelation Function	266
4.11.4	Fitting of ARMA Models	267
4.12	Markov Models	271
4.13	Closure	274
4.14	References	274

Part II Decision Making	277
Chapter 5 Systems Analysis Techniques	279
5.1 Systems Analysis Techniques	279
5.2 Optimization	280
5.2.1 Classification of Optimization Techniques	282
5.3 Linear Programming	282
5.3.1 Assumptions in LP	283
5.3.2 Mathematical Representation of an LP Problem	283
5.3.3 Formulation of an LP Model	285
5.3.4 Reduction of a General LP Problem to a Standard Form	286
5.3.5 Canonical Form of an LP Problem	287
5.3.6 Graphical Solution of a LP Problem	288
5.3.7 Simplex Method of LP	290
5.3.8 Duality in LP	294
5.3.9 Post Optimality Analysis	296
5.3.10 Important Classes of LP Problems	296
5.4 Nonlinear Programming	297
5.4.1 Lagrange Multipliers and Kuhn-Tucker Conditions	299
5.4.2 Classification of Nonlinear Programming Methods	300
5.4.3 Unconstrained Nonlinear Programming Methods	300
5.4.4 Constrained Nonlinear Programming Methods	304
5.4.5 Some Common Problems in NLP Applications	306
5.5 Dynamic Programming	307
5.5.1 Recursive Equation of DP	309
5.5.2 Discrete Differential DP	312
5.5.3 Advantages and Disadvantages of DP	313
5.6 Stochastic Optimization	314
5.6.1 Chance-constrained Linear Programming	315
5.6.2 Stochastic Dynamic Programming	316
5.7 Multi-Objective Optimization	319
5.7.1 Classification of Multi-objective Optimization Techniques	324
5.7.2 Generating Techniques	324
5.7.3 Surrogate Worth Trade-off Method	326
5.8 Goal Programming	328
5.8.1 Goal Programming Model	330
5.9 Simulation	337
5.9.1 Classification of Simulation Models	338
5.9.2 Monte Carlo Simulation	339
5.9.3 Time Management in Simulation	340
5.9.4 Design of Sampling Strategy	341
5.9.5 Steps in Simulation Modeling	342
5.9.6 Inputs to Simulation Models	343
5.9.7 Outputs of Simulation Models	344
5.9.8 Pros and Cons of Simulation Models	344
5.10 Closure	345

Appendix	5A.1 Generation of Random Numbers	346
	5A.2 Transformation of Random Numbers	347
5.11	References	349
Chapter 6	Economic Considerations	351
6.1	Basic Principles of Project Economics	352
6.1.1	Cash Flow Diagram	353
6.1.2	Discount Rate	353
6.1.3	Discount Factors	355
6.1.4	Sunk Cost	357
6.1.5	Intangible Values	357
6.1.6	Salvage Value	358
6.1.7	Marginal Returns	358
6.1.8	Planning Horizons	358
6.2	Demand and Utility of Water	359
6.2.1	Water Demand and Cost	359
6.2.2	Elasticity of Water Demand	361
6.2.3	Utility Theory	361
6.3	Project Economics and Evaluation	363
6.3.1	Project Cost	363
6.3.2	Project Installation Cost	363
6.3.3	Rehabilitation and Resettlement Costs	364
6.3.4	Operation, Maintenance and Replacement Costs	365
6.3.5	Total Annual Cost	365
6.3.6	Project Benefits	366
6.4	Discounting Techniques	366
6.5	Benefit-Cost Ratio Method	367
6.5.1	Steps of BC Analysis	368
6.5.2	Incremental Benefit and Cost	370
6.5.3	Economic Rationale of Benefit-Cost Analysis	372
6.6	Other Discounting Methods	373
6.6.1	Present Worth Method	373
6.6.2	Rate-of-Return Method	375
6.6.3	Comparison of BC Ratio and IRR Method	377
6.6.4	Annual Cost Method	379
6.6.5	Comparison of Discounting Techniques	380
6.7	Project Feasibility and Optimality	381
6.7.1	Cost and Benefit Curves	383
6.7.2	Optimal Allocation of Water to Individual Users	383
6.7.3	Optimal Allocation of Water among Different Uses	384
6.7.4	Allocation of Ground Water	385
6.7.5	Project Optimality	385
6.8	Allocation of Project Cost	386
6.8.1	Cost Allocation Practices in India	389
6.8.2	Funding Needs in Water Sector	389
6.8.3	Case Study of Dharoi Project	390

6.9	Closure	392
6.10	References	392
Chapter 7	Environmental and Social Considerations	395
7.1	Dynamism of Environment	396
7.2	Water in Environment	397
7.3	Environmental Impacts of Water Resources Projects	398
7.3.1	Adverse Impacts	401
7.3.2	Beneficial Impacts	403
7.4	Environmental Impacts of Reservoirs	405
7.4.1	Physical Impacts	406
7.4.2	Biological Impacts	409
7.4.3	Small Dams Versus Big Dams	410
7.5	Environmental Problems in Command Areas	413
7.6	Environmental Impact Assessment	415
7.6.1	Environmental Impact Assessment Procedure	416
7.6.2	Techniques of Environmental Impact Assessment	417
7.6.3	Indices for Environmental Impact Assessment	427
7.6.4	Current EIA Procedures	429
7.7	Integration of Environmental Aspects in Water Resources Planning	430
7.7.1	Optimization Methods	432
7.8	Environmental Considerations in Reservoir Planning and Operation	433
7.8.1	Guidelines of ICOLD	433
7.8.2	Guidelines for Planning	435
7.9	Sustainable Development	436
7.9.1	Defining Sustainable Development	437
7.9.2	Issues in Sustainable Development	440
7.10	Social Impacts	442
7.10.1	Rehabilitation and Resettlement	444
7.11	Case Study - Sardar Sarovar Project, India	448
7.11.1	The Project	449
7.11.2	The Controversy	451
7.11.3	The Protests by NGO's	452
7.11.4	Project Status	453
7.12	Closure	454
7.13	References	454
	Appendix 7A The Report of World Commission on Dams	457
Chapter 8	Rational Decision Making	459
8.1	Concept of Rationality	461
8.2	Risk Analysis and Management	462
8.2.1	Classification of Risks	466
8.2.2	Sources of Risk	467
8.2.3	Estimation of Risk	469
8.2.4	Risk Management	471
8.3	Uncertainty Analysis	472

8.3.1	Classification of Uncertainty	472
8.3.2	Sources of Uncertainty	474
8.3.3	Analysis of Errors	474
8.3.4	Analysis of Uncertainty	480
8.3.5	Value of Information	484
8.4	Utility Theory	485
8.4.1	Expected Monetary Value of a Decision	487
8.4.2	Improving the Decision Policy	489
8.4.3	Sensitivity Analysis	489
8.5	Systems Techniques for Rational Decision Making	492
8.5.1	Stochastic Optimization	492
8.5.2	Stochastic Simulation	494
8.6	Bayesian Decision Making	495
8.6.1	Bayes' Theorem	495
8.6.2	Application of Bayes' Theorem	496
8.7	Closure	501
8.8	References	501
 Part III Water Resources Planning and Development		503
 Chapter 9 Water Resources Planning		505
9.1	Integrated Planning	508
9.2	Stages in Water Resources Planning	509
9.2.1	Relationship among Stages	511
9.3	Data Collection and Processing	513
9.3.1	Specification and Sources of Data	513
9.3.2	Data Adequacy	514
9.3.3	Data Quality Control	515
9.3.4	Data Systems	515
9.4	Estimation of Future Water Demands	516
9.4.1	Water Requirements for Irrigation	517
9.4.2	Municipal Water Use	519
9.5	Plan Initiation and Preliminary Planning	520
9.5.1	Dependency of Water Sector Plan on Other Sectors	522
9.5.2	Articulation of Project Objectives	522
9.5.3	Project Constraints	523
9.5.4	Planning for Operation	524
9.5.5	Conjunctive Use Planning	525
9.6	Institutional Set-up	525
9.6.1	Involvement of Experts	526
9.6.2	Decision Making Levels	527
9.6.3	Compatibility among Agencies	528
9.6.4	Capacity Building	528
9.7	Public Involvement	528
9.7.1	Advantages of Public Involvement	530

9.7.2	Activities in Public Involvement Process	531
9.8	Formulation and Screening of Alternatives	533
9.8.1	Classification of Alternatives	533
9.8.2	Generation of Alternatives	534
9.8.3	Techniques for Screening Alternatives	534
9.8.4	Evaluation of Alternatives and Finalization	534
9.9	Models for Water Resources Planning	535
9.9.1	System Decomposition	536
9.9.2	Selection of Systems Analysis Tools	537
9.9.3	Use of Multi-objective Analysis	538
9.9.4	Object-Oriented Modeling Approach	540
9.9.5	Model Credibility	540
9.10	Sensitivity Analysis	541
9.10.1	Risk and Uncertainty Analysis	541
9.10.2	Uncertainties Associated with Objectives and Constraints	542
9.10.3	Post-evaluation of Projects	543
9.11	Interaction between Analyst and Decision-maker	543
9.11.1	Presentation of Results	544
9.12	Water Resource Planning – Case Studies	545
9.12.1	Ganga-Brahmaputra-Barak Basin Study	545
9.12.2	Water Resources Planning for Egypt	549
9.13	Closure	550
9.14	References	551
Chapter 10	Reservoir Sizing	555
10.1	Need for Reservoirs	556
10.1.1	Classification of Reservoirs	558
10.2	Characteristics and Requirements of Water Uses	558
10.3	Reservoir Planning	561
10.3.1	Site Selection Criteria for a Reservoir	561
10.3.2	Investigations for Planning a Reservoir	562
10.4	Estimation of Water Yield Using Flow Duration Curves	566
10.4.1	Procedure to Prepare a Flow Duration Curve	567
10.4.2	Use of Flow Duration Curves	568
10.5	Hydropower Generation	569
10.5.1	Components of Hydropower Projects	571
10.5.2	Estimating Hydropower Potential and Demand	573
10.6	Reservoir Losses	574
10.6.1	Evaporation Losses	575
10.6.2	Seepage Losses	576
10.6.3	Leakage through Dam	576
10.6.4	Water Balance of a Reservoir	576
10.7	Range Analysis	577
10.7.1	Hurst Phenomenon	578
10.7.2	Dependence in Hydrologic Time-Series	579
10.7.3	Sensitivity of Reservoir Storage to Inflow Statistics	580

10.8	Regulation Regime Function	581
10.8.1	Development of Components of Regime Function	582
10.9	Reservoir Capacity Computation	583
10.9.1	Storage Zones in a Reservoir	584
10.10	Storage Requirement for Conservation Purposes	585
10.10.1	Mass Curve Method	586
10.10.2	Sequent Peak Algorithm	589
10.10.3	Stretched – Thread Rule	590
10.10.4	Storage-Yield Analysis	591
10.10.5	Simulation Method (Behavior Analysis)	593
10.10.6	Reservoir Screening	595
10.11	Flood Control Storage Capacity	595
10.11.1	Reservoir Design Flood	596
10.12	Reservoir Routing	598
10.12.1	Reservoir Routing Techniques	599
10.12.2	Mass Curve Method	599
10.12.3	Modified Puls Method	600
10.12.4	Coefficient Method	601
10.12.5	Reservoir Routing with Controlled Outflow	602
10.12.6	Major Applications of Storage Routing	602
10.12.7	General Comments	603
10.13	Fixing Top of Dam	606
Appendix 10.A	Definitions	607
Appendix 10.B	Fixing Live Storage Capacity of Dharoi Reservoir	609
10.14	References	611
Part IV Systems Operation and Management		613
Chapter 11 Reservoir Operation		615
11.1	Conflicts in Reservoir Operation	616
11.2	Critical Issues in Reservoir Operation	617
11.2.1	Use of Flood Storage	618
11.2.2	Use of Total Storage	618
11.2.3	Release of Stored Water	619
11.2.4	Release by Reservoir	619
11.2.5	Use of Available Water	619
11.2.6	Release Elevation	619
11.3	Basic Concepts of Reservoir Operation	620
11.3.1	Long-range Planning Schedules	621
11.3.2	Rigid Operation Schedules	621
11.3.3	Standard Linear Operating Policy	621
11.4	Rule Curves	623
11.4.1	Derivation of Rule Curves	623
11.4.2	Operation of a Reservoir Using Rule Curves	624
11.4.3	Concept of Storage Zoning	625
11.5	Operation of a Multi-Reservoir System	627

11.5.1	Reservoirs in Series	628
11.5.2	Hydropower Reservoirs	630
11.5.3	Reservoirs in Parallel	632
11.5.4	Other Rules	634
11.5.5	Selective Withdrawal	639
11.6	Reservoir Operation for Flood Control	639
11.6.1	Flood Control Reservation Diagram	641
11.6.2	Approaches to Reservoir Operation during Floods	642
11.6.3	Pre-depletion of Reservoirs	643
11.6.4	Normal and Emergency Operation	645
11.6.5	Flood Control Operation of a Multi-reservoir System	647
11.7	System Engineering for Reservoir Management	650
11.7.1	Optimization	650
11.7.2	Simulation	652
11.7.3	Network Flow Models	654
11.7.4	Linear Decision Rule	654
11.7.5	Recomposition-decomposition Approach	656
11.8	Real-Time Reservoir Operation	660
11.8.1	Logistics Required for Real-time Operation	662
11.8.2	Special Considerations in Real-time Operation	662
11.8.3	Information Dissemination	663
11.8.4	Advantages of Real-time Operation	664
11.9	Development of Operating Rules for Sabarmati System	664
11.9.1	Solution Approach	666
11.9.2	Data Availability and Processing	667
11.9.3	Integrated Conservation Operation of the System	667
11.9.4	Flood Control Operation of the System	670
11.10	Closure	675
11.11	References	676
Chapter 12 Reservoir Sedimentation		681
12.1	Reservoir Sedimentation	684
12.1.1	Problems due to Reservoir Sedimentation	686
12.1.2	Factors Influencing Reservoir Sedimentation	686
12.1.3	Trap Efficiency	687
12.1.4	Sedimentation and Life of a Reservoir	689
12.1.5	Allocation of Space for Sediments	691
12.2	Loss of Storage Capacity	691
12.2.1	Rate of Loss of Storage Capacity	692
12.2.2	Unit-Weight of Deposited Sediments	694
12.2.3	Aggradation and Degradation	696
12.2.4	Distribution of Sediments in Reservoirs	697
12.2.5	Empirical Area Reduction Method	697
12.2.6	Economics of Reservoir Sedimentation	701
12.3	Sediment Yield of Watersheds	702
12.3.1	Methods of Sediment Yield Determination	704

12.3.2	Comparison with Nearby Watersheds and Reservoirs	704
12.3.3	Stream Gaging	705
12.3.4	Mathematical Modelling of Reservoir Sedimentation	706
12.3.5	Universal Soil Loss Equation (USLE)	706
12.3.6	HEC-6 Model	709
12.3.7	The WEPP Model	712
12.4	Reservoir Surveys	715
12.4.1	Contour Survey Method	717
12.4.2	Range Survey Method	717
12.4.3	Instruments for Reservoir Survey	719
12.5	Assessment of Reservoir Sedimentation Using Remote Sensing	721
12.5.1	Identification of Water Spread Area	722
12.5.2	Analysis of Imageries	723
12.5.3	Case Study- Assessment of Sedimentation in Dharoi Reservoir ..	725
12.6	Methods to Control Sediment Inflow into a Reservoir	727
12.6.1	Off-stream Reservoirs	728
12.6.2	Check Dams	728
12.6.3	Watershed Management to Reduce Soil Erosion	728
12.6.4	Vegetative Measures	729
12.6.5	Engineering Measures	730
12.6.6	Watershed Prioritization	731
12.7	Sediment Routing	734
12.7.1	Reservoir Drawdown	734
12.7.2	Density Currents	734
12.7.3	Sediment By-pass	736
12.8	Recovery of Storage Capacity	737
12.8.1	Flushing	737
12.8.2	Dredging	738
12.9	Closure	739
12.10	References	739
Chapter 13 Water Quality Modeling		743
13.1	Relevant Properties of Water	744
13.2	Water Quality Monitoring	746
13.2.1	Monitoring Network	747
13.2.2	Sampling Program	748
13.2.3	Water Quality Standards	749
13.2.4	Water Quality Based Classification of Rivers	749
13.3	River Water Quality Modeling	752
13.3.1	Components of a River Water Quality Model	755
13.3.2	Hydraulic and Thermal Models	755
13.3.3	Biochemical Model	756
13.3.4	Geochemical Processes	756
13.3.5	Sorption/ Desorption	757
13.3.6	Pollutant Concentration and Load	758
13.3.7	Transport of Solutes in Rivers	759

13.3.8	Governing Advective-Diffusion Equation	763
13.4	Modeling of Oxygen in Rivers	765
13.4.1	Dissolved Oxygen (DO)	766
13.4.2	Biochemical Oxygen Demand	766
13.4.3	Chemical Oxygen Demand (COD)	768
13.4.4	Reaeration	768
13.4.5	Modeling of Dissolved Oxygen	770
13.5	Catchment-scale Water Quality Models	772
13.6	Water Quality in Lakes and Reservoirs	775
13.6.1	Differences between Lakes and Reservoirs	776
13.6.2	Chemical Considerations	777
13.6.3	Biological Considerations	778
13.6.4	Lake Mass Balance	779
13.7	Groundwater Quality	781
13.7.1	Models for Groundwater Quality	782
13.8	Closure	784
13.9	References	785
Chapter 14 River Basin Planning and Management		787
14.1	Definition and Scope of River Basin Management	789
14.1.1	Scope of RBM	790
14.1.2	Operations	791
14.1.3	Water Charges	792
14.1.4	Water Rights	794
14.2	Planning and River Basin Management	796
14.2.1	The Planning Process	796
14.2.2	River Basin Planning Systems	797
14.3	Integrated Water Resources Management	797
14.3.1	Conjunctive use of Surface and Ground Water	802
14.3.2	Models for Integrated Water Resources Management	803
14.3.3	Impact of Climate Change on Basin Management	806
14.4	Decision Support Systems (DSS)	809
14.4.1	Definition and Objectives	810
14.4.2	Need and Types of DSS	810
14.4.3	Components of a DSS	811
14.4.4	Designing a DSS	813
14.4.5	Applications	816
14.5	Institutional Aspects of Basin Management	817
14.5.1	Models of RBM	818
14.5.2	Decentralisation and Privatization	819
14.5.3	Monitoring and Analysis	820
14.5.4	Practical Aspects of RBM	821
14.5.5	Role of Financiers	822
14.5.6	Co-operation among Basin Management Organizations	822
14.5.7	Some Important River Basins Organizations	822
14.6	Public Involvement	825

14.6.1 Approaches for PI	826
14.6.2 Information Dissemination and Follow-up	826
14.7 Inter-Basin Water Transfer	827
14.7.1 Planning for IBWT Projects	828
14.7.2 Evaluation of IBWT Projects	829
14.7.3 Examples of IBWT Projects	830
14.8 Management of International River Basins	832
14.8.1 International River Basin Organisations	832
14.8.2 International Initiatives for Freshwater Management	835
14.9 Closure	837
14.10 References	838
Appendix A: Conversion Factors	843
Appendix B: Useful Internet Sites	845
Index	849