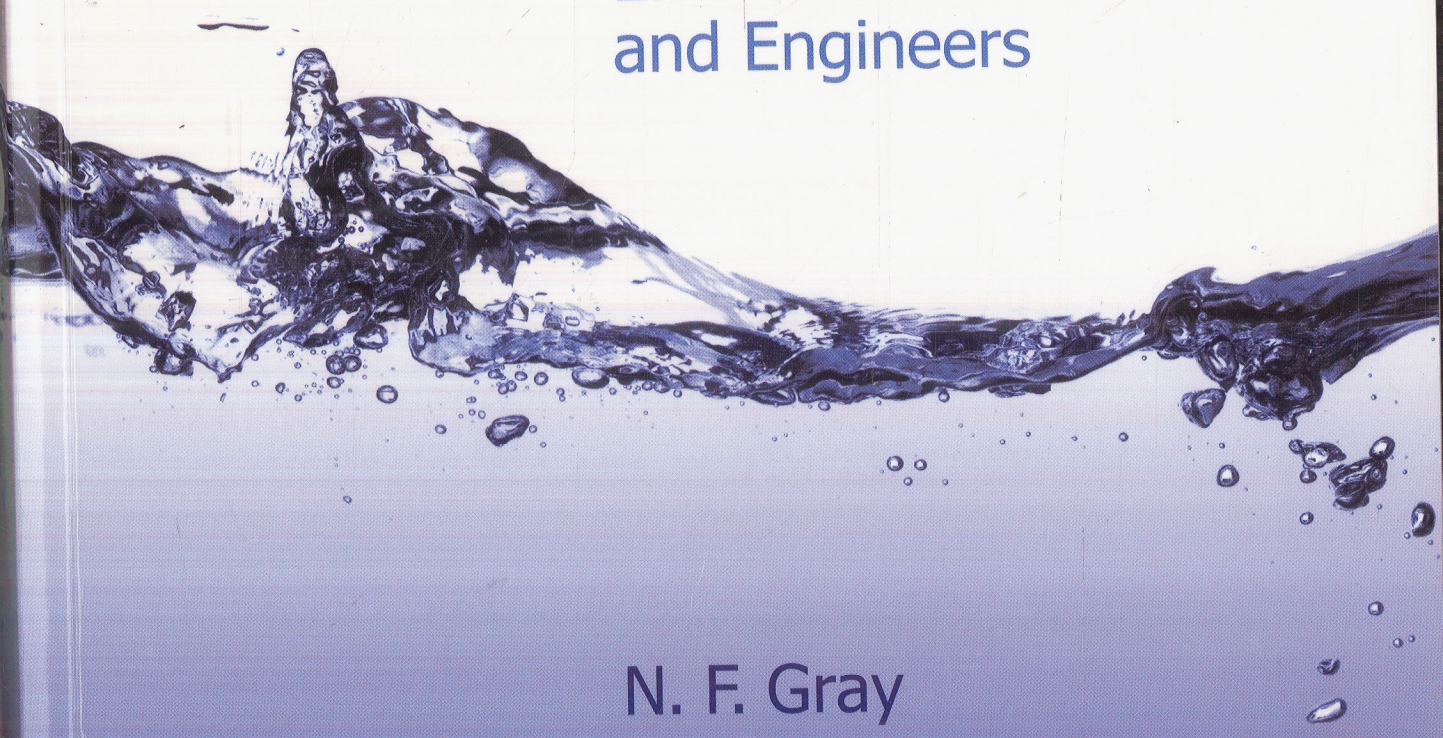


THIRD EDITION

Water Technology

An Introduction for
Environmental Scientists
and Engineers



N. F. Gray



Contents

<i>Preface</i>	<i>xvii</i>
<i>Acknowledgements</i>	<i>xix</i>

Part I

Water Resources and Ecology	1
1. Basic Considerations in Hydrobiology	3
<hr/>	
1.1 Hydrological cycle	3
1.2 Comparison between freshwater and saline water	6
1.3 Freshwater habitats	7
1.4 The catchment as area of study	8
1.5 Effect of climate change on freshwaters	9
References	11
Further reading	12
Interactive sites	12
2. Water Resources and Demand	13
<hr/>	
2.1 Surface waters	13
2.1.1 Rivers and lakes	13
2.1.2 Reservoirs	18
2.2 Groundwater	20
2.2.1 Groundwater quality	25
2.3 Water demand	27
References	33
Further reading	34
Interactive sites	35
3. Factors Determining the Distribution of Animals and Plants in Freshwaters	39
<hr/>	
Introduction	39
3.1 Natural dispersion	39
3.1.1 Expected species	39
3.1.2 Alien or exotic species	40

3.2	Catchment water quality	44
3.3	River flow and substrate	46
3.4	Dissolved solids	50
3.5	Dissolved oxygen and temperature	55
3.6	Suspended solids	58
3.7	River zonation	61
3.8	Lentic systems	62
	References	64
	Further reading	65
	Interactive sites	66
4.	Basic Aquatic Ecosystems	67
<hr/>		
	Introduction	67
4.1	Community structure	67
4.2	Allochthonous and autochthonous inputs	73
4.3	Functional feeding groups	74
4.4	Habitat zonation	82
4.5	Lentic ecology	86
	References	90
	Further reading	91
	Interactive sites	91
5.	Micro-organisms and Pollution Control	93
<hr/>		
	Introduction	93
5.1	Nutritional classification	94
5.2	Oxygen requirement of bacteria	97
5.3	Microbial oxygen demand	98
	5.3.1 Self-purification	98
	5.3.2 Oxygen balance	100
	5.3.3 Reaeration	100
	5.3.4 The oxygen-sag curve	103
5.4	The BOD test	109
	References	116
	Further reading	116
	Interactive sites	116
6.	Water Pollution	117
<hr/>		
	Introduction	117
6.1	Toxic substances	118
6.2	Suspended solids	124

6.2.1	Inert solids	124
6.2.2	Oxidizable solids	126
6.3	Deoxygenation	127
6.4	Addition of non-toxic salts	130
6.4.1	Algal toxins	135
6.5	Heating of the water	138
6.6	The effect on the buffering system	140
6.6.1	Acid rain	140
6.6.2	Acid mine drainage	141
6.7	Groundwater pollution	144
6.8	Conclusion	145
	References	146
	Further reading	147
	Interactive sites	147

Part II

Water Quality Management and Assessment 149

7. Water Basin Management 151

	Introduction	151
7.1	Basic management programme for rivers	151
7.2	Water quality and catchment management plans	155
7.2.1	Water quality management plans	155
7.2.2	Catchment management	155
7.3	The Water Framework Directive	161
7.3.1	Introduction	161
7.3.2	River basin districts	163
7.3.3	River basin characterization	164
7.3.4	Implementation of the Water Framework Directive in the UK	165
7.3.5	River basin planning	167
7.3.6	Environmental monitoring	169
7.3.7	Ecological classification system for surface and ground waters	169
7.3.8	Priority and other specific polluting substances	170
7.3.9	Conclusion	177
7.4	Flood control and diffuse pollution	178
7.4.1	Sustainable urban drainage systems	182
7.4.2	Agriculture and water quality protection	187
7.4.3	Afforestation and water quality protection	187
7.4.4	Conclusion	190

References	190
Further reading	191
Interactive sites	192

8. Water Quality and Regulation **194**

Introduction	194
8.1 Potable waters	194
8.2 Surface waters not used primarily for supply	212
8.3 Wastewaters	216
8.4 Groundwaters	221
8.5 Regulation	225
8.6 Integrated pollution control (IPC)	226
References	230
Further reading	230
Interactive sites	231

9. Water Quality Assessment **233**

9.1 Physico-chemical and biological surveillance	233
9.2 Sampling surface waters	234
9.2.1 Sampling programmes	234
9.2.2 Mixing	237
9.2.3 Safety	239
9.2.4 Hydrology	240
9.2.5 Chemical sampling	246
9.2.6 Biological sampling	247
9.3 Biological indices	256
9.3.1 Pollution indices	257
9.3.2 Diversity indices	274
9.3.3 Using biological indices	277
9.3.4 Multivariate analysis	279
9.4 Chemical data	282
9.4.1 Chemical indices	282
9.4.2 Mass balance and modelling	283
9.5 The UK General Quality Assessment Classification Scheme	288
9.5.1 Chemical GQA	288
9.5.2 Biological GQA	288
9.5.3 Nutrient GQA	289

9.5.4	Aesthetic GQA	290
9.5.5	River habitat survey	291
References		294
Further reading		296
Interactive sites		297

Part III **Drinking Water Treatment and Supply** **299**

10. Water Treatment and Distribution **301**

Introduction to treatment	301
10.1 Unit processes	303
10.1.1 Preliminary screening	303
10.1.2 Storage	304
10.1.3 Aeration	307
10.1.4 Chemical pre-treatment	307
10.1.5 Coagulation	307
10.1.6 Sedimentation	309
10.1.7 Filtration	312
10.1.8 Disinfection	317
10.1.9 Fluoridation	319
10.1.10 Advanced water treatment	320
10.1.11 Sludge production and disposal	320
10.2 Water distribution	322
References	325
Further reading	326
Interactive sites	327

11. Drinking Water Contamination **328**

Introduction	328
11.1 Problems arising from resource	329
11.1.1 Taste and odour	330
11.1.2 Iron and manganese	333
11.1.3 Nitrate	334
11.1.4 Organic micro-pollutants	337
11.1.5 Arsenic and fluoride	339
11.1.6 The future	340
11.2 Water quality problems arising from water treatment	341
11.2.1 Chlorine and chlorinated organic compounds	342
11.2.2 Fluoride	344

11.3	Water quality problems arising from the distribution system	345
11.3.1	Polycyclic aromatic hydrocarbons (PAHs)	346
11.3.2	Animals and biofilm	348
11.4	Water quality problems arising in home plumbing situations	350
11.4.1	Corrosion	350
11.4.2	Lead	352
11.4.3	Copper	354
11.5	Water quality problems in perspective	355
	References	356
	Further reading	357
	Interactive sites	357

12. Pathogens and Their Removal **360**

	Introduction	360
	Classification of pathogens	360
	Strategies for controlling pathogen transfer	362
12.1	Waterborne pathogens	363
12.1.1	Primary bacterial pathogens	363
12.1.2	Opportunistic bacterial pathogens	365
12.1.3	Viruses	368
12.1.4	Protozoa	370
12.1.5	Conclusion	373
12.2	Microbial assessment of drinking water quality	374
12.2.1	Monitoring pathogens	374
12.2.2	Heterotrophic plate count bacteria	376
12.2.3	Enumeration techniques	378
12.2.4	New technologies	381
12.2.5	Standards	382
12.3	Removal of pathogenic organisms	383
12.3.1	Environmental factors of survival	384
12.3.2	Wastewater treatment	385
12.3.3	Water treatment	392
12.4	Microbial source tracking	396
	References	398
	Further reading	399
	Interactive sites	399

Part IV

Wastewater Treatment **401**

13. Nature of Wastewater **403**

13.1	Composition of wastewater	403
13.2	Sewage collection	411

13.3	Surface run-off	415
13.4	Charging	416
13.5	Industrial and agricultural wastewaters	417
13.6	Working with sewage	419
	References	421
	Further reading	421
	Interactive sites	422
14.	Introduction to Wastewater Treatment	425
<hr/>		
14.1	Requirements of treatment	425
14.2	Basic unit processes	428
14.2.1	Screens	432
14.2.2	Grit separation	433
14.2.3	Other preliminary processes	435
14.2.4	Storm water	435
14.2.5	Primary sedimentation (primary treatment)	436
14.2.6	Biological (secondary) treatment	444
14.2.7	Secondary sedimentation	444
14.2.8	Tertiary treatment	446
14.2.9	Sludge treatment	446
14.3	Pre-treatment of industrial wastewaters	446
14.4	Design of wastewater treatment plants	449
14.4.1	Selection of processes	449
14.4.2	SCADA	450
14.4.3	Example of treatment plant	453
	References	458
	Further reading	458
	Interactive sites	459
15.	Biological Aspects of Secondary Sewage Treatment	460
<hr/>		
15.1	Processes	460
15.2	Kinetics	469
15.2.1	Bacterial kinetics	469
15.2.2	Rates of reaction	471
15.2.3	Enzyme reactions	473
15.2.4	Environmental factors affecting growth	475
15.2.5	Kinetic equations of bacterial growth	476
15.3	Treatability, toxicity and biodegradability assessment	480
15.3.1	The activated sludge respiration inhibition test	481
15.3.2	The BOD inhibition test	482
15.3.3	The Microtox [®] bioassay test	483
15.3.4	Dehydrogenase enzymatic assay	483

15.4 Bioaugmentation	483
References	486
Further reading	486
Interactive sites	487
16. Fixed-film Systems	488
<hr/>	
16.1 The basis of the process	488
16.2 Percolating filters	488
16.2.1 Film development	489
16.2.2 Design and modifications	495
16.3 Operational problems of percolating filters	500
16.3.1 Ponding	500
16.3.2 Nitrification	502
16.3.3 Fly nuisance	503
16.4 Other fixed-film reactors	504
16.4.1 Rotating biological contactors	504
16.4.2 Submerged aerobic filters	507
16.4.3 Fluidized beds	509
16.4.4 Nitrifying and denitrifying filters	510
References	511
Further reading	512
Interactive sites	512
17. Activated Sludge	513
<hr/>	
17.1 The process	513
17.2 Process control	515
17.2.1 Biomass control	515
17.2.2 Plant loading	517
17.2.3 Sludge settleability	519
17.2.4 Sludge activity	520
17.3 Modes of operation	521
17.3.1 Aeration	521
17.3.2 Aeration management	522
17.3.3 Oxygen transfer	525
17.3.4 The use of pure oxygen	528
17.4 Aeration tank design	528
17.4.1 Tank configuration	528
17.4.2 Completely mixed reactors	530
17.5 Common modifications	533
17.5.1 Tapered aeration (plug flow)	533

17.5.2	Contact stabilization (both plug and completely mixed)	533
17.5.3	Incremental feeding or step aeration (plug flow)	534
17.5.4	Sequencing batch reactors (SBRs)	535
17.5.5	Low-area high-rate systems	536
17.6	Ecology	538
17.7	Operational problems	539
17.7.1	Flocculation	539
17.7.2	Floc morphology	540
17.7.3	Sludge problems	541
17.7.4	Identifying problems	545
17.8	Remedial measures	550
17.8.1	Operational control	550
17.8.2	Chemical addition	551
17.8.3	Process modification	552
17.9	Nutrient removal	553
17.9.1	Denitrification	553
17.9.2	Phosphorus removal	556
17.9.3	Biological nutrient removal systems	558
	References	561
	Further reading	562
	Interactive sites	563

18. Natural Treatment Systems 564

	Introduction	564
18.1	Stabilization ponds	565
18.1.1	Introduction	565
18.1.2	Anaerobic lagoons	565
18.1.3	Oxidation ponds	568
18.1.4	Aeration lagoons	574
18.2	Plants and wetlands	574
18.2.1	Plants	574
18.2.2	Wetlands	575
18.3	Land treatment	580
18.3.1	Slow-land irrigation	580
18.3.2	Overland flow	580
18.3.3	Infiltration-percolation	581
18.3.4	Sub-surface irrigation	582
	References	582
	Further reading	583
	Interactive sites	584

19. Anaerobic Treatment	585
<hr/>	
Introduction	585
19.1 Flow-through systems (digestion)	588
19.1.1 Design	590
19.1.2 Operation	595
19.1.3 Hydrolysis	597
19.2 Biogas and other products of digestion	598
19.3 Contact anaerobic systems	600
19.3.1 Anaerobic activated sludge	601
19.3.2 Up-flow anaerobic sludge blanket (UASB) process	601
19.3.3 Static media filter	602
19.3.4 Fluidized and expanded media	602
References	603
Further reading	603
Interactive sites	604
20. Physico-chemical Treatment Processes	605
<hr/>	
Introduction	605
20.1 Equalization	605
20.2 Coagulation	608
20.3 Sedimentation	613
20.3.1 Sedimentation theory	614
20.3.2 Design of sedimentation tanks	619
20.4 Flotation	620
20.5 Chemical precipitation	621
20.5.1 Removal of calcium and magnesium	621
20.5.2 Phosphate removal	623
20.6 Adsorption	626
20.6.1 Powdered activated carbon (PAC)	627
20.6.2 Granular activated carbon (GAC)	628
20.7 Ion exchange	631
20.8 Membrane filtration	633
20.8.1 Microfiltration	634
20.8.2 Ultrafiltration	635
20.8.3 Reverse osmosis	636
20.8.4 Nanofiltration	637
20.8.5 Process design	638
20.8.6 Electrodialysis	640
References	642
Further reading	642
Interactive sites	643

21. Sludge Treatment and Disposal	645
<hr/>	
21.1 Sludge characteristics	645
21.2 Sludge treatment	648
21.2.1 Thickening	649
21.2.2 Stabilization	651
21.2.3 Dewatering	654
21.3 Sewage sludge disposal	663
21.3.1 Incineration	664
21.3.2 Sea disposal	665
21.3.3 Landfill	665
21.3.4 Disposal to agricultural land	666
21.3.5 Composting and other uses	673
References	682
Further reading	683
Interactive sites	683
22. Household and Small-scale Treatment Systems	686
<hr/>	
Introduction	686
22.1 Cesspools	687
22.2 Septic tanks	689
22.2.1 The process	689
22.2.2 Design	692
22.2.3 Operation	693
22.2.4 Maintenance	694
22.2.5 Special wastewaters	696
22.3 Percolation areas	697
22.4 Small complete treatment systems	700
22.4.1 Biological or submerged aerated filters	701
22.4.2 Rotating biological contactors and percolating filters	702
22.4.3 Sand filtration	702
22.4.4 Peat filters	703
22.4.5 Discharge of effluent	705
References	705
Further reading	706
Interactive sites	706
The Future	709
23. Sustainability Principles in Water Management	711
<hr/>	
23.1 The global perspective	711
23.2 Climate change	712

23.3	Sustainability	716
23.4	Managing water supplies	719
23.4.1	Water safety plans	720
23.4.2	Water security plans	722
23.5	Conclusion	723
	References	724
	Further reading	725
	Interactive sites	726
	<i>Index</i>	727