



Don D. Ratnayaka
Malcom J. Brandt
K. Michael Johnson

TWORT'S Water Supply

6th Edition



Contents

Foreword by A. C. Twort.....	xxv
Preface.....	xxvii
Abbreviations for Organisations.....	xxix
Contributing Authors, Reviewers and Advisors	xxxi
CHAPTER 1 The Demand for Public Water Supplies	1
1.1 Categories of Consumption	1
1.2 Levels of Total Consumption.....	2
1.3 Domestic Demand	2
Components of Domestic In-House Consumption.....	4
Outdoor Domestic Use for Garden Irrigation and Bathing Pools	5
1.4 Standpipe Demand.....	9
1.5 Suggested Domestic Design Allowances.....	10
1.6 Non Domestic Demand	10
1.7 Public and Miscellaneous Use of Water.....	14
1.8 Water Losses	15
1.9 Real Losses (leakage) from 24-hour Supply Systems.....	20
1.10 Supply Pipe Leakage and Consumer Wastage	22
1.11 Minimum Night Flow as Indicator of Leakage and Wastage.....	22
1.12 Variations in Demand (Peaking Factors).....	23
Maximum and Minimum Hourly rate of consumption	24
Seasonal Variations	24
1.13 Growth Trends of Consumption and Forecasting Future Demand	25
1.14 Water Conservation and Demand Management.....	26
1.15 The Question of Metering Domestic Supplies in the UK	28
1.16 Effect of Price on Water Demand.....	30
1.17 Assessing Future Demand in Developing Countries.....	31
1.18 Consumption Surveys.....	32
1.19 Test-metering In-house Domestic Consumption.....	33
References	34
CHAPTER 2 Water Supply Regulation, Protection, Organisation and Financing	37
Development, Regulation and Protection.....	37
2.1 Control of Public Water Supplies	37
2.2 Control of Abstractions	38

2.3	Public Water Supplies in the USA.....	38
2.4	Public Water Supplies in Mainland Europe	39
2.5	Public Water Supplies in Scotland and Northern Ireland.....	39
2.6	Water Supply Abstraction and Regulation in the England and Wales	40
2.7	The 'Privatisation' of Water in England and Wales	40
2.8	Experience with Water Privatisation in UK	41
2.9	Functions of the US Environmental Protection Agency	42
2.10	The Environment Agency (UK).....	43
2.11	The European Water Framework Directive.....	44
2.12	Other Pollution Control Measures in the UK.....	45
	Organisation	47
2.13	Organization of a Water Utility.....	47
2.14	Staffing Levels	48
	Project Appraisal and Financing of Capital Works	49
2.15	Appraisal Requirements	49
2.16	Economic Comparison of Proposed Capital Projects	50
2.17	Comments on the Use of Discounting.....	51
2.18	Short and Long Term Marginal Costing.....	52
2.19	Other Aspects of Project Assessment	52
2.20	Sustainability and Engineering Choices	53
2.21	Financing of Capital Works	53
2.22	Depreciation and Asset Management Planning.....	54
2.23	Private Sector Participation in Water Supply	55
2.24	Private Sector Build Contracts	55
2.25	Private Sector Operation Agreements	56
2.26	Charging for Public Water Supplies	57
2.27	Comparison of Charges for Water and Other Data	58
	References	60
	CHAPTER 3 Hydrology and Surface Supplies.....	63
	Part I Hydrological Considerations.....	63
3.1	Introduction.....	63
3.2	Catchment Areas	64
3.3	Data Collection	65
3.4	Streamflow Measurement	65
3.5	Rainfall Measurement.....	68
	Measurement of Catchment Rainfall	69
3.6	Evaporation and Transpiration Measurement.....	71
3.7	Soil Moisture Measurement.....	73
3.8	Catchment Losses	73
3.9	Streamflow Naturalisation.....	75
3.10	Long Term Average Catchment Run-off.....	77

3.11	Minimum Rainfalls	78
3.12	Minimum Rates of Run-off	79
3.13	Maximum Rainfalls.....	81
3.14	Maximum Run-offs	82
	Part II Yield of Surface Sources	85
3.15	Introduction, Definitions and Concepts.....	85
3.16	History of Yield Estimation in the Uk	88
3.17	Methods of Yield Estimation—General	88
3.18	River Intake Yields.....	88
3.19	Yield of Direct Supply Impounding Reservoirs	91
3.20	Yield of a Pumped Storage Reservoir.....	94
3.21	Yield of Regulating Reservoirs.....	95
3.22	Yield of Catchwaters.....	97
3.23	Compensation Water.....	99
3.24	Yield of Water Resources Systems.....	100
3.25	Conjunctive Use and Operation Rules	101
3.26	Rainwater Collection Systems.....	102
3.27	The Likely Effects of Climate Change	103
	References	105

CHAPTER 4 Groundwater Supplies..... **109**

4.1	Groundwater, Aquifers and their Management	109
4.2	Yield Uncertainties and Types of Abstraction Works.....	112
	Need for Hydrogeological Survey	113
	Types of Abstraction Works	113
4.3	Potential Yield of an Aquifer	113
4.4	Assessment of Aquifer Characteristics	117
4.5	Groundwater Modelling	120
	Data Requirements.....	121
	Model Calibration.....	122
4.6	Test Pumping of Boreholes and Wells	122
	Test Pumping Regimes.....	123
	Use of Observation Wells and Monitoring	124
4.7	Geophysical and Other Investigation Methods.....	125
4.8	Borehole Linings, Screens and Gravel Packs	126
4.9	Construction of Boreholes and Wells	128
4.10	Development and Refurbishing Boreholes and Wells	131
4.11	Pollution Protective Measures: Monitoring and Sampling.....	131
4.12	River Flow Augmentation by Groundwater Pumping.....	133
4.13	Artificial Recharge and Aquifer Storage Recharge	134
4.14	Groundwater Mining	136
4.15	Island Water Supplies	137

4.16	Collector Wells and Other Underground Water Developments	140
4.17	Borehole and Well Layouts	141
4.18	Choice of Pumping Plant for Wells and Boreholes.....	143
4.19	Environmental Impact Assessments	145
	References	145
CHAPTER 5	Dams, Reservoirs and River Intakes	149
5.1	Introduction.....	149
5.2	Essential Reservoir Conditions.....	150
5.3	Watertightness	150
5.4	Strength and Durability of a Dam	153
5.5	Types of Dam	153
	Embankment Dams	154
5.6	Types of Design	154
5.7	Pore Pressure and Instrumentation in Earth Dams	155
5.8	Stability Analysis in Dam Design	157
5.9	Drainage Requirements for an Earth Dam	159
5.10	Surface Protection of Earth Dams	160
5.11	Rockfill and Composite Dams.....	161
	Concrete and Masonry Dams.....	163
5.12	Gravity Dam Design	163
5.13	Gravity Dam Construction	165
5.14	Roller-compacted Concrete Dams	166
5.15	Arch Dam Design	167
5.16	Buttress or Multiple Arch Dams	168
	Flood and Discharge Provision	168
5.17	Design Flood Estimation	168
	Unit Hydrograph Approach.....	170
5.18	Spillway Flood Routing	172
5.19	Diversion During Construction	174
5.20	Flood Spillways	175
	Integral Spillway.....	175
	Chute Spillway	176
	Bellmouth Spillway	177
	Emergency Spillways.....	178
5.21	Draw-off Arrangements	179
5.22	Seismic Considerations	180
	Dam Regulation, Supervision and Inspection.....	180
5.23	Statutory Control Over Dam Safety.....	180
5.24	Dam Deterioration Signs	182
5.25	Reservoir Sedimentation	183
5.26	Environmental Considerations and Fishpasses	185

5.27	Statutory Consents and Requirements.....	186
5.28	River Intakes	186
	Appendix—Dam Incidents	190
	References	191
CHAPTER 6	Chemistry, Microbiology and Biology of Water.....	195
6.1	Introduction.....	195
	Part I Significant Chemical and Physico-chemical Parameters in Water	195
6.2	Acidity	195
6.3	Acrylamide	196
6.4	Algal Toxins	196
6.5	Alkalinity	196
6.6	Aluminium	197
6.7	Ammoniacal Compounds.....	197
6.8	Antimony	198
6.9	Arsenic	198
6.10	Asbestos	198
6.11	Biochemical Oxygen Demand (Bod)	199
6.12	Boron	199
6.13	Bromide And Iodide	199
6.14	Cadmium.....	199
6.15	Calcium	200
6.16	Carbon Dioxide.....	200
6.17	Chloride	200
6.18	Chlorinated Hydrocarbons.....	200
6.19	Chlorine Residual.....	201
6.20	Colour	201
6.21	Copper.....	202
6.22	Corrosive Quality	202
6.23	Cyanide	203
6.24	Detergents.....	203
6.25	Disinfection By-products.....	203
6.26	Electrical Conductivity and Dissolved Solids	205
6.27	Endocrine Disrupting Substances	205
6.28	Epichlorohydrin	206
6.29	Fluoride.....	206
6.30	Hardness	206
6.31	Hydrocarbons	207
6.32	Iron	208
6.33	Lead.....	208
6.34	Manganese	209
6.35	Nickel.....	209

6.36	Nitrate And Nitrite.....	209
	Nitrate	210
	Nitrite.....	210
6.37	Organic Matter and Chemical Oxygen Demand (Cod).....	211
	Organic Micropollutants	211
6.38	Pesticides	212
6.39	pH Value or Hydrogen Ion	213
6.40	Phenols	213
6.41	Phosphates.....	213
6.42	Polynuclear Aromatic Hydrocarbons (PAHs).....	214
6.43	Radioactive Substances.....	214
6.44	Selenium	216
6.45	Silica.....	216
6.46	Silver	216
6.47	Sodium	216
6.48	Sulphates.....	217
6.49	Suspended Solids	217
6.50	Taste And Odour	217
6.51	Turbidity.....	218
6.52	Zinc	218
Part II Water Quality Standards for Chemical and Physical Parameters		219
6.53	Drinking Water Standards (Chemical and Physical).....	219
	The WHO Guidelines for Drinking-water Quality	219
	The European Commission Directive on the Quality of Water Intended for Human Consumption (CEU, 1998a)	219
	The UK Water Supply (Water Quality) Regulations	221
	The US EPA National Primary Drinking Water Regulations.....	224
6.54	Comment on the Application of Health Related Standards.....	225
6.55	Raw Water Quality.....	227
6.56	Sampling for Physical and Chemical Parameters	231
	Sampling Frequencies to WHO, EC, UK and US EPA Requirements	231
	Minimum Sampling Requirements Where no Regulations Apply.....	232
	Sampling Techniques for Physical and Chemical Parameters.....	232
	On-site Testing and Field Analysis.....	232
	Water Quality Monitoring at Treatment Works.....	233
6.57	Priorities in Water Quality Control.....	234
	Simple Checks at Source Works	234
	Microbiological Testing (See Also Sections 6.69 and 6.70)	234
	Chemical Testing	234
	Source Watch (See Also Part VI)	235
6.58	Methods of Chemical Analysis.....	235
6.59	Quality Assurance of Water Treatment Chemicals and Materials in Contact with Drinking Water	236

Part III	Water Microbiology.....	237
6.60	Diseases in Man that may be caused by	
	Water-borne Bacteria and other Organisms.....	237
6.61	Bacterial Diseases.....	237
6.62	Other Bacteria.....	239
6.63	Protozoal Diseases	239
6.64	Viral Diseases	241
6.65	Microbiological Standards for Drinking Water	241
6.66	Use of Coliforms as an Indicator of Microbiological Pollution	243
6.67	Frequency of Sampling for Microbiological Parameters	244
6.68	Sampling for Routine Microbiological Parameters.....	244
	Method of Sampling.....	245
6.69	Routine Tests for Bacterial Contamination of Water.....	246
6.70	Methodology for Microbiological Examination	247
6.71	Protozoal Examination.....	248
6.72	Virological Examination.....	249
6.73	Nuisance Organisms	249
Part IV	Water Biology.....	250
6.74	Introduction.....	250
6.75	Source Water and Storage Reservoirs.....	250
6.76	Transfer Stages	254
6.77	Treatment Stages.....	254
6.78	Service Reservoirs and Distribution Systems.....	255
Part V	New and Emerging Issues	255
6.79	Introduction.....	255
6.80	Chemical Issues	255
6.81	Microbiological Issues.....	257
Part VI	Water Safety Plans.....	259
6.82	Introduction.....	259
6.83	Water Safety Plans	260
6.84	Development of Water Safety Plans	260
	Catchment.....	261
	Treatment.....	261
	Piped Distribution Systems	261
	Non-piped, Community and Household Systems.....	262
	References.....	262

CHAPTER 7	Storage, Clarification and Chemical Treatment	267
7.1	Raw Water Storage	267
	Potential Problems in Raw Water Storage	268
	Screening	270
7.2	Passive Screens.....	270
7.3	Active Screens.....	271

7.4	Microstrainers	272
	Sedimentation and Settling Tanks.....	273
7.5	General Design Considerations.....	273
7.6	Plain Settling	273
7.7	Theory of Design of Tanks	275
7.8	Grit Tanks	276
	Chemically Assisted Sedimentation or Clarification.....	276
7.9	Chemically Assisted Sedimentation.....	276
7.10	Chemical Mixing.....	277
7.11	Chemical Coagulation and Flocculation	280
7.12	Types of Flocculators.....	281
	Performance Considerations.....	282
7.13	Effect of Organic Content and Algae.....	283
	Clarifiers.....	286
7.14	Horizontal Flow Clarifiers.....	286
7.15	Design Criteria	288
7.16	Sludge Blanket or Solids Contact Clarifiers.....	289
7.17	High Rate Clarifiers	292
	Tube or Plate Settlers	292
	Lamella Clarifiers.....	294
	Other High Rate Clarifiers.....	295
7.18	Dissolved Air Flotation	296
7.19	Sludge Removal From Clarifiers	299
7.20	Chemical Dosing Equipment and Plant Layout.....	301
	Plant Layouts	305
	Coagulants and Coagulant Aids	307
7.21	Aluminium Coagulants	307
7.22	Iron Coagulants.....	309
7.23	Coagulant Aids and Polyelectrolytes	310
7.24	Rainwater Harvesting.....	311
	References	311
CHAPTER 8	Water Filtration Granular Media Filtration	315
8.1	Rapid Filtration—Mechanism	315
8.2	Design And Construction Of Rapid Gravity Filters	316
	Filter Media	316
	Underdrain Systems	317
	Filter Configuration.....	319
	Filtration Rates	319
	Head Loss, Air Binding and Negative Head	320
	Solids Retention	321
	Flow Control.....	321

8.3	Backwashing	322
8.4	Operation of Filters.....	324
8.5	Construction and Operation of Pressure Filters	325
	Multilayer and other Methods of Filtration.....	327
8.6	Use of Anthracite Media	327
8.7	Use of Anthracite to Uprate Filters.....	328
8.8	Granular Activated Carbon Adsorbers.....	329
8.9	Upward Flow Filtration.....	331
8.10	Direct Filtration.....	332
8.11	Filter Problems.....	332
	Slow Sand Filtration.....	333
8.12	Introduction and History	333
8.13	Mode of Action of Slow Sand Filters	334
8.14	Construction and Cleaning of Slow Sand Filters.....	335
8.15	Use of Pre-treatment with Slow Sand Filters.....	337
8.16	Limitations and Advantages of Slow Sand Filters	338
8.17	Membrane Filtration.....	339
8.18	Miscellaneous Filters.....	344
	<i>Cryptosporidium</i> Oocysts and <i>Giardia</i> Cysts Removal.....	345
8.19	<i>Cryptosporidium</i>	345
8.20	<i>Giardia</i> Cysts.....	347
	References	347

CHAPTER 9 Waterworks Waste and Sludge Disposal.....**351**

9.1	Types of Waste	351
9.2	Types and Quantities of Sludges	351
	Quantities.....	353
9.3	Methods of Disposal	355
9.4	Sludge Thickening and Disposal.....	357
9.5	Sludge Dewatering.....	358
9.6	Beneficial Uses of Sludge	362
	References	363

CHAPTER 10 Specialized and Advanced Water Treatment Processes.....**365**

	Softening of Water.....	365
10.1	Hardness Compounds	365
10.2	Principal Methods of Softening.....	365
10.3	The Lime-soda Process of Softening	366
10.4	Softening Plant	367
10.5	Water Softening by Crystallisation	367
10.6	Stabilisation after Softening	368
10.7	Base Exchange Softening	369
10.8	Plant for Ion Exchange Softening.....	369

10.9	Removal of Hardness and Alkalinity by Ion Exchange	370
10.10	Demineralisation of Water by Ion Exchange.....	370
	Removal of Iron, Manganese and Other Metals	372
10.11	Iron and Manganese-General	372
10.12	Removal of Iron and Manganese from Underground Waters.....	372
10.13	Removal of Iron and Manganese from River and Reservoir Waters.....	376
10.14	Removal of other Metals.....	377
	Arsenic	377
	Lead.....	378
	Aluminium	381
10.15	Removal of Radionuclides	381
	Defluoridation and Fluoridation.....	382
10.16	Defluoridation	382
10.17	Fluoridation	383
	Aeration	383
10.18	Purpose.....	383
10.19	Cascade Aerators.....	384
10.20	Packed Tower Aerators.....	385
10.21	Spray Aerators.....	386
10.22	Injection Aerators	387
10.23	Other Types of Aerators	387
	Nitrate Removal.....	388
10.24	General	388
10.25	Ion Exchange Process for Nitrate Removal	388
10.26	Biological Process for Nitrate Removal.....	389
10.27	Membrane Processes for Nitrate Removal.....	390
	Removal of Ammonia	390
10.28	Chemical and Physical Methods	390
10.29	Biological Methods	391
	Removal of Volatile Organic Compounds from Groundwater	392
10.30	General	392
10.31	Packed Tower Aerators.....	392
10.32	Adsorption and Chemical Oxidation	393
	Taste and Odour Removal	393
10.33	Causes of Tastes and Odours	393
10.34	Methods of Removal of Tastes and Odours.....	394
	Hydrogen Sulphide Removal.....	395
	Natural Organic Matter and Micropollutants Removal	396
10.35	General	396
	Granular Activated Carbon Adsorbers	397
10.36	Advanced Treatment Processes.....	397

Biological Activated Carbon Reactors	398
Magnetic Ion Exchange Process	398
10.37 Advanced Oxidation Processes	399
10.38 Colour Removal	400
Corrosion Causes and Prevention	401
10.39 Physical and Electrochemical Corrosion	401
10.40 Bacterial Corrosion.....	402
10.41 Corrosion Caused by Adverse Water Quality	402
10.42 Corrosiveness of Various Waters	404
10.43 Dezincification.....	405
Desalination.....	406
10.44 Introduction	406
10.45 Ion Exchange	407
10.46 Electrodialysis.....	407
10.47 Reverse Osmosis and Nanofiltration.....	408
10.48 RO and NF plant design.....	412
10.49 Thermal Processes.....	416
10.50 The Costs of Desalination.....	417
References	419
CHAPTER 11 Disinfection of Water	425
11.1 Disinfectants Available	425
Chlorine and Chloramine Processes of Disinfection	425
11.2 Action of Chlorine	425
11.3 Chlorine Compounds Produced	426
11.4 Factors Relating to the Disinfection Efficiency of Chlorine.....	427
11.5 Chlorine Residual Concentration and Contact Time.....	428
11.6 Efficiency of Chlorine in Relation to Bacteria, Enteric Viruses and Protozoa	430
11.7 Chlorination and the Production of Disinfection by Products	432
11.8 The Ammonia-Chlorine or Chloramination Process	432
11.9 Breakpoint Chlorination	433
11.10 Superchlorination	434
11.11 Typical Chlorine Dose; Taste and Odour Problems	435
11.12 Use of Chlorine Gas	435
11.13 Dechlorination	437
11.14 Ammoniation	438
11.15 Hypochlorite Production on Site by Electrolysis	439
11.16 Testing for Chlorine	441
11.17 Use of Chlorine Dioxide	442
11.18 Calcium Hypochlorite Powder	443
11.19 Calcium Hypochlorite Granules.....	443

11.20	Sodium Hypochlorite Solution.....	444
	Ozone Process of Disinfection	444
11.21	Action of Ozone	444
11.22	Production of Ozone.....	446
11.23	Ozone Dissolution and Contact	448
	Ultraviolet Radiation.....	451
11.24	UV Disinfection.....	451
11.25	Generation of UV Radiation	451
11.26	Concept of UV Dose and Factors Influencing Dose	
	Delivery in UV Reactors.....	454
11.27	By-product Formation	455
11.28	Validation of UV Reactors	456
11.29	Boiling Water.....	456
	Disinfection of Waterworks Facilities	457
11.30	Disinfection of Water Mains and Tanks.....	457
11.31	Control of Aftergrowth in Distribution Mains.....	458
11.32	Disinfestation of Distribution Mains, Wells and Boreholes.....	458
	References	459
CHAPTER 12	Hydraulics.....	463
12.1	The Energy Equation of Fluid Flow	463
12.2	Boundary Layers.....	465
12.3	Pipe Flow	466
	Units Used	468
12.4	Headlosses in Pipes (1)—The Colebrook-White Formula.....	468
	Darcy-Weisbach Formula	468
	Colebrook-White Formula	469
12.5	Headlosses in Pipes (2)—Empirical Formulae	471
12.6	Local Head Losses at Fittings.....	473
12.7	Open Channel Flow.....	474
12.8	Critical Depth of Flow	477
12.9	Weirs, Flumes and Gates	479
	Weirs	480
	Flumes.....	481
	Gates	482
12.10	Froude Numbers	483
12.11	Head Losses in Channels.....	484
12.12	Hydraulic Jump	487
12.13	Non-uniform, Gradually Varied Flow	488
12.14	Measurement Weirs	490
	Broad-Crested Weir.....	491
	Sharp-Crested, or Thin-Plate Weirs.....	491
	Crump Weirs	493

12.15	Measurement flumes.....	494
	Rectangular-Throated Flume	494
	Other Standard Flumes	495
12.16	Venturi and Orifice Flow Meters.....	496
12.17	Other Flow Meters.....	497
	Appendix—Computational Fluid Dynamics (CFD).....	496
	References	496
CHAPTER 13	System Design and Analysis.....	499
13.1	Introduction.....	499
13.2	System Layouts	500
13.3	Pipeline Planning	502
13.4	Distribution System Characteristics	504
13.5	Designing Trunk Mains.....	506
13.6	Designing Distribution Pipework	507
13.7	Hydraulic Design of Pipelines	508
13.8	System Curves.....	509
13.9	Longitudinal Profile.....	512
13.10	Air in Pipes.....	514
13.11	Transient Pressures: Water Hammer and Surge	516
13.12	Cavitation.....	519
13.13	Example of Sizing a Pumping Main.....	520
13.14	Design of a Gravity Main.....	522
13.15	Pipeline Design Techniques	524
	Manual and Spreadsheet Calculations of Network Flows.....	524
	Analysing Existing Systems using Modelling Software.....	525
13.16	Water Quality Modelling	528
13.17	Updating of Network Models.....	528
13.18	Software Developments	529
	References	530
CHAPTER 14	Distribution Practice	531
14.1	Management of Network Assets.....	531
14.2	Service Levels.....	533
14.3	Distribution Organisation	535
	Differences Under Intermittent Supply Conditions.....	537
	Distribution Network Extensions	537
14.4	Fire-Fighting Requirements	538
14.5	Service Pipes	539
	Service Pipe Materials	540
14.6	Domestic Flow Requirements and Design of Service Pipes	543
	Flow Requirements	543
	Service Pipe Design	545

14.7	Waterworks Byelaws	545
	Distribution System Maintenance.....	546
14.8	Network Performance.....	546
14.9	Mains Rehabilitation and Cleaning.....	547
	Mains Cleaning Methods.....	547
14.10	Pipe Lining Methods	548
14.11	Pipe Replacement	549
14.12	Controlling Water Losses.....	550
14.13	Leakage Strategy.....	551
14.14	District Metering.....	553
14.15	Locating Leaks.....	554
	Waste Metering and Step-Testing	554
	Locating Leaks by Sound.....	555
	Other Leak Location Technologies.....	556
14.16	Repairing Leaks.....	557
14.17	Rehabilitation, Leak Detection and Development of Distribution Systems in Disrepair	557
	Reference Standards.....	559
	References.....	559
CHAPTER 15	Pipeline Design and Construction	561
15.1	Pipe Development	561
15.2	Materials and Potable Water	561
15.3	Types of Pipes and Organisations Setting Standards.....	562
	Pipeline Design.....	562
15.4	Introduction.....	562
15.5	Structural Design of Pipes.....	562
15.6	Flexible Pipe Design	565
15.7	Above Ground Pipelines	566
	Iron Pipes.....	567
15.8	Cast or 'Grey' Iron Pipes.....	567
15.9	Ductile Iron Pipes	567
15.10	External Coatings and Internal Linings	569
15.11	Joints for Iron Pipes	569
	Steel Pipes.....	571
15.12	Steel Pipe Manufacture and Materials	571
15.13	External and Internal Protection of Steel Pipe	572
15.14	Mortar and Concrete Linings	574
15.15	Joints for Steel Pipes	575
15.16	Cathodic Protection	577
	Plastic Pipes	578
15.17	Polyethylene Pipes	578

15.18	Polyvinyl Chloride (PVC) Pipes.....	580
15.19	Glass Reinforced Plastics (GRP).....	581
	Concrete Pipes	583
15.20	Prestressed Concrete Pressure Pipes	583
15.21	Reinforced Concrete Cylinder Pipes.....	585
15.22	Asbestos Cement Pipes	586
15.23	Anchorage and Thrust Blocks	587
	Pipeline Construction	589
15.24	Choice of Pipes	589
15.25	Pipe Laying and Installation	590
15.26	Testing of Pipelines.....	593
15.27	Making Connections	595
15.28	Underwater Pipelines	595
	Reference Standards	596
	References.....	598
CHAPTER 16	Valves and Meters	599
	Part I Valves.....	599
16.1	Valve Development	599
16.2	Valve Functions.....	599
16.3	Isolation	600
16.4	Regulation.....	600
16.5	Control.....	600
16.6	Valve Selection and Specification.....	603
16.7	Gate Valves	605
16.8	Butterfly Valves.....	606
16.9	Globe Valves	607
16.10	Screwdownd Valves.....	607
16.11	Ball Valves.....	608
16.12	Plug Valves.....	609
16.13	Diaphragm Valves.....	609
16.14	Pinch Valves.....	610
16.15	Needle Valves	610
16.16	Sleeve Valves	611
16.17	Hollow Jet Discharge Valves.....	611
16.18	Non-return (or check) Valves	611
16.19	Flap Valves.....	612
16.20	Cavitation at Valves	613
16.21	Valve Operating Equipment	614
16.22	Valve Closure Speed.....	614
16.23	Washouts.....	615
16.24	Air Valves	616

16.25	Valve Chambers	619
Part II	Measurement of Flow and Consumption.....	620
16.26	Purposes of Flow Measurement.....	620
16.27	Types of Flowmeter	621
16.28	Volumetric Flowmeters.....	621
16.29	Permanent Flowmeter Installations	624
16.30	Temporary Flow Measurement Devices	625
16.31	Supply (Revenue) Meters.....	625
16.32	The Accuracy of Water Meters	627
16.33	Future Trends in Metering.....	628
	References	629

CHAPTER 17 Pumping; electrical plant; control and instrumentations.....631

Part I	Pumps.....	631
17.1	Pumping Plant.....	631
17.2	Centrifugal Pumps	631
17.3	Types of Centrifugal Pump	632
	Submersible Pumps.....	633
17.4	Characteristics of Centrifugal Pumps	635
	Affinity Laws	636
	NPSH	637
	Specific Speed.....	638
17.5	Axial Flow and Mixed Flow Pumps	638
17.6	Reciprocating Pumps.....	640
17.7	Choice of Pumps for Water Supply	641
	Standby Pumping Plant.....	641
17.8	Boosting	642
	Addition of Fixed Extra Flow or Pressure	642
	Maintenance of a Given Pressure	643
17.9	Increasing Pumping Station Output.....	644
17.10	Station Arrangement and Plant Layout	644
17.11	Pump Suction Design.....	645
17.12	Thermodynamic Pump Performance Monitoring System.....	647
17.13	Cavitation Damage	648
17.14	Corrosion Protection	648
17.15	Transient Pressures: Water Hammer and Surge	648
17.16	Efficiencies and Fuel Consumptions	649
17.17	Pump Drives	650
Part II	Electrical Plant	650
17.18	Electric Motors for Pump Drives	650
17.19	The Induction Motor	651
	Rated Output, Starting Torque and Start Frequency.....	652
17.20	Induction Motor Starting Methods	653

17.21	Induction Motor Protection	655
17.22	Speed Control of Induction Motors	655
17.23	Effect of Electricity Tariffs	657
17.24	Electrical Power Supplies	657
17.25	Standby and Site Power Generation	658
17.26	Transformers	659
17.27	HV and LV Switchboards	660
17.28	Motor Control Centres	660
17.29	Electrical Cabling	661
17.30	Heating and Ventilation	661
Part III	Control and Instrumentation (C&I)	661
17.31	Introduction	661
17.32	Control	662
17.33	Automation	662
17.34	Instrumentation	663
	Level	663
	Pressure	664
	Water Quality	664
17.35	Systems	665
17.36	Communications	667
17.37	Hardware	668
17.38	Ancillary Equipment	669
17.39	Operation and Maintenance	669
	References	669

CHAPTER 18	Treated Water Storage	671
18.1	Functions of Treated Water Storage	671
18.2	Storage Capacity Required	672
	Minimum Storage to Even Out Hourly Demand	672
	Contingency Storage	673
18.3	Ground or Elevated Storage	674
18.4	Statutory Consents and Requirements	674
18.5	Water Quality Considerations	675
18.6	Sampling and Water Testing	675
18.7	Instrumentation	675
18.8	Overflow and Drain Down Capacity	676
18.9	Ventilation	677
18.10	Water Retaining Concrete Design	677
18.11	Welded Steel Plate Design	678
	Service Reservoirs	679
18.12	Reservoir Shape and Depth	679
18.13	Covering and Protecting Reservoirs	680
18.14	Service Reservoir Structures	681

18.15	Rectangular Jointed Concrete Reservoirs	681
18.16	Monolithic Concrete Reservoirs	684
18.17	Circular Reinforced Concrete Reservoirs	685
18.18	Pre-stressed Concrete Reservoirs.....	686
18.19	Steel Plate Reservoirs.....	687
18.20	Other types of Ground Level Tank	688
18.21	Drainage and Waterproofing Concrete Service Reservoirs	689
18.22	Access to Service Reservoirs.....	689
18.23	Service Reservoir Pipework.....	690
	Inlet Pipework	690
	Outlet Pipework.....	691
	Overflow and Draindown Arrangements	692
	Valves	692
18.24	Valve Houses for Service Reservoirs	693
18.25	Baffles in Service Reservoirs	693
18.26	Testing Service Reservoirs	694
18.27	Searching for Leaks	694
	Water Towers.....	695
18.28	Use of Water Towers.....	695
18.29	Concrete Water Towers	696
18.30	Welded Steel Water Towers	697
18.31	Segmental Plate Tanks	698
18.32	Pipework and Access for Water Towers.....	698
	Reference Standards.....	698
	References.....	698
	Conversion Table	699