

Table of Contents

Chapter 1 Introduction to Small Water Systems

1.1	Water as a Limited Resource	2
1.2	The Water Supply System	3
1.2.1	Sources of Water	4
1.2.1.1	Ocean	4
1.2.1.2	Surface Water	6
1.2.1.3	Groundwater	7
1.2.1.4	Reclaimed Water	8
1.2.2	Storage Facilities	9
1.2.3	Treatment Facilities	9
1.2.3.1	Water Treatment	10
1.2.4	Distribution Systems	10
1.3	Selection of a Water Source	12
1.3.1	Water Rights	12
1.3.2	Sanitary Survey	12
1.3.3	Contamination	14
1.3.3.1	Physical Characteristics	15
1.3.3.2	Chemical Characteristics	16
1.3.3.3	Biological Factors	16
1.3.3.4	Radiological Factors	17
1.4	The Safe Drinking Water Act	18
1.5	Small Water System Operators	22
1.5.1	Operation and Maintenance	23
1.5.2	Supervision and Administration	24
1.5.3	Public Relations	25
1.5.4	Safety	25
1.6	Math Assignment	26
1.7	Additional Resources	26
Chapter Review		28

Chapter 2 Wells

2.1	Groundwater—Critical Link to Wells	32
2.1.1	Water (Hydrologic) Cycle	32
2.1.2	Aquifers	33
2.1.2.1	Porosity and Specific Yield	34
2.1.2.2	Overdraft	35
2.1.2.3	Saltwater Intrusion	35
2.1.3	Pollution Control	36
2.1.3.1	Geologic and Hydrologic Data	38
2.1.4	Wellhead Protection	39
2.1.4.1	National Program	40
2.1.4.2	Groundwater Protection Tips	46
2.2	Well Site Selection	49
2.2.1	Horizontal Distance	51
2.2.2	Design of Well Fields	54
2.2.3	Special Construction of Collection Systems Under Gravity Flow	55
2.2.4	Sanitary Control of Future Construction	55
2.3	Structure and Components	55
2.3.1	Types of Wells	56
2.3.1.1	Dug Wells	56
2.3.1.2	Bored Wells	56
2.3.1.3	Driven Wells	56
2.3.1.4	Drilled Wells	60
2.3.1.5	Shallow Collector Wells—Ranney Type	65
2.3.2	Subsurface Features of a Well	66
2.3.2.1	Conductor Casing	66
2.3.2.2	Well Casing	67
2.3.2.3	Intake Section of a Well	67
2.3.2.4	Annular Grout Seal	69
2.3.2.5	Gravel Pack	71

2.3.3	Surface Features of a Well	73
2.3.3.1	Well-Casing Vent	73
2.3.3.2	Gravel Tube	74
2.3.3.3	Sounding Tube	75
2.3.3.4	Pump Pedestal	75
2.3.3.5	Pump Motor Base Seal	76
2.3.3.6	Sampling Taps	76
2.3.3.7	Air Release and Vacuum Breaker Valves	76
2.3.3.8	Pump Blowoff	76
2.3.4	Well Appurtenances	77
2.3.4.1	Check Valves	77
2.3.4.2	Pump Control Valves	77
2.3.4.3	Foot Valves	80
2.3.4.4	Flowmeters	80
2.3.4.5	Sand Traps and Sand Separators	81
2.3.4.6	Surge Suppressors	82
2.3.4.7	Air and Vacuum Valves	83
2.3.4.8	Pressure Relief Valves	83
2.3.4.9	Hydropneumatic Pressure Tank Systems	85
2.4 Testing and Evaluation 92		
2.4.1	Well Yield Tests	93
2.4.1.1	Bailing Test Method	93
2.4.1.2	Air Blow Test Method	93
2.4.1.3	Variable Rate Method	94
2.4.1.4	Constant Rate Method	94
2.4.1.5	Step-Continuous Composite Method	95
2.5 Maintenance and Rehabilitation 95		
2.5.1	Factors Affecting the Maintenance of Well Performance	96
2.5.1.1	Overpumping	96
2.5.1.2	Clogging or Incrustation of Screen	96
2.5.1.3	Corrosion or Collapse of Screen	98
2.5.1.4	Biofouling	99
2.5.2	Preventive Maintenance and Repairs	99
2.5.3	Casing and Screen Maintenance	99
2.5.3.1	Surging	100
2.5.3.2	High-Velocity Jetting	101
2.5.3.3	Acid Treatment	103
2.5.3.4	Chlorine Treatment	105
2.5.3.5	Polyphosphates	105
2.5.3.6	Explosive Charges	105

2.5.4	Water Quality Monitoring	106
2.5.5	Downhole Video Inspection	106
2.5.6	Summary	107
2.6 Well Pumps and Service Guidelines 108		
2.6.1	Types of Pumps	108
2.6.1.1	Centrifugal Pumps	108
2.6.1.2	Other Pumps	110
2.6.1.3	Right-Angle Gear Drives	112
2.6.2	Selecting a Pump	113
2.6.3	Service Guidelines	114
2.6.4	Motors	115
2.6.5	Pump Testing and Evaluation	116
2.6.5.1	Guidelines for Testing	117
2.6.5.2	Evaluating Test Results	118
2.6.5.3	Pump Electrical	126
2.7 Disinfection of Wells and Pumps 129		
2.7.1	New Wells	129
2.7.2	Existing Wells	131
2.7.3	Contaminated Wells	131
2.7.4	Chlorine Requirement Calculations	132
2.8 Electrical Supply and Controls 135		
2.8.1	Electrical Supply	135
2.8.1.1	Motor Starters	135
2.8.1.2	Auxiliary Power	135
2.8.2	Pump Controls	137
2.8.2.1	Control Systems	138
2.8.2.2	Equipment	140
2.9 Troubleshooting 140		
2.9.1	Decline in Yield	144
2.9.2	Sand in Well Water Systems	144
2.9.2.1	Problems Associated with Sand	145
2.9.2.2	Flushing Mains	146
2.9.2.3	Test for Sand, Volumetric Method	146
2.9.2.4	Acceptable Concentrations	148
2.9.2.5	Responding to Complaints	148
2.10 Abandoning and Plugging Wells 149		
2.10.1	Permits	149
2.10.2	Abandoning and Plugging Guidelines	150

2.11 Operator Responsibility and Recordkeeping	152
2.11.1 Routine Facility Servicing	152
2.11.2 Records	153
2.12 Math Assignment	160
2.13 Additional Resources	160
Chapter Review	161

Chapter 3

Small Water Treatment Plants

3.1 Importance of Small Water Treatment Plants	168
3.1.1 Surface Waters	169
3.1.2 Groundwaters	172
3.1.3 Operator Responsibility	173
3.2 Coagulation	173
3.3 Flocculation	182
3.4 Settling (Sedimentation)	183
3.5 Filtration	190
3.6 Disinfection	203
3.7 Corrosion Control	218
3.8 Solids-Contact Clarification	220
3.8.1 Fundamentals of Operation	224
3.8.2 Maintenance	227
3.9 Slow Sand Filtration	227
3.9.1 Procedure for Treating Water	229
3.9.2 Components	230
3.9.2.1 Filter Tank	230
3.9.2.2 Underdrain System	233
3.9.2.3 Sand Media Bed	233
3.9.2.4 Flow Control Piping, Valves, and Gauges	234
3.9.2.5 Outlet Chamber	236

3.9.2.6 Finished Water Holding Facility	237
3.9.2.7 Hydraulic Controls and Monitoring Devices	238
3.9.3 Typical Filter Operating Cycle	239
3.9.3.1 Daily Operation	240
3.9.3.2 Cleaning the Filter Media	240
3.9.4 Preventive Maintenance	245
3.9.5 Troubleshooting	246
3.9.6 Finished Water Standards	247
3.9.7 Factors Affecting Filter Performance	248
3.9.7.1 Source Water Quality	248
3.9.7.2 Cyclic Influences	249
3.9.7.3 Mode of Operation	251
3.9.7.4 Hydraulic Loading Rate	251
3.9.8 Recordkeeping	253
3.9.9 Process Modifications	255
3.9.10 Example Slow Sand Filter Plant	255
3.9.10.1 Construction Features	255
3.9.10.2 Startup	256
3.9.10.3 Operation	257
3.9.10.4 Filter Cleaning	258
3.9.10.5 Shutdown	259
3.10 Iron and Manganese Control	259
3.11 Softening	261
3.11.1 Ion Exchange Softening	264
3.12 Operation	268
3.13 Maintenance	271
3.13.1 Tools	271
3.14 Safety	271
3.15 Math Assignment	273
3.16 Additional Resources	274
Chapter Review	275

Chapter 4

Disinfection

4.1 Drinking Water Safety	280
4.1.1 Safe Drinking Water Laws	280

4.2 Factors Influencing Disinfection 283

- 4.2.1 pH 283
- 4.2.2 Temperature 283
- 4.2.3 Turbidity 283
 - 4.2.3.1 Organic Matter 284
 - 4.2.3.2 Inorganic Matter 284
- 4.2.4 Reducing Agents 284
- 4.2.5 Microorganisms 284
 - 4.2.5.1 Removal Processes 284

4.3 Disinfection Process 285

- 4.3.1 Physical Means of Disinfection 285
- 4.3.2 Chemical Disinfectants Other Than Chlorine 286
- 4.3.3 Chlorine 287
 - 4.3.3.1 Chlorine Disinfection Action 287
 - 4.3.3.2 Reaction with Water 288
 - 4.3.3.3 Reaction with Impurities in Water 289
- 4.3.4 Hypochlorite 290
 - 4.3.4.1 Reactions with Water 290
 - 4.3.4.2 Differences Between Chlorine Gas and Hypochlorite Compound Reactions 291
 - 4.3.4.3 Onsite Chlorine Generation 291
- 4.3.5 Chlorine Dioxide 291
 - 4.3.5.1 Reaction in Water 292
 - 4.3.5.2 Reactions with Impurities in Water 292
- 4.3.6 Breakpoint Chlorination 292
- 4.3.7 Chloramination 294
 - 4.3.7.1 Methods for Producing Chloramines 294
 - 4.3.7.2 Chlorine-to-Ammonia-Nitrogen Ratios 295
 - 4.3.7.3 Special Water Users 296
 - 4.3.7.4 Blending Chloraminated Waters 296
 - 4.3.7.5 Chloramine Residuals 296
- 4.3.8 Nitrification 296
 - 4.3.8.1 Nitrification Prevention and Control 297
- 4.3.9 Chlorine Residual Testing 298
 - 4.3.9.1 Chlorine Residual Curve 299
 - 4.3.9.2 Critical Factors 300
- 4.3.10 CT Values 300
- 4.3.11 Process Calculations 301

4.4 Points of Chlorine Application 303

- 4.4.1 Prechlorination 303
- 4.4.2 Postchlorination 303
- 4.4.3 Rechlorination 303
- 4.4.4 Wells 303
- 4.4.5 Mains 305
- 4.4.6 Tanks and Reservoirs 305

4.5 Operation of Chlorination Equipment 305

- 4.5.1 Hypochlorinators 305
- 4.5.2 Chlorinators 307
 - 4.5.2.1 Chlorinator Flow Path 310
 - 4.5.2.2 Chlorinator Parts and Their Purpose 312
- 4.5.3 Chlorine Containers 313
 - 4.5.3.1 Plastic 313
 - 4.5.3.2 Steel Cylinders 314
 - 4.5.3.3 Ton Tanks 315
- 4.5.4 Safety Around Chlorine 316
- 4.5.5 Removing Chlorine from Containers 316
 - 4.5.5.1 Connections 316
 - 4.5.5.2 Valves 317
 - 4.5.5.3 Ton Tanks 317
- 4.5.6 Performance of Chlorination Units 317
 - 4.5.6.1 Hypochlorinators 318
 - 4.5.6.2 Chlorinators 322
- 4.5.7 Normal and Abnormal Operation 327
 - 4.5.7.1 Container Storage Area 327
 - 4.5.7.2 Evaporators 328
 - 4.5.7.3 Chlorinators, Including Injectors 330
 - 4.5.7.4 Daily Operations 335
 - 4.5.7.5 Laboratory Tests 337
- 4.5.8 Troubleshooting Gas Chlorinator Systems 338
- 4.5.9 Disinfection Troubleshooting 339
- 4.5.10 Chlorination System Failure 339

4.6 Maintenance 339

- 4.6.1 Chlorine Leaks 339
- 4.6.2 Installation 343

4.7 Chlorine Dioxide Facilities 345

- 4.7.1 Safe Handling of Chemicals 347

4.7.2	Operation	347
4.7.2.1	Prestart Procedures	347
4.7.2.2	Startup	349
4.7.2.3	Shutdown	349
4.7.3	Maintenance	350
4.7.4	Troubleshooting	351
4.8	Measurement of Chlorine Residual	353
4.8.1	Methods of Measuring Chlorine Residual	353
4.8.2	ORP Probes	354
4.9	Chlorine Safety Program	355
4.9.1	Chlorine Hazards	355
4.9.2	Why Chlorine Must Be Handled with Care	356
4.9.3	Chlorine Safety for Operators	356
4.9.4	Hypochlorite Safety	359
4.9.5	Chlorine Dioxide Safety	359
4.9.6	Operator Safety Training	359
4.9.7	CHEMTREC	360
4.10	Ultraviolet Systems	360
4.10.1	Lamp Types	361
4.10.2	System Types	361
4.10.3	Safety	362
4.10.4	Operation	363
4.10.4.1	UV Light Intensity Effectiveness	363
4.10.4.2	Minimum UV Dose Management	363
4.10.4.3	Routine Operations Tasks	365
4.10.4.4	Wiping System	366
4.10.4.5	Equipment Shutdown/Startup Preliminary Steps	366
4.10.4.6	Shutdown Sequence	367
4.10.4.7	Cleaning the Tank	367
4.10.4.8	Startup Sequence	367
4.10.4.9	Monitoring Lamp Output Intensity	367
4.10.4.10	Monitoring Influent and Effluent Characteristics	368
4.10.5	Emergency Alarms	368
4.10.6	Maintenance	369
4.10.6.1	Quartz Sleeve Cleaning	369
4.10.6.2	Lamp Maintenance	370

4.10.7	Troubleshooting	371
4.10.7.1	System Hydraulics	371
4.10.7.2	Biofilms on UV Channel Walls and Equipment	371
4.10.7.3	Particles Shielding Bacteria	371

4.11 Ozone Systems 371

4.11.1	Equipment	372
4.11.2	Gas Preparation	372
4.11.3	Electrical Supply Unit	373
4.11.4	Ozone Generator	373
4.11.5	Ozone Contactor	374
4.11.6	Ozone Residuals	374
4.11.7	Safety	375
4.11.8	Maintenance	375
4.11.9	Applications of Ozone	375
4.11.10	Advantages and Limitations of Ozone	376

4.12 Mixed-Oxidants (MIOX) Systems 377

4.13 Typical Chlorination Math Problems 378

4.13.1	Chlorinators	378
4.13.2	Hypochlorinators	382

4.14 Math Assignment 385

4.15 Additional Resources 386

Chapter Review 387

Chapter 5 Safety

5.1 Safety Program 392

5.1.1	Tailgate Safety Sessions	393
5.1.1.1	Tailgate Safety Sample Script	393
5.1.2	Employee Right-To-Know Laws	394

5.2 Vehicle Safety 395

5.2.1	Towing A Trailer	395
5.2.2	How to Charge a Battery	395
5.2.3	Boat Safety	397

5.3 Personal Safety 398

- 5.3.1 Monitoring Equipment 398
- 5.3.2 Personal Protective Equipment 403
- 5.3.3 Slips and Falls 404
- 5.3.4 Handling and Lifting 405
- 5.3.5 Electrical Safety 406
- 5.3.6 Corrosive Chemicals 406

5.4 Safety Around Wells 407

- 5.4.1 Location of Well Site 407
- 5.4.2 New Wells 407
- 5.4.3 Sanitary Seal 408
- 5.4.4 Surface Portion of Well 408
- 5.4.5 Tank Coatings 408
- 5.4.6 Well Chemicals 409
- 5.4.7 Working Around Electrical Units 411
- 5.4.8 Abandoning and Plugging Wells 413
- 5.4.9 Safety Inspection 413

5.5 Pump Safety 413

- 5.5.1 Guards Over Moving Parts 414
- 5.5.2 Maintenance and Repair 414
- 5.5.3 Lockout/Tagout Procedure 416
- 5.5.4 Storage of Lubricants and Fuel 418

5.6 Working in Streets 419

- 5.6.1 Fundamental Principles 420
- 5.6.2 Definitions 420
- 5.6.3 Major Temporary Traffic Control Considerations 425
- 5.6.4 Individuals Qualified to Control Traffic 426
- 5.6.5 Permission to Work Within the Right-of-Way of Streets or Highways 426
- 5.6.6 General Responsibilities 427
- 5.6.7 Regulations Concerning Street or Highway Work 427
- 5.6.8 Temporary Traffic Control Zones 430
 - 5.6.8.1 Tapers 433
- 5.6.9 Pedestrian Safety 436
- 5.6.10 Worker Safety 439
 - 5.6.10.1 Speed Limits in Work Zones 440
 - 5.6.10.2 Flagger Control 440

- 5.6.11 Using Temporary Traffic Control Zone Devices 444

5.6.12 Excavations in Streets 459

- 5.6.12.1 Trenches 459
- 5.6.12.2 Cave-Ins 461
- 5.6.12.3 Ladders 462
- 5.6.12.4 Locate Underground Utilities Before You Dig 462

5.7 Safety Around Water Storage Facilities 464

- 5.7.1 Slips and Falls 464
- 5.7.2 Ladders 464
- 5.7.3 Application of Coatings 466
- 5.7.4 Confined Spaces 467

5.8 Working near Noise 471**5.9 Safety Inspections 474****5.10 Additional Resources 476****Chapter Review 477**

Chapter 6

Laboratory Procedures

6.1 Basic Laboratory Concepts 484

- 6.1.1 Laboratory Units—The Metric System 484
- 6.1.2 Chemical Names and Formulas 486

6.2 Laboratory Equipment and Techniques 488

- 6.2.1 Water Laboratory Equipment 488
- 6.2.2 Using Laboratory Glassware 492
 - 6.2.2.1 Reading Volumes 492
 - 6.2.2.2 Using Pipets 493
- 6.2.3 Chemical Solutions 495
 - 6.2.3.1 Mass Concentration 495
 - 6.2.3.2 Molar Concentration 496
 - 6.2.3.3 Normality 497
- 6.2.4 Data Recording and Recordkeeping 498
- 6.2.5 Laboratory Quality Control 499

6.3	Laboratory Safety	500
6.3.1	Laboratory Hazards	500
6.3.2	Personal Safety and Hygiene	501
6.3.3	Preventing Laboratory Accidents	502
6.3.3.1	Chemical Storage	502
6.3.3.2	Moving Chemicals	502
6.3.3.3	Proper Laboratory Techniques	503
6.3.3.4	Accident Prevention	504
6.4	Water Quality Tests	507
6.4.1	Instrument-Based Tests	507
6.4.1.1	Temperature	507
6.4.1.2	pH	509
6.4.1.3	Turbidity	511
6.4.2	Titration-Based Tests	514
6.4.2.1	Alkalinity	515
6.4.2.2	Hardness	520
6.4.2.3	Chlorine Residual	522
6.4.3	Tests for Plant Processes	529
6.4.3.1	Jar Test for Coagulation/ Flocculation	529
6.4.3.2	Chlorine Demand	534
6.4.4	Biological Tests	538
6.4.4.1	Test Methods Overview	539
6.4.4.2	What Is Tested	542
6.4.4.3	General Materials Required for Microbial Testing	542
6.4.4.4	Procedures for Testing Total Coliform Bacteria	544
6.4.4.5	Additional Test Methods	568
6.5	Sampling	569
6.5.1	Representative Sampling	569
6.5.1.1	Source Water Sampling	569
6.5.1.2	In-Plant Sampling	570
6.5.1.3	Distribution System Sampling	570
6.5.2	Types of Samples	573
6.5.2.1	Grab Samples	573
6.5.2.2	Composite Samples	573
6.5.3	Sampling Devices	574
6.5.4	Sampling Techniques	575
6.5.4.1	Surface Sampling	575
6.5.4.2	Depth Sampling	575
6.5.4.3	Water Tap Sampling	576
6.5.4.4	First-Draw Sampling	577

6.5.5	Sampling Containers and Preservation of Samples	577
6.5.5.1	Chain-of-Custody Samples	577
6.5.6	Reporting	577

6.6 Math Assignment 579

6.7 Additional Resources 579

Chapter Review 580

Chapter 7

Introduction to Small System Management

7.1 Developing Water Rates 584

7.1.1	General Action Strategy	584
7.1.2	Developing a Hypothetical Water District	585

7.2 Revenue Requirements 587

7.2.1	Forecasting Expenditures	588
7.2.1.1	Declining Demand for Water	588
7.2.1.2	System Growth Rate	588
7.2.1.3	Inflation	589
7.2.1.4	Capital Improvement Program	589
7.2.1.5	Financial Assistance	591
7.2.2	Itemizing System Expenses	592
7.2.3	Establishing the Revenue Base	594

7.3 Cost Allocation Methods 597

7.3.1	Commodity-Demand Method	597
7.3.2	Base-Extra Capacity Method	598
7.3.3	Examples of Cost Allocations	599

7.4 Distributing Costs to Customers 602

7.5 Rate Design 603

7.5.1	Information and Data Requirements	604
7.5.2	Rate Components	604
7.5.3	Typical Rate Structure	608

7.6 Administration of Rates and Charges 610

7.6.1	Consumer Confidence Reports	611
-------	-----------------------------	-----

7.7 Planning for Financial Stability 612

7.7.1 Measuring Stability 612
 7.7.2 Budgeting 614
 7.7.3 Recordkeeping 615
 7.7.3.1 Computer Recordkeeping Systems 616
 7.7.3.2 Types of Records 616
 7.7.3.3 Disposition of Utility Records 618
 7.7.4 Check-Up Program for Small Systems 619

7.8 Emergency Response 619

7.8.1 Federal Requirements 619
 7.8.2 Responding to Emergency Situations 620
 7.8.3 Homeland Defense 623
 7.8.3.1 Guarding Against Unplanned Physical Intrusion 624
 7.8.3.2 Making Security a Priority for Employees 624
 7.8.3.3 Coordinating Actions for Effective Emergency Response 625
 7.8.3.4 Investing in Security and Infrastructure Improvements 625
 7.8.4 Managing Contamination Threats 627
 7.8.4.1 Evaluating and Responding to Threats 628
 7.8.4.2 *Cryptosporidium* 630

7.9 Additional Resources 631

Chapter Review 632

**Appendix A
 Introduction to Basic Math for Operators**

Introduction 638

Basic Concepts (Sections A.1–A.4) 639

A.1 Numbers and Operations 639

A.1.1 Addition 639
 A.1.2 Subtraction 639
 A.1.3 Multiplication 640
 A.1.4 Division 640

A.2 Order of Operations 640

A.2.1 More on Exponents 644

A.3 Basic Algebra (Solving Equations) 644

A.4 Percentages 647

Intermediate Concepts (Sections A.5–A.6) 650

A.5 Units 650

A.5.1 Distance or Length 650
 A.5.2 Area 651
 A.5.2.1 Surface Area of a Rectangle 651
 A.5.2.2 Surface Area of a Triangle 652
 A.5.2.3 Surface Area of a Trapezoid 653
 A.5.2.4 Surface Area of a Circle 653
 A.5.2.5 Surface Area of a Cylinder 654
 A.5.2.6 Surface Area of a Cone 655
 A.5.2.7 Surface Area of a Sphere 656
 A.5.3 Volume 656
 A.5.3.1 Cube 657
 A.5.3.2 Rectangular Prism 657
 A.5.3.3 Triangular Prism 658
 A.5.3.4 Cylinder 658
 A.5.3.5 Cone 658
 A.5.3.6 Sphere 659
 A.5.4 Mass and Weight 659
 A.5.5 Density, Specific Weight, and Specific Gravity 660
 A.5.6 Concentration 660
 A.5.7 Velocity and Flow Rate 662
 A.5.8 Force and Pressure 664
 A.5.9 Work, Head, and Power 669

A.6 Metric System 672

A.6.1 SI Base Units 672
 A.6.2 Measures of Length 674
 A.6.3 Measures of Capacity or Volume 674
 A.6.4 Measures of Weight 674
 A.6.5 Temperature 675

Advanced Concepts (Sections A.7–A.8) 676

A.7 Pumps 676

A.7.1 Pressure 676
 A.7.2 Work 677
 A.7.3 Power 678
 A.7.4 Horsepower 678
 A.7.5 Head 682

A.7.6	Pump Characteristics	684
A.7.7	Evaluation of Pump Performance	686
	A.7.7.1 Capacity	686
	A.7.7.2 Efficiency	687
A.7.8	Pump Speed-Performance Relationships	690
A.7.9	Friction or Energy Losses	691
A.8	Analysis and Presentation of Data	695
A.8.1	Causes of Variations in Results	695
	A.8.1.1 Water or Material Being Examined	696
	A.8.1.2 Sampling	696
	A.8.1.3 Testing	696
A.8.2	Controlling Variation	696
	A.8.2.1 Reading Charts	698
A.8.3	Describing Data or Results	698
	A.8.3.1 Graphs and Charts	699
	A.8.3.2 Numerical Representation of Data	704
A.8.4	Moving Averages	711
A.8.5	More Applications of Graphs	713
	A.8.5.1 Volume of Sludge in a Digester	713
	A.8.5.2 Tracking BOD Loading	716
A.8.6	Regression Analysis (Prediction Equations, Trends, and Correlations)	718
	A.8.6.1 Correlations	723

A.9 Typical Water Treatment Plant Problems (English System) 724

A.9.1	Flows	724
A.9.2	Chemical Doses	724
A.9.3	Wells	726
A.9.4	Small Water Treatment Plants	727
A.9.5	Disinfection	730
A.9.6	Laboratory Procedures	732

A.10 Typical Water Treatment Plant Problems (Metric System) 733

A.10.1	Flows	733
A.10.2	Chemical Doses	734
A.10.3	Wells	735
A.10.4	Small Water Treatment Plants	736
A.10.5	Disinfection	739
A.10.6	Laboratory Procedures	741

Answer Key 745

Glossary 747

Index 779

- A**
- AADT (Annual Average Daily Traffic), 421
 - Abandoning wells, 39, 149–151, 413
 - Abnormal conditions, chlorination, 305, 322, 327, 333–334
 - Absorption, 222
 - Accident prevention, 504–506
 - Accidents, 392, 393, 395, 487
 - Accidents, laboratory, 502–506
 - Acid rain, 2
 - Acid titration curve, 516
 - Acid treatment of wells, 103–105
 - Acidic, defined, 509
 - Acids, safety, 406, 409, 501
 - Acids, used in laboratories, 503
 - Acquisition, water rights, 12
 - Additional resources, 26, 160, 274, 386, 476, 579, 631
 - chlorination, 386
 - disinfection, 386
 - hardness in water, 520
 - laboratory procedures, 484, 506, 509, 510, 514, 520, 528, 538, 557, 562, 564
 - laboratory safety, 506
 - microbiological test methods, 568
 - sampling, 577
 - Administration
 - contaminated water supply, 623
 - contingency planning, 619
 - emergency response, 619–623
 - operator's duties, 22
 - Administrative expenses, 587, 594, 596, 600, 613
 - Adsorption, 192
 - Aeration, 260
 - Agricultural runoff, 3, 6, 293
 - Air blow test method, wells, 93–94
 - Air chargers, wells, 86–89
 - Air gap, 81, 323
 - Air lines, wells, 73, 74
 - Air release valve, wells, 73, 74, 76, 83
 - Air rotary drilling, wells, 64–65
 - Air-lift pumps, 108
 - Algal blooms, 7, 249
 - Aliquot, 558
 - Alkalinity, 174
 - and buffering, 511, 516
 - conditions, 518
 - monitoring, 532
 - procedure, 517
 - test, 515–520
 - Alluvial, 60, 145
 - Alum, 173
 - Ambient temperature, 344
 - Amendments to the Safe Drinking Water Act (SDWA), 40
 - Ammonia, 284, 289, 291–296, 340, 344, 345
 - Ammonia, test for leaks, 323–324
 - Ammonia-oxidizing bacteria (AOB), 296
 - Amperometric titration method, 353, 524
 - Annual Average Daily Traffic (AADT), 421
 - Annual report, 611
 - Annular grout seal, wells, 69
 - Annular space, 62, 106
 - Anthracite, 193
 - AOB. *See* Ammonia-oxidizing bacteria (AOB)
 - Appropriate water rights, 12
 - Aquifers, 7, 32, 33
 - Arithmetic assignment. *See* Math assignment
 - Arrow boards, traffic, 423
 - Arsenic, 19
 - Artesian wells, 7, 8
 - As-built plans (record drawings), 24
 - Aseptic, 561
 - Assessment of system vulnerability, 620
 - Autoclave, 492, 543, 565
 - Automatic sampling, 574
 - Auxiliary power, 135
 - Available chlorine, 105
 - Available chlorine residual, 288, 292
 - Awareness, safety, 392, 440
- B**
- Backflow prevention, 81, 270
 - Backwash
 - filtration, 196–203
 - softening, 265
 - Bacteria
 - defined, 573
 - detection methods, 539
 - disinfection, 203
 - pathogenic, 280
 - quantity affect on sample, 546
 - types of counts, 539
 - Bacterial cells, 287
 - Bacterial cultures, 539
 - Bacteriologic safety indicator, 538
 - Bailing test method, wells, 93
 - Barium, 19
 - Barricades, traffic control, 457–458
 - Base costs, 598
 - Base-extra capacity method, 598
 - Bases (caustics), used in laboratories, 501
 - Battery, charging, 395–397
 - Bill-frequency analysis, 604
 - Biofouling, wells, 99
 - Biological, water quality, 13
 - Biological tests, 538–568
 - Bitter tastes, 286
 - Blanks, 543
 - Blowoff, wells, 73, 76
 - Boats, safety, 397
 - Boils, 199
 - Bonds, 589, 590
 - Bored wells, 56, 60
 - Bowls, pump, wells, 67, 108
 - Brake horsepower, 109
 - Breakpoint chlorination, 209, 210, 292–294, 335, 536, 537
 - Breakthrough, 197
 - Brilliant Green Bile (BGB) Broth, 540, 544
 - Brine disposal, 266
 - Brine stage, 265
 - Bromine, 286
 - Bruises, injury, 500
 - Budget
 - preparation, 614
 - operator responsibility, 25
 - Buffer, 291
 - Buffer solution, 511
 - Buffered dilution water, 543, 546
 - Burns, laboratory, 500, 505
 - Byproducts, disinfection, 19
- C**
- Cable-tool drilling, wells, 60, 61, 66
 - Cadmium, 19
 - Caisson, wells, 65
 - Calcium carbonate equivalent, 173, 515, 519, 520
 - Calcium hypochlorite, 204, 290
 - Calculations
 - coagulation, 178
 - disinfection, 207–208

- Calculations (*continued*)
 - filtration, 200–203
 - sedimentation, 189–190
 - wells, 118–122
- Calibration, instrument, 490–491, 493
- Calibration of feeders, 177, 178
- Call Before You Dig program (811), 462
- Capital costs, 587, 596, 598, 605
- Capital improvement program, 589
- Carbon monoxide, safety, 398
- Carcinogen, 285, 523
- Carcinogen chlororganic compounds, 523
- Carelessness, 392
- Cash basis, 596
- Cash flow, 587
- Cash reserve, 588
- Casing, wells, 46, 67, 73
- Cathodic protection, 227, 330
- Caustic soda, 501
- Caustics, 501
- Cave-ins, 461
- Centrifugal pumps, uses, 108
- Certification
 - operator, 21, 22, 268
 - responsibility, 22
- Chain-of-custody sample protocol, 577
- Channelizing devices, traffic, 423
- Check valves, 77, 79, 80
- Chemical disinfectants, 286
- Chemical feeders, 177–179
- Chemical names, 486–488
- Chemical solution, 495–498
 - tank, 305
- Chemical treatment, corrosion, 219
- Chemicals
 - labeling, laboratory, 503–504
 - movement, 502–503
 - names, 486–488
 - safety, 406
 - solutions, 495–498
 - storage, 502
 - water quality, 13, 15
- Chemistry, disinfection, 285–302
- CHEMTREC, 360, 623
- Chloramination
 - blending, 296
 - chlorine to ammonia-nitrogen ratios, 295–296
 - contact time, 300
 - critical factors, 300
 - how to produce chloramines, 294–295
 - nitrification, 295, 296–298
 - postammoniation, 294, 295
 - preammoniation, 294
 - prechlorination, 295
 - residuals, 295, 296
 - special water users, 296
 - use, 294
- Chloramines, 206, 207, 210, 290, 292–298
- Chloride, 20
- Chlorinated hydrocarbons, 16
- Chlorination. *See also* Chlorinators; Hypochlorinators; Disinfection
 - abnormal operation, 333–334
 - additional resources, 386
 - ammonia test for leaks, 323–324
 - amperometric titration, 353, 524
 - breakpoint, 209, 210, 292–294, 335, 536, 537
 - CHEMTREC, 360
 - chloramination, 294
 - chloramines, 290, 292–298
 - chlorinator, 307–313, 322–327, 330–339
 - chlorine, 287
 - chlorine dioxide, 345–353
 - chlorophenol, 294
 - contact time, 300
 - container storage, 313–316
 - corrosion, 313, 330, 355
 - critical factors, 300
 - CT values, 208, 300
 - demand, 288, 302, 534
 - dichloramine, 293
 - distribution system, 335
 - dosage, 288
 - DPD method, 206
 - DPD test, 337, 353, 354, 528
 - emergency repair kits, 341, 342
 - equipment, 305–339
 - failure, 339
 - first aid, 358
 - flow diagram, 304
 - formulas, 320, 336
 - free available residual chlorine, 292
 - hazards, 355
 - hypochlorinator, 305–307, 318
 - hypochlorite, 290–291
 - injection point, 300
 - injector water supply, 323
 - laboratory tests, 337
 - leaks, 315, 316, 323, 332, 339–343, 357
 - mains, 305
 - maintenance, 339, 357
 - maintenance, hypochlorinators, 214, 322
 - math assignment, 385
 - math, example problems, 378
 - mixing, 300
 - monitoring, 281
 - monochloramine, 293
 - nitrification, 295, 296
 - normal operation, 305, 318, 326
 - operation, 317–338
 - operator training, safety, 359
 - organic matter, 284, 292
 - pathogen removal, 285
 - performance, 317
 - pH, 283, 288, 300, 345
 - phenol, 294
 - points of application, 303, 304
 - poppet valves, 214
 - population served, 281
 - postchlorination, 300, 303, 304, 335
 - prechlorination, 290, 295, 300, 303, 304, 335
 - precursor, THM, 303
 - process calculations, 301
 - rechlorination, 303
 - reducing agents, 283, 284, 289, 300
 - removing chlorine, 316, 317
 - reservoirs, 305
 - residual chlorine, 285, 288, 293, 296, 298, 300, 331, 353, 522, 534
 - safety, 314, 316, 355–360
 - sampling, 281, 282
 - self-contained breathing apparatus, 316, 340, 355, 357
 - storage of containers, 327, 343, 383
 - tanks, 305, 341
 - tastes and odors, 294, 303, 335
 - temperature, 283, 300
 - training, safety, 359
 - trichloramine, 294
 - trihalomethanes (THMs), 284, 285, 303, 345
 - troubleshooting, 334, 338, 339, 352
 - turbidity, 283, 300
 - variables, 284
 - viruses, 280, 281, 284, 345
 - water supply systems, 303
 - waterborne diseases, 280
 - wells, 303
 - withdrawal from cylinder, 210
- Chlorination equipment, 305
 - air gap, 323
 - amperometric titration, 354
 - cathodic protection, 330
 - chemical solution tank, 305
 - CHEMTREC, 360
 - chlorinator, 307–313, 322, 330–339
 - chlorine dioxide, 345–353
 - connections, 317
 - containers, 313–317
 - corrosion, 313, 330, 355
 - cylinders, 314–315
 - detection, chlorine leaks, 333, 339–343, 356
 - dew point, 324
 - diaphragm pump, 312
 - DPD test, 337, 353, 354, 524, 528
 - eductator, 305
 - ejector, 305, 312
 - emergency repair kit, 341, 342, 372
 - evaporator, 324, 328
 - failure, 339
 - fusible plugs, 314, 315
 - hypochlorinator, 305–307, 318
 - injector, 305, 310, 331, 338
 - installation, 305, 343
 - laboratory, 337, 347
 - leaks, 315, 316, 323, 332, 339–343, 357
 - lifting clamp, 315
 - location, 343
 - maintenance, 322, 339, 357

- manifold, 313, 344
- math, example problems, 378
- metering, 310, 313
- operation, 317–335
- parts, 312
- pigtail tubing, 317
- plan review, 343
- poppet valves, 319
- pressure controls, 308
- residual analyzer, 331, 332, 353
- review of plans and specifications, 343
- rotameter, 310
- safety, 314, 316, 322, 355–360
- self-contained breathing apparatus, 316, 340, 355, 357
- shutdown, 318
- solution feeders, 305–307
- startup, 318, 323
- storage, containers, 327, 343
- ton tanks, 315–316
- troubleshooting, 334, 338
- trunnions, 315
- vacuum-controlled chlorinators, 307–313
- valves, 314, 317, 319, 323, 329
- ventilation, 344
- water supply system, 323
- weighing, 314, 344
- wrench, 317
- yoke-type connectors, 316, 317
- Chlorinators, 307–313, 322, 328–339.
 - See also* Chlorination
 - maintenance, 322
 - troubleshooting, 322
 - uses, 322
- Chlorine
 - ammonia, 289, 292, 294, 296
 - ammonia test for leaks, 333–334
 - available, 105
 - available residual, 288, 292
 - CHEMTREC, 360
 - chloramines, 290, 292–298
 - concentrations, effects, 356
 - container storage, 327
 - demand, 288, 301, 302, 534
 - detection, leaks, 332, 339–343, 357
 - detention rate curve, 299
 - disinfection, 287–290
 - disinfection action, 287
 - dose, 288, 302
 - emergency repair kits, 340, 341
 - first aid, 358
 - frozen, 330
 - hydrogen sulfide, 290
 - hypochlorite, 290
 - hypochlorous acid, 288, 291, 523
 - ice, 330
 - leaks, 315, 316, 317, 323, 332, 338, 339–343, 357
 - maximum removal rate, 316, 344
 - on-site generation, 291
 - pH, 283, 288, 300, 345
 - physiological response, 356
 - prechlorination, 290, 295, 300, 303, 304, 335
 - properties, 355
 - protection from, 357
 - rate of withdrawal, 323, 344
 - reaction with impurities, 289
 - reaction with water, 288
 - residual, 285, 288, 292, 293, 295, 298, 300, 331, 353, 534
 - safety, 316
 - uses, 204
 - withdrawal rate, 316, 344
- Chlorine demand
 - solution, 535
 - test, 534–538
- Chlorine dioxide
 - ammonia, 345
 - corrosion, 346
 - facilities, 345–353
 - generation, 346
 - iron and manganese, 292
 - maintenance, 351, 352
 - operation, 347–353
 - pH, 345
 - phenolic tastes and odors, 292
 - reaction in water, 292
 - reactions with impurities, 292
 - safety, 347, 359
 - shutdown, 350
 - sodium chlorite, 347
 - startup, 349
 - taste and odor control, 292
 - trihalomethanes, 293, 345
 - troubleshooting, 352, 353
- Chlorine residual test, 522–529
- Chlorine treatment, 105, 132–134
- Chloroform, 523
- Chlorophenol, 294
- Chlororganics, 292, 523
- Chromium, 19
- Chromocult Coliform Agar
 - Presence–Absence Membrane Filter Test, 539
- Cistern, water storage, 6
- Clarifiers, 220–222
- Clarity of water, 205
- Clear wells
 - description, 9
 - small plants, 170
- Clogged well screen, 100
- Clothing, safety, 403, 404
- Coagulation
 - alkalinity, 174
 - alum, 173
 - calculations, 179
 - calibration of feeders, 177, 178
 - chemical feeders, 177–179
 - dosage, 174
 - floc, 171
 - flocculation, 174
 - gang stirrer, 174
 - jar test, 174, 175
 - mixing, 174, 175
 - pathogen removal, 284
 - pH, 174
 - polymer, 177
 - process, 174, 176
 - streaming current meter, 175
 - temperature, 174
- Coatings, tanks, 408, 467
- Coliform
 - bacteria, 281
 - disinfection, 281
- Coliform Agar ES, 568
- Coliform bacteria, 281, 538
- Coliform tests
 - Colilert method, 541, 566
 - fermentation tubes, 540
 - membrane filter, 557–560, 563
 - Presence–Absence (P–A) Method, 564–566
- Coliform-positive samples, 538
- Colilert method, 541, 566
- Colilert test (enzyme substrate test), 566–568
- Colisure test (enzyme substrate test), 566–568
- Colitag Presence–Absence (P–A) Test, 539, 568
- Collapsed well, 56
- Collapsed well screen, 99
- Color, 15, 20, 510
- Colorimeter, 510, 527
- Colorimetric measurement, 510
- Column pipe, wells, 110, 112
- Combined chlorine, 207
- Combined residual chlorine, 523, 534
- Combustible gases, 398
- Commodity costs, 597, 599
- Commodity-demand method, 597
- Community water system, 21
- Competent person
 - confined spaces, 469
 - defined by OSHA, 439
 - hazard assessment of work site, 439
 - shoring, 459
- Complaint handling, operator's duties, 25
- Composite sample, 569, 573
- Compound substance, 487
- Conductor casing, wells, 67, 73
- Cone of depression, 36, 52
- Confined space, 398, 408, 467
- Confined space entry permit, 467, 468
- Connection fees, 589
- Connections, equipment, 316
- Conservation, 2
- Consolidated formation, 62
- Constant rate method, wells, 94–95
- Construction cost index (CCI), 589
- Construction, wells, 55
- Consumer confidence report (CCR), 611
- Consumer demands for water, 10
- Consumer price index (CPI), 589

- Contact time, chlorine, 207, 300
 Contactor, ozone, 375
 Containers
 chlorine, 313–317, 326
 sampling, 571, 578
 Contaminated water supply
 contamination, 627–631
 countermeasures, 630
 Cryptosporidium, 630
 emergency treatment, 629
 incident commander, 627
 response, 627
 wells, 131–132
 Contamination. *See also* Water quality
 groundwater, 3
 Contingency planning, 619
 Contingency reserve, 588
 Control devices and zones. *See* Traffic control
 Control of
 corrosion, 219
 iron and manganese, 259
 Controls, pumps, wells, 137–140
 Copper, 19, 20
 Copper Rule. *See* Lead and Copper Rule
 Corrosion
 chemical treatment, 219
 control, 219
 damages, 219
 Langelier Index, 219
 lime, 219
 polyphosphate, 105, 219
 small plants, 171
 soda ash, 219
 water quality problems, 218
 water treatment plants, 171
 wells, 98–99
 Corrosion problems
 chlorination, 313, 355
 chlorine dioxide, 346
 Corrosive chemicals, 406
 Corrosive materials, 501
 Corrosivity, 11
 Cost allocation, 597–602
 Cost-based rates, 598
 Cost-of-service studies, 598
 Costs
 treatment, 3
 water rates, 2
 Coverage ratio, 612
 Cross-connections, 13, 149
 Cryptosporidiosis, 7, 233, 538
Cryptosporidium, 281, 283, 377, 630
 CT values, 300
 Culture strategy, test, 540
 Culture tubes, 489
 Currents, in tanks, 185
 Custom designed plant, 172
 Customer service costs, 598
 Cuts, injury, 500, 504
 Cylinders, chlorine, 314–315
 Cysts, 284
- D**
- Daily log or diary, 270
 Daily tasks, 268, 269
 Damages
 corrosion, 219
 Dams and reservoirs. *See* Reservoirs
 Dangerous air contamination, 398, 400, 469
 Data recording, 498
 DBPR. *See* Disinfectants and Disinfection Byproducts Rule (DBPR)
 Debt service, 594
 Decibel, noise exposure, 472
 Decision sight distance, defined, 425
 Deep-well pumps, 108, 109, 110, 115
 Deionized water *versus* distilled water, 534–535
 Demand, chlorine, 288, 301, 302
 Demand costs, 597, 598
 Demineralized water, 542
 Depreciation, 590
 Depth sampling, 570, 575, 576
 Detection, chlorine leaks, 333, 339–343, 356, 357
 Detention rate curve, chlorine, 299
 Detention time
 chlorine, 300
 curves, 299
 nitrification, 297
 reservoirs, 14
 settling (sedimentation), 184, 189
 Dew point, 324
 Diaphragm pump, 307
 Diatomaceous earth, 191, 192
 Diatoms, 294
 Dichloramine, 293, 294, 523
 Dilution water, 543
 Direct fire protection costs, 598, 605
 Direct runoff, 6
 Diseases, 203, 280
 Disinfectants and Disinfection Byproducts Rule (DBPR), 281
 Disinfection, 280–386. *See also* Chlorination
 action, 287
 additional resources, 386
 agents of disinfection, 285
 bacteria, 281
 bacteria, pathogenic, 280
 bacterial cells, 285
 bitter taste, 286
 breakpoint chlorination, 292, 335
 bromine, 286
 byproducts, 19, 286
 calcium hypochlorite, 290, 291
 calculations, 301
 chemical disinfectants, 286
 chloramines, 290, 292, 298
 chlorination, 287
 chlorinator, 307–313
 chlorine, 287–290
 chlorine dioxide, 291, 345–353
 coliform, 281
 combined chlorine, 207
 concentration, 207
 contact time, 207, 300
 critical factors, 300
 Cryptosporidium, 281, 283, 377
 CT values, 300
 cysts, 284
 definition, 203
 disease, waterborne, 280
 diseases, 203, 280
 dosage, 209, 213, 288
 DPD method, 206
 enzymes, 287
 fecal coliforms, 538
 flow diagram, 304
 formulas, 320, 336
 free chlorine, 207
 Giardia lamblia, 19, 209, 228, 248, 281, 282, 300, 377
 giardiasis, 203, 247, 280
 heat, 286
 hepatitis, 280
 hypochlorinator, 216
 hypochlorite, 290–291
 influencing factors, 283
 inorganic matter, 284
 iodine, 286
 math assignment, 385
 math, example problems, 378
 maximum contaminant level, 281
 microbial standards, 281
 microorganisms, 284–285
 mixed-oxidants system, 377–378
 mixing, 205
 monitoring, 281
 organic matter, 284, 292
 ozone, 286, 371
 parasites, 280
 pathogen removal, 284
 pathogenic organisms, 280
 pH, 283, 288, 300, 345
 physical means, 285
 points of application, 303
 population served, 281
 postchlorination, 300, 303, 304, 335
 prechlorination, 293–334
 process calculations, 301
 processes, 285–303
 protozoa, 280
 purpose, 283
 recordkeeping, 299
 reducing agents, 283, 284, 289, 300
 removal processes, pathogens, 284
 reporting, 282
 residual chlorine, 285, 288, 292, 293, 296, 300, 331, 353–355, 522, 534, 536
 safety, 409
 sampling, 281, 282
 small plants, 171

- sodium hypochlorite, 204
 - spore-forming bacteria, 284
 - standards, microbial, 281
 - sterilization, 280
 - taste, bitter, 286
 - temperature, 283, 300
 - time of contact, 204
 - total chlorine, 296
 - trihalomethanes, 284, 285, 303, 345
 - troubleshooting, 334, 338, 339, 352
 - turbidity, 283, 300
 - ultrasonic waves, 286
 - ultraviolet radiation, 204
 - ultraviolet rays, 285, 286, 368
 - ultraviolet (UV) systems, 285, 360, 368
 - variables, 283
 - viruses, 203, 281, 284, 345, 376
 - water treatment plants, 171
 - waterborne diseases, 280
 - wells, 129–134
 - withdrawal rate of chlorine, 210
 - Disinfection byproducts (DBPs), 19, 286
 - Displacement well pumps, 108
 - Disposal of
 - brine, 266
 - records, 618
 - sludge, 186
 - Distances to wells, 51–54
 - Distilled water
 - in culture media, 546
 - versus deionized water, 534
 - Distribution systems
 - description, 10
 - flushing mains, 146
 - sampling, 570–573
 - Diversion works, 169
 - Dosage, coagulation, 174
 - Dose, chlorine, 288, 302
 - DPD Colorimetric Method, 525–529
 - DPD method, 206
 - DPD test, 296, 337, 353
 - DPD titration method, 524
 - DPD titrimetric method, 524
 - Drawdown, wells, 13, 117, 144
 - Drilled wells, 60–65
 - Driller's log, wells, 38
 - Driller's report, wells, 156
 - Drinking water, 280–281
 - laws, 280
 - regulations, 19
 - safety, 280
 - sampling, 18, 569–578
 - turbidity removal, 19
 - Driven wells, 56–60
 - Driving, safety, 395
 - Drums, traffic control, 457
 - Dual media filter, 193
 - Dug wells, 56, 58
 - Duties of operators, 23, 24, 269
 - Dysentery, contamination of water supply, 6
- ## E
- E. coli* (EPA Method 1603), 563
 - E*Colite Test, 539, 568
 - EDTA titrant, 521
 - Eductor, 305
 - Effective size, 68, 233
 - Ejector, 305, 312
 - Electric shock, 500, 504
 - Electrical, safety, 406, 411
 - Electrical supply, pumps, 135
 - Electrochemical probe, 510
 - Electrochemical reaction, 218
 - Emergency(ies)
 - administration, 619–620
 - chlorine repair kits, 341
 - contaminated water supply, 623
 - preparation for, 619–620
 - procedures, 626
 - response plan, 619–626
 - treatment, 627
 - Emergency traffic control situations, 441
 - Employee “Right-To-Know” laws, 394
 - Endpoint, 495, 515
 - Endrin, 19
 - Enzyme substrate coliform test, 541
 - Enzyme Substrate Method, 539
 - Enzyme substrate tests, 539, 566–568
 - Enzymes, 287
 - Epidemiology, 13
 - Equipment
 - chlorination, 305, 310
 - electrochemical probe, 510
 - laboratory, 488–495 (*see also* Laboratory equipment)
 - ozone, 372–374
 - safety, 398–403
 - sampling, 574, 575
 - ultraviolet (UV) systems, 361
 - Equity, 596
 - Escherichia coli* (*E. coli*), 563
 - Evaluation of wells, 92
 - Evaporation, 32, 33
 - Evaporator, chlorine, 324, 328
 - Evapotranspiration, 5
 - Excavations in streets
 - cave-ins, 461
 - ladders, 462
 - safety rules, 459
 - shoring, 459
 - spoil, 459
 - trenches, 459
 - underground utilities, 462–463
 - Expenses, 612, 613
 - Explosions, 500, 501
 - Explosive charges, wells, 105
 - Explosive conditions, safety, 25, 399
 - Explosive limits, 399, 402
 - Extra capacity costs, 598
- ## F
- Facultative bacteria, 538
 - Failure, chlorination, 339
 - Falls, safety, 404, 464
 - FC test. *See* Fecal coliform (FC) test
 - Fecal coliform (FC) test, 539, 549, 561, 565
 - E. coli*, 539
 - Fermentation tubes, 540, 544
 - Field testing of deposits, wells, 98
 - Filter aids, 192, 197, 200
 - Filtration
 - anthracite, 193
 - backwashing, 195–201
 - boils, 199
 - breakthrough, 195, 197
 - calculations, 201–203
 - controller, 193
 - diatomaceous earth, 191, 192
 - dual media filter, 193
 - filter aids, 192, 197, 200
 - gravity, 190, 191
 - head loss, 194, 195, 200
 - iron and manganese control, 260
 - media, 192, 193
 - mixed media filter, 193
 - mudballs, 197, 199
 - operation, 194
 - pathogen removal, 285
 - polymers, 192, 197, 200
 - precoat filters, 191
 - pressure, 191, 192, 194, 196, 197, 200
 - process, 190, 192
 - purpose, 192
 - rapid sand filters, 194
 - rate, 194, 199
 - rate-of-flow controller, 194
 - rinsing pressure filters, 198
 - sand, 190, 192
 - slow sand filters, 190, 192, 229–259 (*see also* Slow sand filter)
 - softening, 261–264
 - surface wash, 194, 196
 - troubleshooting, 199
 - turbidity, 194
 - types, 190
 - underdrain, 191, 194, 196, 197, 233
 - waste backwash water, 197
 - Financial stability, 612
 - Fire
 - blanket, uses, 505
 - classifications, 506
 - extinguisher, 505–506
 - laboratory, 500, 505
 - protection costs, 597, 598, 605
 - First aid
 - chlorine, 359
 - laboratory, 502
 - First-draw sampling, 577
 - Fixed costs, 588
 - Flag tree warning devices, traffic control, 455
 - Flagging, traffic control, 440–444

Flame-polished glass, 505
 Flammable conditions, 402
 Flammable or explosive materials used in laboratories, 500
 Floc, 171
 Flocculation
 mixing, 182
 operation, 182–183
 process, 171, 182
 short-circuiting, 183
 troubleshooting, 183
 Flow measurement, 169
 Flow pattern, 304
 Flowmeters, wells, 80–81
 Fluoride, 19
 Flushing, mains, sand, 146
 Foaming agents (MBAS), 20
 Foot valve, wells, 76, 77, 80
 Forecasting expenditures, 588
 Formation
 consolidated, 62
 unconsolidated, 57
 Formazin Turbidity Units (FTU), 512
 Formulas
 chlorination, 320, 336
 disinfection, 320, 336
 laboratory, chemicals, 486–488
 sampling, 571
 Free available residual chlorine, 207, 292
 Free chlorine, 207
 Free residual chlorine, 523
 Friction loss table, 120
 Frozen chlorine, 330
 FTU. *See* Formazin Turbidity Units (FTU)
 Fuel, safety, 418
 Fusible plugs, 314, 315

G

Gang stirrer, 174, 175
 Garnet, 193
 Gases, safety, 399
 Geologic data, 38
 Geological log, 13
Giardia lamblia, 19, 209, 228, 229, 237, 247, 248, 281, 282, 300, 377
 Giardiasis, 6, 203, 233, 247, 280, 538
 Glasses, safety, 501
 Glassware, laboratory, 492–495, 542
 Grab sample, 573, 575
 Gravel-envelope wells, 56, 66, 70, 74
 Gravel-packed wells, 57, 66
 Gravity filters, 190, 191
 Greensand, 260
 Grounds, maintenance, 271
 Groundwater
 advantages, 32
 aquifers, 32, 33
 hydrologic cycle, 33, 34
 importance, 40
 movement, 32

 origin, 32
 overdraft, 35
 pollution, 32, 37, 38
 porosity, 34
 protection, 39
 recharge, 9
 recordkeeping, 38
 safety, 49
 sampling, 570
 soil moisture, 32
 source, 7, 8, 13
 specific yield, 34
 transmissivity, 34
 treatment, 172–173
 wells, 8, 32
 yield, 34, 144
 zone of saturation, 7, 33
 Grout seal, wells, 69–71
 Guards, safety, 414

H

Halliburton grout method, 70
 Handling and lifting, 405
 Hands-only CPR, 359
 Hardness test, 520–522
 Hardness treatment, 173
 Hard-rock wells, 56, 66
 Hazardous materials
 disposal, 504, 505
 laboratory, 500–501
 Hazardous wastes, 3
 Hazards
 chlorination, 355
 safety, 271, 392
 Head, 108, 111
 Head loss, filtration, 194, 195, 200
 Health hazards
 disease, 6
 groundwater recharge, 9
 laboratory, 500
 Hearing protection, 473
 Heat, disinfection, 286
 Hepatitis, 6, 280
 Heterotrophic bacteria, 19, 282, 294
 High resolution redox (HRR), 354
 High service pumps, 171
 High Test Hypochlorite (HTH), 290
 High-level flag tree warning devices, traffic control, 454, 455
 High-rate settlers, 186
 High-velocity jetting, wells, 101–102
 Holding time, sampling, 577, 578
 Homeland defense, 623–626
 HRR (high resolution redox), 354
 HTH (High Test Hypochlorite), 290
 Hydraulic gradient, 51
 Hydraulic rotary drilling, wells, 60, 62–64
 Hydrogen sulfide, 400
 chlorine reaction with, 289
 Hydrogeologist, 35

Hydrologic (water) cycle, 5, 32
 Hydrologic data, 38
 Hydropneumatic tanks, wells, 81, 83, 85–91
 Hydrostatic pressure, 64
 Hygiene, laboratory, 501
 Hypochlorinators, 305–307, 318. *See also*
 Chlorination
 maintenance, 213–214
 operation, 351–353
 troubleshooting, 322
 Hypochlorite
 calcium hypochlorite, 290
 calculation example, 382
 disinfection, 290
 HTH (High Test Hypochlorite), 290
 hypochlorous acid, 288, 290, 293, 523
 ion, 288
 reactions with water, 289–290
 safety, 359
 sodium hypochlorite, 291
 Hypochlorous acid, 288, 290, 293, 523

I

Ice, chlorine, 330
 IDLH (Immediately Dangerous to Life or Health), 344
 IESWTR. *See* Interim Enhanced Surface Water Treatment Rule
 Immediately Dangerous to Life or Health (IDLH), 344
 Impermeable, 6
 Incident commander, 627
 Incrustation, well screens, 96–98
 Indicators, 510
 Industrial facilities, wells, 52
 Inflation, 589
 Injection point, chlorine, 299, 300
 Injector, chlorine, 305, 307, 310, 331, 338
 Injector water supply, 310
 Injuries, safety, 393
 Inlets, 184–186
 Inorganic
 chemicals, 16, 19
 compounds, 487
 matter, 284
 In-plant sampling, 570
 Inspection
 ladders, 466
 maintenance, 227
 safety, 413, 474–475
 safety report form, 475
 Installation
 chlorination equipment, 305, 343
 Instrument calibration, 493, 511
 Instrument-based water quality tests, 507–514
 Intake, wells, 67–69
 Intake structures, multilevel, 7

- Interim Enhanced Surface Water Treatment Rule (IESWTR), 281
- Inventory records, 618
- Investor-owned utilities, 596
- Iodine, 204
- Iodine, disinfection, 286
- Ion, 487
- Ion exchange, 264–267
- Iron, 20
- Iron and manganese
aeration, 260
chlorine, 260
control, 259
dechlorination, 260
filtration, 260
greensand, 260
ion exchange, 260
objections, 259
polyphosphates, 260
potassium permanganate, 260
superchlorination, 260
- Iron and manganese control
chlorine dioxide, 292
SMCL (secondary maximum contaminant level), 20
- Irrigation runoff, 2, 12
- Irrigation water, 8
- J**
- Jar test, 174, 175, 224, 226, 261
alkalinity monitoring, 532
apparatus, 529, 530
coagulation/flocculation, 529–534
jar shape, selecting, 529
polymer and coagulant aid dosages, 531
procedure, 529, 531
- Jet pumps, 59, 110
- Jetting, well screens, 101–102
- Jobs, knowledge and skills needed, 22
- Joint, mechanical, 55
- K**
- Kemmerer depth sampler, 576
- Kinetic energy, 83
- L**
- Lab results, reporting, 577
- Labeling sample container, 503, 577
- Laboratory. *See also* Laboratory equipment;
Laboratory glassware; Laboratory
procedures; Laboratory safety
chlorination, 337, 353
disinfection, 332, 353
jar test, 529
metric system units, 484–486
- Laboratory equipment
autoclave, 492
colorimeter, 525–528
glassware (*see* Laboratory glassware)
pH meter, 510
turbidimeter, 513
turbidity meter, 513
- Laboratory glassware
culture tube, 489
meniscus, 492, 493
pipets, 493–495
test tubes, 489
- Laboratory procedures
accident prevention, 502–506
acid titration curve, 516
additional resources, 484, 509, 510, 520,
528, 538, 557, 562, 564
additional test methods, 568
alkalinity test, 515–520
bacterial cultures, 539
basic concepts, 484–488
biological tests, 538–568
calibration, 493, 511
chain-of-custody protocol, 577
chemical burns, 505
chemical names, 486–488
chemical solutions, 495–498
chemical storage and movement,
502–503
chlorine demand test, 534–538
chlorine residual test, 522–529
coliform bacteria, 538
Colilert method, 541, 566
corrosive materials, 501
data recording, 498
enzyme substrate tests, 566–568
equipment, 488–492 (*see also* Laboratory
equipment)
erratic laboratory results, 511
error sources, 569
Escherichia coli, 563, 564
fecal coliform, 538
fire extinguisher, 505–506
formulas, 486–488
glassware, 492–495 (*see also* Laboratory
glassware)
hardness test, 520–522
hazardous materials, 500
hazards in laboratory, 500–501
identification strategies, testing, 540
instrument-based tests, 507–514
jar test, 529
labeling chemicals, 503–504
liquid media sterilization, 543
math assignment, 579
media, 540
media preparation and storage, 543–544
membrane filter, 541
membrane filter (MF) method, 557–561
membrane filter method-*E. coli*, 563–564
membrane filter procedure
modifications, 561–562
meniscus, 492, 493
metric system, 484–486
microbial testing material, 542–544
most probable number (MPN)
procedure, 544–557
MPN Index, 551, 555
MPN (most probable number)
procedure, 540, 544–557
multiple tube fermentation, 540,
544–557
notebooks, 498
pH test, 509–511
plant process tests, 529–538
Presence–Absence (P–A) Method, 541,
564–566
quality control, 499
recordkeeping, 498
reference-type sample, 499
reporting lab results, 577–578
safety, 500–506
sampling, 569–578 (*see also* Sampling)
devices, 574
techniques, 575–577
solutions, 493, 495
standardized solutions, 516
techniques, 488–495, 503
temperature test, 507
test methods, overview, 539–542, 568
thermometer types, 507–508
titrations, 514–529
total coliform bacteria testing, 544–568
toxic fumes, 505
turbidity test, 511–514
turbidity units (TU) and measures, 512
using glassware, 492–495
waste disposal, 505
water quality tests, 507–568
worksheets, laboratory, 498, 499
- Laboratory safety
accident prevention, 502, 504
acids, 501
additional resources, 506
bases, 501
bruises, 500
burns, 500, 505
caustics, 501
chemical storage, 502
corrosive materials, 501
cuts, 500, 504
electric shock, 500, 504
explosions, 500, 501
fires, 500, 505–506
first aid, 502
flammable materials, 501
glasses, safety, 501–502
hazardous materials, 500–501
hazards, 500
hygiene, 501–502
mercury, 503
movement of chemicals, 502–503
Occupational Safety and Health
Administration (OSHA), 500
personal safety, 501–502

- Laboratory safety (*continued*)
 prevention of accidents, 502, 504
 protective clothing, 502
 shock, 500, 504
 techniques, 503
 toxic materials, 500, 501, 505
- Laboratory tests, 337
- Ladders, safety, 462, 464–465
- Lakes. *See also* Reservoirs
 sources of water, 6–7
- Land subsidence, 8
- Langelier Index (LI), 219
- Lauryl tryptose broth, 540
- Laws, drinking water, 280–283
- Layout, small plants, 256
- Lead, 19
- Lead and Copper Rule
 first-draw sampling, 577
- Leaks, chlorine, 316, 323, 332, 339–343, 357
- LEL (lower explosive limit), 399, 402
- LES endo agar, 540
- chlorine tanks, 314, 315
- Lifting, safety, 273, 405
- Lighting devices, traffic control, 458
- Lime, corrosion control, 219
- Limits on water, 2
- Lindane, 19
- Liquid media sterilization, 543
- Location, chlorination equipment, 343
- Location, wells, 49
- Lockout/tagout procedure, 416–418
- Log removals, 248
- Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR), 283
- Lower explosive limit (LEL), 399, 402
- Lubricants, safety, 418
- Lubricating oils, 114
- M**
- Mains
 disinfection, 305
 water flushing, 146
- Maintenance
 chlorination, 322, 339, 357
 chlorinators, 209
 chlorine dioxide, 350
 equipment, 23
 grounds, 271
 hypochlorinators, 214
 inspections, 271
 ozone, 375
 plant grounds, 271
 safety, 392
 slow sand filters, 245
 small plants, 168
 solids-contact clarification units, 227
 tools, 272
 ultraviolet (UV) systems, 369–371
 wells, 95–107
- Manganese, 20
- Manifold, 91, 313, 344
- Manual on Uniform Traffic Control Devices (MUTCD), 419
- Manual sampling, 574
- Marble test, 264
- Mass concentration, 495
- Math assignment
 chlorination, 385
 disinfection, 385
 laboratory procedures, 579
 safety, 273
 wells, 160
- Maximum contaminant level (MCL), 17, 18, 281
- MBAS (foaming agents), 20
- MCL (maximum contaminant level), 17, 18, 281
- m-ColiBlue24® Test, 539, 568
- Mechanical joint, 55
- Media
 filtration, 190, 191
 preparation and storage, 543–544
- Meg, 142
- Membrane filter
 counting colonies, 562
 inoculation, 558
 need, 541, 549
- Membrane filter (MF) method, 539, 557–561
- Membrane filter method–*E. coli* (EPA Method), 539, 541–542, 563–564
- Membrane filter procedures modifications, 561–562
- Meniscus, 492, 493
- Mercury, 19, 362, 371, 503
- Mesh, 81
- Meter equivalents, 606
- Metering, chlorine, 310, 323, 325, 334
- Methoxychlor, 19
- Metric system, 484–486, 672–675
- Microbes, 540
- Microbial standards, 19, 281, 282
- Microbial testing, materials, 542
- Microorganisms, 204, 284
- Mixed media filter, 193
- Mixed-oxidant disinfection, 377
- Mixing
 chlorine, 299
 coagulation, 174, 176
 disinfection, 205
 flocculation, 182
- Mole, 496
 control systems, 484
 disinfection, 280, 282
- Monitoring, water quality
 changes, 106
 slow sand filters, 228
 wells, 99, 106
- Monitoring equipment, safety, 398, 399
- Monochloramine, 293, 523
- Most Probable Number (MPN) procedure, 539, 540, 544–557
- Motor starters, pumps, 135
- Motors, pumps, 127
- Mouth-to-mouth resuscitation, 359
- Movement, groundwater, 32
- Moving parts, safety, 414
- MPN Index, 551, 555
- MPN (most probable number) procedure, 539, 540, 544–557
- Mudballs, 197, 199
- Multilevel, 7
- Multiple tube fermentation, 540
- Multiple Tube Fermentation Method (MPN Procedure), 539, 540, 544–557
- Multiple-block rate structure, 605
- Multistage pumps, 109
- MUTCD (Manual on Uniform Traffic Control Devices), 446
- N**
- Nameplate, 143
- Negligence, safety, 392
- Nephelometer, 512
- Nephelometric method, 512
- Nephelometric Turbidity Unit (NTU), 512
- Nitrate, MCL (maximum contaminant level), 19
- Nitrification, 295–298
- Nitrite-oxidizing bacteria, 296
- Noise, 471
- Noise exposure, safety, 471–474
- Noncommunity water system, 21
- Non-permit-required confined space, 469
- Nontransient noncommunity water system, 21
- Normal conditions, chlorination, 303, 305, 313, 318, 327
- Notebooks, lab, 498
- NTU. *See* Nephelometric Turbidity Unit (NTU)
- O**
- Objective, water treatment, 10
- Occupational Safety and Health Act of 1970 (OSH Act of 1970), 439, 500
- Occupational Safety and Health Administration (OSHA), 500
- Odor, 12, 16
- Odor control. *See* Taste and odor control
- Odor threshold, 20
- Oil-lubricated pumps, 110, 112, 114, 131
- O&M. *See* Operation and maintenance (O&M)
- On-site chlorine generation, 291
- Operating expenses, 612, 613
- Operating pressure differential, 89
- Operating ratio, 612

- Operation
 - chlorination, 305–339
 - chlorine dioxide, 345–353
 - disinfection, 285–303
 - Operation, small plants
 - backflow prevention, 270
 - certification, operator, 268
 - daily log or diary, 270
 - daily tasks, 269
 - duties, operator, 24, 268–269
 - laboratory tests, 270
 - maintenance, 271
 - periodic tasks, 269
 - plant operation, 269
 - procedures, 268–269
 - recordkeeping, 268
 - responsibilities, operator, 173, 268
 - safety, 271, 273
 - system records, 270
 - training operators, 268
 - Operation and maintenance (O&M)
 - disinfection, 203–218
 - expenses, 612, 613
 - filters, 199
 - floculation, 182, 183
 - hypochlorinators, 204
 - operator's duties, 23
 - sedimentation, 183–188
 - small plants (*see* Operation, small plants)
 - softening, 261, 264
 - solids-contact clarification, 220–227
 - Operator
 - certification, 21, 22, 268
 - complaint handling, 25
 - duties, 23, 24, 268–269
 - operation and maintenance, 23–24
 - pay, 23
 - public relations, 25
 - qualifications, 22
 - recordkeeping, 24
 - requirements, 10
 - responsibility, 22, 38, 40, 46, 152, 173, 268, 271
 - safety, 25, 271, 273, 347, 355
 - safety training programs, 359
 - salary, 23
 - sampling, 18
 - staffing needs, 23
 - supervision and administration, 24–25
 - training courses, 26, 264
 - Organic compounds, 487
 - Organic matter, chlorine demand, 284
 - Organics
 - chlorine demand, 292
 - compounds, 487
 - MCL (maximum contaminant level), 19
 - source, 13
 - Organism, 538
 - Orifice, 81
 - Origin, groundwater, 32
 - ORP (oxidation-reduction potential) probe, 354
 - OSH Act of 1970 (Occupational Safety and Health Act of 1970), 500
 - OSHA. *See* Occupational Safety and Health Administration (OSHA)
 - Outlet chamber, 236–237
 - Outlet gates. *See* Intake structures
 - Outlet structures. *See* Intake structures
 - Outlets, tank, 175
 - Overdraft, wells, 32
 - Overflow rates, 186, 222
 - Overpumping, wells, 96
 - Overturn, lake, 7
 - Oxidation, 172
 - Oxidation-reduction potential (ORP) probe, 354
 - Oxidizing agent, 292
 - Oxygen deficiency/enrichment, 398, 469
 - Ozone
 - advantages, 376–377
 - applications, 375–376
 - characteristics, 375, 376
 - chemical reaction, 374, 375
 - contactor, 374
 - costs, 377
 - description, 371, 372
 - disinfection, 286, 371
 - effectiveness, 371, 372, 376, 377
 - electrical supply, 373
 - equipment, 372
 - gas preparation, 372–373
 - generator, 373–374
 - limitations, 376–377
 - maintenance, 375
 - residual, 374–375
 - safety, 375
 - tastes and odors, 375
- P**
- Package plants, 171, 172
 - Parasites, 280, 630, 631
 - Parshall flume, 176
 - Pathogen removal
 - coagulation, 284
 - disinfection, 284, 285
 - filtration, 285
 - sedimentation, 285
 - Pathogenic organisms, 247, 280, 284, 538, 549
 - Pathogens, 538
 - Pay, operator, 23
 - Payback time calculation, 590
 - PCMS (portable changeable message sign), 452
 - Pedestal, pump, wells, 73, 75–76
 - Pedestrian safety, traffic control, 436
 - Percussion drilling, wells, 60–62
 - Performance testing, wells, 92
 - Permeability, 51, 60
 - Permit-required confined space, 469
 - Personal safety, 398
 - Personnel records, 618
 - Pesticides, 16
 - Pet cock, 76
 - pH
 - chlorination efficiency, 283, 288, 300, 339
 - chlorine dioxide, 339
 - disinfection, 204, 207
 - meter, 510
 - test, 509–511
 - pH meter, 510, 517
 - alternative indicators, 518
 - Phenol, 294
 - Phenolic tastes and odors, 292, 294
 - Phenolphthalein alkalinity, 518
 - Physical, disinfection, 285–286
 - Physical, water quality, 15
 - Physiological response, chlorine, 356
 - Piezometer, 238
 - Pigtail tubing, 317, 326
 - Pipets, laboratory, 493
 - Piston pump, 110, 113
 - Plan review, chlorination, 343
 - Planning, expenses, 612
 - Plant operations records, 616
 - Plant process tests, 529–538
 - PLC. *See* Programmable logic controller (PLC)
 - Plugging, wells, 38, 149, 413
 - Plunging, wells, 100
 - Points of chlorine application, 303–305
 - Policy, safety, 410
 - Pollution
 - groundwater, 32, 37, 38
 - sources, 38
 - wells, 32
 - Polymers
 - coagulation, 177
 - filtration, 192, 197, 200
 - Polyphosphates
 - corrosion control, 105, 219
 - iron and manganese, 260
 - safety, 260
 - wells, 105
 - Poppet valves, 214, 319
 - Population served, 281, 282
 - Pore, 34
 - Porosity, 34
 - Portable changeable message sign (PCMS), 452
 - Positive displacement pumps, 80, 108
 - Postammoniation, 294
 - Postchlorination, 300, 303, 304, 335
 - Potable water, 523
 - Potassium permanganate, iron and manganese, 260
 - Preammoniation, 294
 - Prechlorination, 290, 293, 295, 300, 303, 304, 335
 - Precipitate, 172, 528
 - Precipitation, 528
 - Precoat filters, 191, 192

- Precursors, THM (trihalomethane), 303
 Preparation for emergencies, 626
 Prescriptive water rights, 12
 Presence–Absence Broth, 568
 Presence–Absence (P–A) Method, 539, 541, 564–566
 Present worth, 590
 Preservation of samples, 577, 578
 Pressure
 differential, operating, 89
 filters, 191, 196, 197, 200, 227
 hydrostatic, 64
 relief valves, wells, 83–84
 tanks, wells, 81, 85, 87, 90
 Presumptive test
 example, 565, 566
 total coliform bacteria, 544
 Prevention of accidents, 392, 502, 504–506
 Preventive maintenance. *See* Maintenance
 Primary regulations, 18
 Prime, pumps, 80
 Procedures, sampling, 569
 Processes, treatment
 coagulation, 171, 173
 disinfection, 171, 203
 filtration, 171, 190
 flocculation, 171, 182
 sedimentation, 183
 solids-contact clarification, 220
 Procurement records, 616–617
 Program, safety, 25, 355, 392–394
 Programmable logic controller (PLC), 363, 365
 Protection from chlorine, 316
 Protective clothing, 357, 404, 409, 466, 501–502
 Protozoa, 203
 Public, safety, 441, 626
 Public health, 9, 10, 13, 627–629
 Public relations, operator's duties, 25
 Public safety, 441
 Pumping, tests, wells, 92
 Pumps, wells
 air-lift, 108
 auxiliary power, 135–137
 bowls, 108
 centrifugal, 108
 column pipe, 110, 112
 controls, 137–140
 deep well, 109–110, 115
 disinfection, 129–134
 displacement, 108, 110
 electrical supply, 135
 evaluation, 116–129
 hydropneumatic tanks, 83, 85–92
 jet, 58, 110, 113
 lubricating oils, 114
 motor starters, 135
 motors, 115–116
 multistage, 109
 oil lubricated, 110, 112, 114
 operating pressure differential, 89
 operator responsibility, 152–160
 pedestal, 75–76
 piston, 110, 113
 positive displacement, 108
 pressure tanks, 83, 85–92
 prime, 80
 pump station, 77
 reciprocating, 108
 recordkeeping, 152–160
 rotary, 110, 112, 114
 safety, 413–419
 sand, 144–149
 selection, 113
 service guidelines, 108–129
 shallow, 59, 108
 small plants, 171
 station, 77
 submersible deep well, 110, 112
 testing, 116–129
 troubleshooting, 140–144
 turbine-type, 109–112, 131
 unbalanced current, 126–127
 variable displacement, 108
 volute-type, 108–109
 water lubricated, 109, 114, 131
 water treatment plants, 171
 Purchase order, 614, 617
- ## Q
- Qualifications for operator jobs, 22
 Quality control, laboratory, 499
 Quality monitoring, wells, 106
 Quartz sleeve, 361, 369
- ## R
- Radioactivity, MCL (maximum contaminant level), 17
 Radiological water quality, 15, 17
 Ranney well, 65–66
 Rapid mix, 171, 174–177, 192, 294, 295, 531
 Rapid sand filters, 194
 Rate
 administration, 610–612
 components, 604–605
 design, 603–610
 of return, 596
 structure, 608
 studies, 584
 Rate of chlorine withdrawal, 316, 344
 Rate-of-flow controller, 194
 Rates, water, 2, 584
 Rates of filtration, 194, 195, 199, 213
 Readyult Coliforms 100
 Presence–Absence Test, 535, 539
 Reagent
 chlorine demand-free water, 535
 chlorine dosing solution, 535
 freshness, 530
 prepared, 525
 stock chlorine solution, 535
 using pipets, 494
 Recarbonation, 264
 Rechlorination, 303
 Reciprocating pump, 108
 Recirculation, 223–226
 Reclaimed water, 8
 Record drawings (as-built plans), 24
 Recordkeeping
 computer, 616
 disinfection, 209
 disposal of, 618
 equipment and maintenance, 616
 groundwater, 38
 inventory, 618
 laboratory, 498
 operation, 268
 operator's responsibility, 25
 personnel, 618
 plant operations, 616
 procurement, 616–617
 pumps, 152–160
 slow sand filters, 255
 small plants, 268
 solids-contact clarification, 220
 types, 616
 wells, 38, 99, 152–160
 Records. *See* Recordkeeping
 Recreation, lakes, 7
 Reducing agents, 283, 284, 289, 300, 534
 Regeneration, 265, 266
 Regulations
 SDWA (Safe Drinking Water Act), 18–22, 280
 street work, 436
 wells, 45
 Rehabilitation, wells, 96
 Rehabilitation costs, 587
 Reliquefaction, 213
 Removal processes
 chlorine, 316
 pathogens, 284, 285
 Removing chlorine, 316
 Repair/replacement fund, 595–596
 Repairs
 safety, 414
 wells, 99
 Replacement costs, 596
 Reporting, disinfection, 281
 Representative sample, 569
 Requisition, 614, 616, 617
 Reserve funds, 588
 Reservoirs
 chlorination, 303
 disinfection, 303
 sampling, 569
 stratification, 7
 Residual analyzer, chlorine, 331, 334, 353, 375
 Residual chlorine, 207–214, 285, 288, 290, 292–296, 298–300, 331, 334, 335, 353, 522, 534

- concentrations, 527, 528
 - types, 523
 - Resistance of organisms, 284
 - Responsibility of operators
 - operation, 268
 - safety, 25, 392
 - small plants, 171, 173, 268
 - wells, 38, 46, 99, 152
 - Revenue requirements, 587–596
 - Reverse circulation, well drilling, 64
 - Rights to use water
 - appropriative, 12
 - prescriptive, 12
 - riparian, 12
 - Right-To-Know laws, 394
 - Rinsing pressure filters, 197
 - Riparian water rights, 12
 - Rivers, 6
 - Rossum sand sampler, 146, 147
 - Rotameter, 310
 - Rotary drilling, wells, 62–66
 - Rotary pumps, 110, 112, 114
 - Roughing filter, 249, 250, 255
 - Routing traffic, 419–463
- S**
- Safe distances to wells, 51–54
 - Safe Drinking Water Act (SDWA), 16–22, 191, 227, 280
 - Safe procedures
 - emergency traffic control situations, 439
 - high-visibility clothing, 441
 - noise exposure, 471–473
 - portable changeable message sign (PCMS), 452
 - regulations, street work, 427
 - speed limits in work zones, 440
 - street work regulations, 427
 - traffic control, 426, 430, 444–458
 - Safe yield for surface water supplies, 14
 - Safety. *See also* Laboratory safety; Traffic control
 - accidents, 392, 393, 398, 411
 - acids, 406, 409
 - additional resources, 476
 - awareness, 392
 - battery, 395–397
 - boats, 397
 - Call Before You Dig program (811), 462
 - carbon monoxide, 398
 - carelessness, 393
 - cave-ins, 461
 - chemicals, 409
 - chlorination, 314, 315, 320, 355–360
 - chlorine, 410
 - chlorine dioxide, 339, 347, 359
 - clothing, 403, 404
 - coatings, 408, 467
 - combustible gases, 398
 - competent person, 439, 459
 - confined space, 398, 403, 467
 - confined space entry permit, 468
 - corrosive chemicals, 406
 - dangerous air contamination, 398, 400, 469
 - definition, 392
 - disinfection, 409
 - drinking water, 280–283
 - driving, 395
 - electrical, 406, 411
 - equipment, 398–403
 - excavations, 459
 - explosive conditions, 399
 - explosive limits, 399, 402
 - falls, 404–405, 464
 - fire blanket, 505
 - fire extinguisher, 506
 - flammable conditions, 399
 - fuel, 418
 - gases, 400
 - General Industry Safety Orders, 500
 - guards, 414
 - handling and lifting, 405
 - hazards, 273, 355, 393
 - hearing protection, 472
 - homeland defense, 623–626
 - hydrogen sulfide, 398
 - hypochlorite, 359
 - injuries, 393
 - inspection, 413, 474–475
 - laboratory (*see* Laboratory safety)
 - ladders, 462, 464–466
 - lifting, 273, 405
 - lockout/tagout procedure, 416–418
 - lower explosive limit (LEL), 399, 402
 - lubricants, 418
 - maintenance, 414–416
 - management, 392
 - monitoring equipment, 398–403
 - moving parts, 414
 - negligence, 392
 - noise, 472
 - non-permit-required confined space, 469
 - objectives, 392
 - operator's responsibility, 25, 173
 - OSHA (Occupational Safety and Health Administration), 439, 500
 - oxygen deficiency/enrichment, 398, 469
 - ozone, 375
 - pedestrian traffic control, 436–439, 454
 - permit-required confined space, 469
 - personal, 398
 - policy, 392
 - prevention of accidents, 392
 - program, 25, 392
 - protective clothing, 403, 404, 409
 - public, 419, 441
 - pumps, 413–419
 - repair, 414–416
 - responsibilities, 25, 392
 - Right-To-Know laws, 394
 - Safety data sheet (SDS), 394
 - shoring, 459, 461
 - slings, 416
 - slips, 404–405, 464
 - small plant hazards, 271
 - storage facilities, water, 464
 - storage of fuel, 418
 - street work, 419–463
 - tailgate safety sessions, 393
 - tanks, 408, 467
 - think safety, 392
 - threat levels, homeland defense, 625
 - toxic gases, 399
 - traffic, 419–463
 - trailers, towing, 395
 - training, 392, 466
 - trenches, 459
 - ultraviolet (UV) systems, 360, 362
 - underground utilities, 462–463
 - unsafe acts, 392, 393
 - upper explosive limit (UEL), 399, 402
 - ventilation, 399, 470
 - waste disposal, 505
 - water storage facilities, 467
 - wells, 407, 409–410
 - working in streets, 419–463
 - Safety data sheet (SDS), 347, 394, 502
 - Safety program
 - operator's duties, 25
 - small plants, 271, 392
 - Salary, operator, 23
 - Sample, unchlorinated, filtering, 558
 - Sample preservation, 577, 578
 - Sampling
 - additional resources, 577
 - automatic, 574
 - bacteria quantity, 546, 556
 - chain-of-custody protocol, 577
 - chlorination, 281, 282
 - collection, 574–578
 - composite sample, 569, 573
 - containers, 571, 577, 578
 - depth, 569, 570, 574–576
 - devices, 574
 - disinfection, 281, 282
 - distribution system, 570–572
 - drawn from main, 570, 571
 - drinking water, 17, 569–578
 - errors, 569
 - first-draw sampling, 577
 - formulas, 571
 - grab samples, 573, 575
 - groundwater, 570
 - holding time, 577, 578
 - in-plant, 570
 - Kemmerer depth sampler, 576
 - labeling container, 577
 - lakes, 570
 - manual, 574, 575
 - parameters, 573
 - preservation, 573, 577, 578
 - procedures, 569
 - reference-type sample, 499

- Sampling (*continued*)
 - reporting lab results, 577
 - representative sample, 569
 - reservoirs, 570
 - results, 569, 571
 - rivers, 569–570
 - small water system, 571
 - source water, 569–570
 - stations, 571, 574
 - surface, 575
 - techniques, 575–577
 - types, 569, 573–574
 - volume, 569, 578
 - water tap, 576
 - well profile, 570
- Sampling bottles, 542
- Sampling tap, wells, 76
- Sand, wells
 - production, 144–149
 - separator, 81–82, 145
 - trap, 81–82
- Sand media, 192, 229, 233–234, 241, 251, 256, 259
- Sanitary landfills, 3
- Sanitary seal, wells, 66, 73
- Sanitary survey, 12–14
 - groundwater, 13
 - surface water, 13–14
 - treatment of water, 14
- Schmutzdecke, 229
- Screens, wells, 67–69, 96, 97, 99–102
- SDS (Safety Data Sheet), 394
- SDWA. *See* Amendments to the Safe Drinking Water Act (SDWA)
- SDWA (Safe Drinking Water Act), 16–22, 191, 227, 280
- Seal, wells, 66, 70
- Seawater intrusion, 3, 8
- Secondary regulations, 18
- Sedimentation (settling)
 - calculations, 189
 - currents in tank, 185
 - detention time, 184, 189
 - disposal of sludge, 186
 - high-rate settlers, 186
 - inlets, 183–185
 - operation, 183–186
 - outlets, 184, 185
 - overflow rate, 185
 - pathogen removal, 285
 - process, 183
 - settling zone, 183, 184
 - short-circuiting, 185
 - sludge zone, 183, 184
 - sludges, 183, 184, 186
 - surface loading (overflow rate), 185
 - temperature, 185
 - tube settlers, 186–188
 - wind, 185
 - zones, 183, 184, 185
- Selection of well site, 49
- Selenium, 16
- Self-contained breathing apparatus, 273, 316, 340, 355, 356, 469
- Septic tank leaching systems, 3
- Service area statistics, 585
- Service charge, 605
- Service guidelines, well pumps, 108–129
- Set point, 137
- Settling. *See* Sedimentation (settling)
- Settling zone, 183, 184
- Sewers, location from well, 54
- Shallow collector wells, 65–66
- Shallow well pumps, 59, 108
- Shock, electric, 464, 500, 502, 504
- Shoring
 - cave-ins, 461
 - safety, 459, 461
- Shortage, water, 2
- Short-circuiting, 183, 185
 - in reservoirs, 14
- Shutdown
 - chlorination, 318
 - chlorine dioxide, 348
 - slow sand filters, 259
 - ultraviolet (UV) systems, 366
- Signs, traffic control, 427, 444.
 - See also* Traffic control
- Silt, source, 15
- Silver, 16
- Site selection, wells
 - collection system construction, 55
 - factors, 50
 - land use control, 54
 - overview, 49
 - regulations, 49
 - safety, 49
 - well fields, 54
- Sling, safety, 416
- Slips, safety, 404–405, 464
- Slow sand filter
 - cleaning media, 240–245, 258–259
 - components, 230
 - control, flow, 234–236
 - daily operation, 240
 - diagram, 230, 232, 235, 244, 256, 258
 - effective size, 233
 - example, 255–259
 - filter tank, 230
 - finished water, 237, 247–248
 - flow control, 234–236
 - hydraulic controls, 238
 - hydraulic loading, 251
 - maintenance, 253
 - media, 233–234, 240–245
 - modifications, 255
 - monitoring, 238, 253, 254
 - operation, 239–245, 257–258
 - outlet chamber, 236–237
 - pathogens, 233, 247
 - performance, 248–253
 - preventive maintenance, 245–246
 - procedures, 229
 - process modifications, 255
- recordkeeping, 253–255
- sand media, 233–234, 240–245
- schmutzdecke, 229
- shutdown, 259
- start-up, 256–257
- troubleshooting, 246–247
- underdrain system, 233
- uniformity coefficient, 234
- Sludge
 - control, 224
 - disposal, 186
 - sedimentation, 183, 184, 186
 - zone, 184, 185
- Slurry, 60, 192
- Small treatment plants, 168
 - clear well, 171
 - coagulation, 171
 - corrosion control, 171
 - custom designed plant, 172
 - disinfection, 171
 - diversion works, 169
 - filtration, 171
 - flocculation, 171
 - flow measurement, 169
 - groundwater, 172–173
 - hardness, 173
 - hazards, 273
 - high service pumps, 171
 - importance, 169
 - iron and manganese control, 172–173
 - layout, 169
 - maintenance, 271
 - operator responsibility, 173, 268
 - package plants, 171
 - pumps, 171
 - raw water storage, 169
 - settling, 171
 - softening, 173, 261, 266
 - storage, 171
 - surface waters, 169
- Small water system sampling, 571
- Soda ash, corrosion control, 219
- Sodium chlorite, 346–347
- Sodium hydroxide, 291, 501
- Sodium hypochlorite, 204, 290, 291
- Softening
 - backwash, 265
 - brine disposal, 266
 - brine stage, 265
 - calculations, ion exchange, 267
 - chemical doses, 261
 - disposal of brine, 266
 - filtration, 264
 - ion exchange softening, 264
 - jar tests, 261
 - maintenance, brine system, 266
 - Marble test, 264
 - operation, 261, 264
 - raw water quality, 264
 - recarbonation, 264
 - regeneration, 265
 - zeolite, 265

- Soil moisture, 7
 - Solenoid pump control valve, 77
 - Solid waste disposal sites, wells, 52
 - Solids-contact clarification
 - advantages and disadvantages, 222
 - alkalinity, 224
 - cathodic protection, 227
 - chemical dosage, 224
 - chemicals, 224
 - clarifiers, 220–222
 - flow rates, 224, 226
 - jar test, 224, 226
 - maintenance, 227
 - operation, 224
 - overflow rate, 223
 - recirculation, 224
 - recordkeeping, 225
 - sludge control, 224, 225
 - slurry, 223–225
 - surface loading (overflow rate), 223
 - temperature, 222, 223
 - turbidity, 222
 - volume over volume (V/V) test, 225
 - Solids-contact units, 220, 222, 224, 226, 227
 - Solution feeders, 305–307, 319
 - Solutions, chemical, 495–498
 - Sounding tube, wells, 75
 - Sources of water
 - contamination, 14
 - description, 4
 - direct runoff, 6
 - groundwater, 7, 8, 13
 - hydrologic cycle, 5
 - lakes, 6–7
 - ocean, 4–5
 - reclaimed water, 8–9
 - reservoirs, 6–7
 - rivers, 7
 - selection of source, 12
 - springs, 8
 - streams, 6
 - surface water, 6, 11
 - water cycle, 4–5
 - wells, 8
 - Space, annular, 62, 71
 - Specific capacity, 144
 - Specific gravity, 530
 - Specific yield, wells, 34
 - Specifications, review, chlorination, 343
 - Speed limits in work zones, 440
 - Spoil, 428
 - Spore-forming bacteria, 284
 - Stage 2 Disinfection By-Products (Stage 2 D/DBP), 283
 - Standard solution, 495
 - Standardization, 495
 - Standardized lab solutions, 514, 516
 - Standards, microbial, 19, 282
 - Startup
 - chlorination, 318, 323
 - chlorine dioxide, 349
 - disinfection, 318, 323
 - slow sand filters, 256–257
 - ultraviolet (UV) systems, 366
 - Static water level, 93, 114–115
 - Station, sampling, 571, 574
 - Statistics, service area, 585
 - Step-continuous composite method, wells, 95
 - Sterilization, 280, 542, 543
 - Stock solution
 - concentrations, 530
 - creating, 530
 - volume calculation, 530, 531
 - Stock solution, preparing, 543
 - Stopping distance, vehicle, 424–425
 - Storage
 - chemicals, 502
 - chlorine containers, 307, 313, 327, 340, 343
 - fuel, 418
 - Storage facilities (water)
 - description, 9
 - safety, 464
 - small plants, 171
 - Stratification, reservoirs, 7
 - Streaming current meter, 175
 - Street work
 - regulations, 436
 - safety, 419–463
 - Structure, wells, 55
 - Submersible deep-well pump, 110
 - Subsidence, land, 8, 35
 - Subsurface features, wells, 66
 - Suction lift, 108
 - Sulfate, SMCL (secondary maximum contaminant level), 20
 - Superchlorination, 260
 - Supernatant, 532
 - Supervision and administration, operator's duties, 24
 - Surface features, wells, 73–76
 - Surface loading (overflow rate), 185, 223
 - Surface wash, 194, 196
 - Surface water, 6
 - Surface water sampling, 532
 - Surface Water Treatment Rule (SWTR), 17, 228, 247, 281, 300
 - Surge suppressors, wells, 82–83
 - Surging, wells, 100
 - Sustained yield for wells, 8
 - SWTR (Surface Water Treatment Rule), 17, 228, 247, 281, 300
 - System records, 270
- T**
- Tailgate safety meeting, 393
 - Tanks
 - chlorine, 305, 315–317, 341
 - coatings, 85, 408
 - safety, 408, 466–467
 - Tapers, traffic control, 433
 - Taste and odor control (T&O)
 - bitter tastes, 286
 - chlorine, 293, 303, 335
 - odor, secondary maximum contaminant level (SMCL), 19
 - ozone, 375
 - water quality, 13
 - TCE (trichloroethylene), 2
 - TDS (total dissolved solids), 20
 - Techniques, laboratory, 502, 503. *See also* Laboratory procedures
 - Temperature
 - chlorination, 283, 300
 - coagulation, 174
 - disinfection, 205, 283, 300
 - sedimentation, 185
 - solids-contact clarification, 222, 223
 - Temperature test, laboratory, 507
 - Temporary traffic control (TTC) zones, 444–458. *See also* Traffic control
 - Test tubes, 489
 - Testing
 - well pumps, 116–127
 - wells, 92
 - Tests
 - biological test goals, 538, 539
 - culturing media, 539, 540
 - enzyme substrate coliform test, 541
 - goals, 539
 - lab methods, 538–541, 568
 - overview, 539–542
 - membrane filter, 541
 - Membrane Filter Method–*E. coli* (EPA Method), 541–542
 - Multiple Tube Fermentation Method (MPN Procedure), 540
 - plant processes, 529–538
 - Presence–Absence (P–A) Method, 541
 - total coliform bacteria, 544–568
 - Thermometer types, 507
 - THMs (trihalomethanes), 16, 171, 284, 303, 335, 345, 523
 - Threat response, 628
 - Threshold odor number, 20
 - Time, detention
 - chlorine, 299
 - curves, 299
 - reservoirs, 14
 - Time of contact, disinfection, 205
 - Time-weighted average (TWA), 473
 - Titration, 495, 514–529
 - T&O. *See* Taste and odor control (T&O)
 - TOC. *See* Total organic carbon (TOC)
 - TON. *See* Threshold odor number (TON)
 - Ton tanks, chlorine, 315, 317
 - Tools, 271
 - Topography, 8
 - Total alkalinity, 518, 532
 - Total chlorine, 296
 - Total coliform bacteria, 539
 - test procedures, 544–568
 - Total Coliform Rule, 538
 - Total coliform test, 539

- Total dissolved solids (TDS), 20
 - Total organic carbon (TOC), 630
 - Total suspended solids (TSS), 363
 - Toxic fumes, 505
 - Toxic gases, 402
 - Toxic materials, 505
 - used in laboratories, 501
 - Toxic metals, 16
 - Traffic control
 - barricades, 458
 - devices, 421, 444–458
 - drums, 457
 - flagging, 440–441
 - high-level flag tree warning devices, 454, 455
 - pedestrian safety, 436–439
 - signs, 421, 452, 455
 - stopping distances, 424
 - street closure, 436, 440
 - tapers, 431–433
 - temporary traffic control (TTC) zones, 430–436
 - trenches, 459
 - Trailers, towing, 395
 - Training
 - collection system operators, 474
 - course, 26, 268
 - flaggers, 441
 - operators, 268
 - safety, 359, 392, 467
 - Training programs, operator safety, 359
 - Transient noncommunity water system, 21
 - Transmissivity, 34
 - Transpiration, 7, 32
 - Treatment, emergency, 627
 - Treatment facilities, purpose, 9–10
 - Treatment processes
 - reclaimed water, 8–9
 - by source water, 10
 - Trenches, safety, 459
 - Trichloramine, 293, 295, 523
 - Trichloroethylene (TCE), 2
 - Trihalomethanes (THMs), 16, 171, 284, 285, 303, 335, 345, 523
 - Troubleshooting
 - chlorination, 334, 338, 339, 344, 353
 - chlorinators, 213
 - chlorine dioxide, 351–353
 - disinfection, 213, 334, 338, 339, 344, 350, 352
 - filtration, 194
 - floculation, 183
 - hypochlorinators, 214
 - sedimentation, 185
 - slow sand filters, 246–247
 - well pumps, 140–144
 - wells, 144
 - Trunnions, 315
 - TSS (Total suspended solids), 363
 - TTC. *See* Temporary traffic control (TTC) zones
 - Tube settlers, 186, 187, 188
 - Tubes, test, 489
 - Turbidity
 - cause, 15
 - chlorination, 283, 300
 - versus* color, 510, 511
 - disinfection, 205, 283, 284, 300
 - filtration, 194
 - measurement, 512
 - meter, 512, 513
 - reading, 514
 - source, 15
 - test, 510, 511
 - units (TU), 185, 512
 - Turbidity meter, 512, 513
 - Turbidity units (TU), 185, 512, 513
 - Turbine-type pumps, 109–110
 - Turnover, lake, 7
 - TWA (time-weighted average), 473
 - Types of wells, 56
 - Typhoid, contamination of water supply, 6
- ## U
- UEL (upper explosive limit), 399, 402
 - Ultrasonic waves, 286
 - Ultraviolet radiation, 204
 - Ultraviolet (UV) systems
 - alarms, 368
 - description, 360
 - disinfection, 285, 286, 360–363, 365, 368
 - dosage, 363, 364
 - equipment, 366
 - fouling, quartz sleeve, 369
 - maintenance, 369, 370
 - operation, 363
 - safety, 362
 - shutdown, 366, 367
 - sleeve cleaning, 369
 - startup, 366
 - troubleshooting, 371
 - types, 361
 - Unchlorinated samples, filtering, 558
 - Unconsolidated formation, 57
 - Underdrain, filter, 191, 194, 196, 197, 233
 - Underground utilities, 462–463
 - Call Before You Dig program (811), 462
 - Uniformity coefficient, 68, 234
 - Unsafe acts, 392, 393
 - Upflow clarifiers. *See* Solids-contact units
 - Upper explosive limit (UEL), 399, 402
 - US Terrorism Alert System, 626
 - UV lamps, 361–363, 365, 369–371
 - UV systems. *See* Ultraviolet (UV) systems
- ## V
- Vacuum breaker valve, wells, 76, 83
 - Vacuum-controlled chlorinator, 307–313, 331
 - Valves
 - check, 76, 77, 79
 - chlorination, 316, 317, 319, 322, 323, 327, 329, 335, 339, 345
 - solenoid, 77
 - vacuum breaker, 76, 83
 - well, 77, 80, 83
 - Variable costs, 588
 - Variable displacement pumps, 108
 - Variable rate method, wells, 93
 - Variables, chlorination, 284
 - Vent, wells, 73–75
 - Ventilation
 - chlorine rooms, 344
 - safety, 399, 409, 469
 - Vertical traffic control panels, 457. *See also* Traffic control
 - Video inspection, wells, 106
 - Viruses, 203, 247, 281, 284, 300, 345
 - Visibility, clothing for worker safety, 441
 - Volatile, 86
 - liquids, 502
 - Volume charge, 588, 605
 - Volume of sample, 573, 578
 - Volume over volume (V/V) test, 225
 - Volute-type pump, 108–109
 - Vulnerability assessment, 619–620
- ## W
- Waste, disposal of lab waste, 505
 - Waste backwash water, 197
 - Waste disposal sites, wells, 52
 - Wastewater facilities, 9, 13, 52
 - Water
 - acid rain, 2
 - conservation, 2
 - contamination, 2
 - costs, 2, 9
 - cycle, 4, 5
 - evaporation, 4
 - groundwater, 6, 7, 13
 - hydrologic cycle, 5, 32
 - irrigation runoff, 2
 - limited resource, 2
 - presence, 2
 - quality monitoring, 99, 106
 - rates, 2
 - sampling, 569
 - seawater intrusion, 3, 8
 - shortages, 2
 - sources, 10
 - surface, 6, 9
 - testing procedures, 538, 539
 - treatment, 10
 - water quality problems, 10, 106, 218
 - Water chemistry, typical units, 495
 - Water cycle, 32
 - Water hammer, 83
 - Water level measuring, wells, 73, 75
 - Water mains, flushing, 146
 - Water quality
 - biological, 16–17, 106

- chemical, 15, 16, 106
- color, 15
- consumer demands, 10
- indicators, 569, 573, 576, 577
- inorganic chemicals, 16
- monitoring
 - changes, 106
 - slow sand filters, 237
 - wells, 99, 106
- odor, 16
- organic chemicals, 16
- physical, 15–16, 106
- problems, 11, 106, 218
- radiological, 17
- taste, 16
- temperature, 16
- tests, 507–568
- turbidity, 15
- Water rates, 2
- Water rights, basic types and acquisition, 12
- Water supply systems
 - chlorination equipment, 310, 315
 - chlorination of, 303
 - description, 3–11
 - distribution systems, 10–11
 - layout, 4
 - sketch, 4
 - sources, 4
 - storage facilities, 9
 - treatment facilities, 9
- Water table, 7, 8, 13
- Water tap sampling, 576
- Water treatment plants
 - clear well, 171
 - coagulation, 171
 - corrosion control, 171
 - costs, 3, 10
 - custom designed plant, 172
 - disinfection, 171
 - diversion works, 169
 - filtration, 171
 - flocculation, 171
 - flow measurement, 169
 - groundwater, 172
 - hardness, 173
 - hazards, 271
 - high service pumps, 171
 - importance, 169
 - iron and manganese control, 172–173
 - layout, 170
 - maintenance, 271
 - objectives, 10
 - operator responsibility, 173, 268
 - package plants, 171
 - pumps, 171
 - purpose, 21
 - raw water storage, 169
 - settling, 171
 - sketch, 170
 - softening, 173, 261, 266
 - storage, 171
 - surface waters, 169
 - water quality problems, 2
- Waterborne diseases, 203, 280
- Water-lubricated pumps, 110, 114, 131
- Weighing, chlorine, 344
- Well casing vent, wells, 73
- Well fields, 54
- Wellhead protection, 39–46
- Wells
 - abandoning, 38, 149–151, 413
 - acid treatment, 103–105
 - advantages, 32
 - adverse conditions, 54
 - air blow test method, 93–94
 - air chargers, 86–89
 - air lines, 73
 - air release valve, 76, 86
 - air rotary drilling, 64–65
 - annular grout seal, 69–71
 - bailing test method, 93
 - biofouling, 99
 - blowoff, 76
 - bored wells, 56
 - bowls, pump, 108
 - cable-tool drilling, 66, 69
 - caisson, 65
 - calculations, 132
 - casing, 66, 70, 73
 - chlorination, 303
 - chlorine treatment, 105, 132–134
 - clogged screen, 96–98
 - collapse, 56
 - collapsed screen, 99
 - components, 55
 - conductor casing, 66, 70, 73
 - constant rate method, 94–95
 - construction, 12, 55
 - contaminated, 131–132
 - controls, pumps, 137–140
 - corrosion, 98–99
 - diameter, 67
 - disinfection, 129–134
 - distances to facilities, 51–54
 - drawdown, 13, 36, 117, 144
 - drilled wells, 60–65
 - driller's log, 38
 - driller's report, 156
 - driven wells, 56–60
 - dug wells, 56, 58
 - electrical supply, pumps, 135
 - evaluation, 92
 - explosive charges, 105
 - field testing of deposits, 98
 - flowmeters, 80–81
 - foot valve, 76, 80
 - gravel-envelope, 66, 70, 71
 - gravel-packed, 66, 69, 71
 - groundwater, 32
 - grout seal, 69–71
 - hard-rock, 66, 71
 - high-velocity jetting, 101–102
 - hydraulic rotary drilling, 62–66
 - hydrologic cycle, 32
 - hydropneumatic tanks, 83, 85–92
 - incrustation, well screens, 96–98
 - industrial facilities, 52
 - inspection, video, 106
 - intake, 67–69
 - jetting, well screens, 101–102
 - maintenance, 95–105
 - operator responsibility, 38, 40, 46, 152–160
 - overdraft, 32
 - overpumping, 96
 - pedestal, pump, 73, 75–76
 - percussion drilling, 60–62
 - performance testing, 92
 - plugging, 39, 149, 413
 - plunging, 100
 - pollution, 32
 - polyphosphates, 105
 - pressure relief valves, 83–84
 - pressure tanks, 83, 85–92
 - pump, 75, 108–129, 135–137
 - pump bowls, 108
 - pump pedestal, 73, 75–76
 - pump station, 77
 - pumping tests, 92
 - quality monitoring, 106
 - Ranney well, 65–66
 - recordkeeping, 38, 99, 152–160
 - regulations, 45
 - rehabilitation, 96
 - repairs, 99
 - responsibility, operators, 35, 38, 46, 99, 152
 - reverse circulation, well drilling, 64
 - rotary drilling, 62–66
 - safe distances, 51–54
 - safety, 406, 410
 - sampling, 570
 - sampling tap, 76
 - sand, 144–149
 - sand separator, 81–82, 145
 - sand trap, 81–82
 - sanitary seal, 66, 73
 - screens, 67–69, 96, 97, 99–102
 - seal, 66, 70
 - sewers, location, 54
 - shallow collector wells, 65–66
 - site selection, 49
 - solid waste disposal sites, 52
 - sounding tube, 75
 - specific yield, 34
 - step-continuous composite method, 95
 - structure, 55
 - subsurface features, 66
 - surface features, 73–76
 - surge suppressors, 82–83
 - surging, 100
 - testing, 92
 - troubleshooting, 144
 - types, 56
 - vacuum breaker valve, 76, 83
 - valves, 76, 77, 83
 - variable rate test method, 93
 - vent, 73–75

Wells (*continued*)

- video inspection, 106
- waste disposal sites, 52
- wastewater facilities, 52
- water level measuring, 73, 75
- water quality monitoring, 99, 106
- well casing vent, 73
- wellhead protection, 39–46
- working pressure, 89
- yield, 34, 144

Wind, sedimentation, 185

Withdrawal rate, chlorine, 210, 315, 343, 344

Worker visibility, clothing, 441

Working in streets, safety, 419–463

Working pressure, well pumps, 89

Worksheets, laboratory, 498

Wrench, chlorine, 272, 317

Wye strainer, 171

Y

Yield

- safe, surface water supplies, 14

- sustained, wells, 8
- wells, 35, 144

Yoke-type connectors, 316

Z

Zeolite, 264

Zinc, SMCL (secondary maximum
contaminant level), 20

Zone of saturation, 7, 33, 332

Zones of settling, 183, 184