

Table of Contents

Chapter I

Producing Safe Water in a Safe Workplace I

1.1 Public Safety and Operator Safety 2

1.2 Drinking Water Regulations 2

- 1.2.1 Types of Water Systems 2
- 1.2.2 Types of Contaminants 3
- 1.2.3 Setting Standards 3
- 1.2.4 Identifying Contaminants to Be Regulated 4
- 1.2.5 Unregulated Contaminants 5
- 1.2.6 Consumer Confidence Report Rule 6
- 1.2.7 Standardized Monitoring Framework 7
- 1.2.8 Primary Drinking Water Standards 7
 - 1.2.8.1 Inorganic Chemical Standards 7
 - 1.2.8.2 Organic Chemical Standards 17
 - 1.2.8.3 Microbial Standards 20
 - 1.2.8.4 Disinfectants and Disinfection Byproducts 42
 - 1.2.8.5 Radiological Standards 44
- 1.2.9 Secondary Drinking Water Standards 45
 - 1.2.9.1 Secondary Maximum Contaminant Levels 46
 - 1.2.9.2 Monitoring 46
 - 1.2.9.3 Secondary Contaminants 47

1.3 Workplace Safety 52

- 1.3.1 Safety Program 53
 - 1.3.1.1 Types of Hazards 54
 - 1.3.1.2 Reporting Incidents 56
 - 1.3.1.3 Emergency Plans 58
- 1.3.2 Accident Prevention 59
 - 1.3.2.1 Operator Safety 59
 - 1.3.2.2 Training Program 66
- 1.3.3 Emergency Preparedness and Response 68
- 1.3.4 Safety Around Water-Filled Structures 69
 - 1.3.4.1 Drowning Prevention 70

- 1.3.5 Facility Maintenance Safety 70
 - 1.3.5.1 Cleaning 70
 - 1.3.5.2 Painting 71
 - 1.3.5.3 Crane Operation 72
 - 1.3.5.4 Explosive Gas Mixtures 72
 - 1.3.5.5 Confined Spaces 73
 - 1.3.5.6 Power Tools 77
 - 1.3.5.7 Welding 78
 - 1.3.5.8 Safety Valves 80
- 1.3.6 Vehicle Operation and Maintenance Safety 80
 - 1.3.6.1 Vehicle Operation 81
 - 1.3.6.2 Vehicle Maintenance 83
- 1.3.7 Electrical Equipment Safety 85
 - 1.3.7.1 Current and Voltage 85
 - 1.3.7.2 Avoiding Electric Shock 85
 - 1.3.7.3 Emergency Procedures 88
 - 1.3.7.4 Transformers 88
 - 1.3.7.5 Electric Starters 89
 - 1.3.7.6 Electric Motors 89
 - 1.3.7.7 Instrumentation 90
 - 1.3.7.8 Control Panels 90
 - 1.3.7.9 Lockout/Tagout Procedure 90
- 1.3.8 Fire Prevention and Protection 93
 - 1.3.8.1 Classification of Fires and Extinguishers 93
 - 1.3.8.2 Storage of Flammables 96
 - 1.3.8.3 Fire Exits 97
- 1.3.9 Chemical Handling 97
 - 1.3.9.1 Acids 101
 - 1.3.9.2 Bases 107
 - 1.3.9.3 Gases and Vapors 110
 - 1.3.9.4 Salts 116
 - 1.3.9.5 Powders 118
 - 1.3.9.6 Chemical Storage Drains 120
- 1.3.10 Distribution System Safety 120
 - 1.3.10.1 Safety Around Wells 121
 - 1.3.10.2 Pump Safety 124
 - 1.3.10.3 Lockout/Tagout 125
 - 1.3.10.4 Storage of Lubricants and Fuels 126

- 1.3.10.5 Traffic Hazards 127
- 1.3.10.6 Safety Around Water Storage Facilities 128

1.4 Additional Resources 132

Chapter Review 133

Chapter 2 Softening 139

2.1 What Makes Water Hard? 140

2.2 Why Soften Water? 141

2.3 Chemistry of Softening 142

- 2.3.1 Hardness 142
- 2.3.2 pH 145
- 2.3.3 Alkalinity 146

2.4 How Water Is Softened 149

- 2.4.1 Chemical Reactions 150
 - 2.4.1.1 Lime 150
 - 2.4.1.2 Removal of Carbon Dioxide 150
 - 2.4.1.3 Removal of Carbonate Hardness 151
 - 2.4.1.4 Removal of Noncarbonate Hardness 151
 - 2.4.1.5 Stability 151
 - 2.4.1.6 Caustic Soda Softening 152
 - 2.4.1.7 Calculating Chemical Dosages 153
- 2.4.2 Handling, Application, and Storage of Lime 157
- 2.4.3 Lime Softening 158
- 2.4.4 Split Lime Treatment 159
- 2.4.5 Lime–Soda Ash Softening 161
- 2.4.6 Caustic Soda Softening 161

2.5 Safety 162

2.6 Interactions with Coagulants 163

2.7 Stability 163

2.8 Sludge Recirculation and Disposal 165

2.9 Jar Tests 166

- 2.9.1 Examples 167
- 2.9.2 Calculating Chemical Feeder Settings 169

2.10 Ion Exchange Softening Process 171

- 2.10.1 Operation 174
 - 2.10.1.1 Service 175
 - 2.10.1.2 Backwash 175
 - 2.10.1.3 Brine 177
 - 2.10.1.4 Rinse 178
- 2.10.2 Control Testing 178
- 2.10.3 Limitations Caused by Iron and Manganese 179
- 2.10.4 Spent Brine Disposal 179
- 2.10.5 Maintenance 180
- 2.10.6 Troubleshooting 182
 - 2.10.6.1 Service Stage 182
 - 2.10.6.2 Backwash Stage 182
 - 2.10.6.3 Brine Injection Stage 183
 - 2.10.6.4 Rinse Stage 183
- 2.10.7 Startup and Shutdown 184
- 2.10.8 Ion Exchange Calculations 185
- 2.10.9 Blending 192

2.11 Recordkeeping 194

2.12 Math Assignment 195

2.13 Additional Resources 204

Chapter Review 205

Chapter 3 Specialized Treatment Processes 209

3.1 Additional Treatment 210

3.2 Iron and Manganese Control 210

- 3.2.1 Measuring Iron and Manganese 211
 - 3.2.1.1 Sample Collection and Analysis 211
 - 3.2.1.2 Treated Water Monitoring 212
- 3.2.2 Remedial Action 213
 - 3.2.2.1 Alternate Source 214
 - 3.2.2.2 Phosphate Treatment 214
 - 3.2.2.3 Removal by Ion Exchange 221
 - 3.2.2.4 Oxidation by Aeration 221
 - 3.2.2.5 Oxidation with Chlorine 224
 - 3.2.2.6 Oxidation with Permanganate 225
 - 3.2.2.7 Operating Filters 231
 - 3.2.2.8 Electromedia Processes 231

- 3.2.3 Chemical Feeder Maintenance 234
- 3.2.4 Responding to Red Water Complaints 234

3.3 Arsenic Control 236

- 3.3.1 Safety 236
- 3.3.2 Chemistry of Arsenic 236
- 3.3.3 New Source Alternative to Treatment 237
- 3.3.4 Reduction or Removal of Arsenic 237
 - 3.3.4.1 Ion Exchange 238
 - 3.3.4.2 Activated Alumina 240
 - 3.3.4.3 Oxidation-Filtration and Iron-Based Adsorption 242
 - 3.3.4.4 Point-of-Use and Point-of-Entry Devices 242
 - 3.3.4.5 Engineered Blending 243
- 3.3.5 Wastewater and Residuals 245
- 3.3.6 Review of Plans and Specifications 246
- 3.3.7 Monitoring 247
 - 3.3.7.1 Compliance Monitoring 247
 - 3.3.7.2 Process Control Monitoring 248
 - 3.3.7.3 Laboratory Analysis 248
- 3.3.8 Recordkeeping and Reporting 249
 - 3.3.8.1 Records 249
 - 3.3.8.2 Reporting 249

3.4 Disinfection Byproducts Control 250

- 3.4.1 Regulatory Compliance 250
 - 3.4.1.1 Stage 1 Regulatory Requirements 251
 - 3.4.1.2 Stage 2 Regulatory Requirements 253
- 3.4.2 Disinfection Byproducts Formation 253
 - 3.4.2.1 THM Formation Chemistry 255
- 3.4.3 Evaluating DBP Production 256
 - 3.4.3.1 Sampling 257
- 3.4.4 THM Calculations 259
- 3.4.5 Control Strategies 261
- 3.4.6 Existing Treatment Processes 262
- 3.4.7 Evaluating Control Options 263
 - 3.4.7.1 Remove THM Precursors 263
 - 3.4.7.2 Remove THMs After They Are Formed 264
 - 3.4.7.3 Alternative Disinfectants 267
- 3.4.8 Selecting and Implementing a Solution 268

3.5 Math Assignment 269

3.6 Additional Resources 269

Chapter Review 270

Chapter 4

Fluoridation 275

4.1 History of Fluoridation 276

4.2 Fluoridation Programs 276

4.3 Safety 277

- 4.3.1 Avoid Overexposure 277
- 4.3.2 Fluoride Poisoning 278
- 4.3.3 Basic First Aid 278
- 4.3.4 Protecting Yourself and Your Family 279
- 4.3.5 Training 279

4.4 Fluoride Compounds 279

4.5 Fluoridation Systems 281

- 4.5.1 Chemical Feeders 281
- 4.5.2 Saturators 282
 - 4.5.2.1 Downflow Saturators 287
 - 4.5.2.2 Upflow Saturators 288
- 4.5.3 Small Hydrofluosilicic Acid Systems 290
- 4.5.4 Large Hydrofluosilicic Acid Systems 291

4.6 Final Equipment Checkup 293

- 4.6.1 Review of Designs and Specifications 293

4.7 Chemical Feeder Startup 294

4.8 Chemical Feeder Operation 295

- 4.8.1 Determining Feed Rates and Preparing Chemical Solutions 295
- 4.8.2 Fluoridation Log Sheets 314
 - 4.8.2.1 Hydrofluosilicic Acid 314
 - 4.8.2.2 Sodium Silicofluoride 315
- 4.8.3 Equipment Check Procedures 319

4.9 Overfeeding Prevention 319

4.10 Underfeeding Prevention 320

4.11 Shutting Down Chemical Systems 320

- 4.12 Maintenance 320**
- 4.13 Math Assignment 321**
- 4.14 Additional Resources 330**
- Chapter Review 331**

Chapter 5 Membrane Treatment Processes 335

- 5.1 Membrane Treatment Technologies 336**
 - 5.1.1 Pressure Vessels or Submerged Flow 339
 - 5.1.2 Membrane Flow Systems 340
- 5.2 Operation and Maintenance 343**
 - 5.2.1 SCADA System 343
 - 5.2.2 Pretreatment 344
 - 5.2.2.1 Bench-Scale Analysis or Pilot-Scale Studies 345
 - 5.2.3 Typical Plant Components 346
 - 5.2.4 Operational Procedures 348
 - 5.2.5 Membrane Performance Monitoring 349
 - 5.2.6 Troubleshooting 350
 - 5.2.6.1 Membrane Fouling 350
- 5.3 Recordkeeping 351**
- 5.4 Maintenance Program 352**
 - 5.4.1 Routine Maintenance 352
 - 5.4.2 Preventive Maintenance 352
 - 5.4.3 Corrective Maintenance 353
- 5.5 Demineralizing Processes 354**
- 5.6 Reverse Osmosis 355**
 - 5.6.1 Safety 357
 - 5.6.1.1 Chemical Safety 357
 - 5.6.1.2 Hydraulic Safety 357
 - 5.6.1.3 Electrical Safety 357
 - 5.6.2 Membrane Structure and Composition 357
 - 5.6.3 Flux 359
 - 5.6.4 Mineral Rejection 361
 - 5.6.5 Membrane Performance and Properties 364
 - 5.6.5.1 Feedwater Temperature and pH 366
 - 5.6.6 Recovery 367

- 5.6.7 Components 371
 - 5.6.7.1 Pressurization Pump 371
 - 5.6.7.2 Piping 372
 - 5.6.7.3 Pressure Vessel Housings 373
 - 5.6.7.4 Concentrate Control Valve 373
 - 5.6.7.5 Sample Valves 373
 - 5.6.7.6 Flush Connections 373
 - 5.6.7.7 Cleaning Connections 373
 - 5.6.7.8 Permeate Rinse 373
 - 5.6.7.9 Permeate Drawback Tank 373
 - 5.6.7.10 Energy Recovery Devices 374
 - 5.6.7.11 Membranes 374
- 5.6.8 Pretreatment 376
 - 5.6.8.1 Removal of Turbidity and Suspended Solids 377
 - 5.6.8.2 pH and Temperature Control 378
 - 5.6.8.3 Other Potential Scalants 378
 - 5.6.8.4 Microbiological Organisms 378
- 5.6.9 Plant Operation 379
- 5.6.10 Membrane Cleaning 383

5.7 Electrodialysis 384

- 5.7.1 Principles of Electrodialysis 386
- 5.7.2 Anion- and Cation-Permeable Membranes and Three-Cell Unit 387
- 5.7.3 Multicompartment Unit 387
- 5.7.4 Safety 390
- 5.7.5 Equipment 391
- 5.7.6 Pretreatment 391
- 5.7.7 Pumping Equipment and Piping 393
- 5.7.8 DC Power Supply 393
- 5.7.9 Membrane Stack 393
- 5.7.10 Chemical Flush System 393
- 5.7.11 Operation 394

5.8 Additional Resources 394

Chapter Review 396

Chapter 6 Process Wastes 401

- 6.1 Regulation of Removed Contaminants 402**
- 6.2 Source Water Pollution Prevention 404**
 - 6.2.1 Source Water Protection 406

6.3 Process Waste Generation 407

- 6.3.1 Wastes Produced by Source Water Treatment 407
- 6.3.2 Mechanical Treatment 410
 - 6.3.2.1 Presedimentation 410
 - 6.3.2.2 Coagulation, Flocculation, and Sedimentation 411
 - 6.3.2.3 Filtration 412
 - 6.3.2.4 Precipitative Softening 416
 - 6.3.2.5 Ion Exchange 417
 - 6.3.2.6 Activated Carbon 418
 - 6.3.2.7 Disinfection 419
 - 6.3.2.8 Other Chemical Additions 420
 - 6.3.2.9 Organic Matter and Oxygen 421
 - 6.3.2.10 Other Pollutants in Water Treatment Plants 421

6.4 Handling and Disposal 423

- 6.4.1 Process Sludge Volumes 424
- 6.4.2 Draining and Cleaning Tanks 428
- 6.4.3 Thickening 431
- 6.4.4 Sludge Dewatering Processes 432
 - 6.4.4.1 Storage Ponds and Lagoons 432
 - 6.4.4.2 Sand Drying Beds 433
 - 6.4.4.3 Belt Filter Presses 435
 - 6.4.4.4 Centrifuges 435
 - 6.4.4.5 Filter Presses 437
 - 6.4.4.6 Vacuum Filters 437
 - 6.4.4.7 Screw Presses 439
 - 6.4.4.8 Thermal Drying 439
- 6.4.5 Chemical Precipitation 439
- 6.4.6 Disposal Practices 440
 - 6.4.6.1 Sludges and Slurries 440
 - 6.4.6.2 Plant Wastewaters 443
- 6.4.7 Environmental Impacts 444
 - 6.4.7.1 Increased Oxygen by Aeration 444
 - 6.4.7.2 Dechlorination 444
 - 6.4.7.3 pH Adjustment 444
- 6.4.8 Monitoring and Reporting 445

6.5 Additional Resources 445**Chapter Review 446****Chapter 7****Instrumentation and Control Systems 449****7.1 Process Monitoring and Manipulation 450**

- 7.1.1 Instrument Measurement 451
- 7.1.2 Explanation of Control Systems 454
 - 7.1.2.1 Modulating Control Systems 454
 - 7.1.2.2 Motor Control Stations 456

7.2 Safety 459

- 7.2.1 Electrical Hazards 459
- 7.2.2 Mechanical and Pneumatic Hazards 460
 - 7.2.2.1 Pneumatic Hazards 461
- 7.2.3 Confined Spaces 462
- 7.2.4 Oxygen Deficiency or Enrichment 462
- 7.2.5 Explosive Gas Mixtures 463
- 7.2.6 Falls and Associated Hazards 464

7.3 Measured Variables and Types of Sensors 465

- 7.3.1 Pressure Measurements 465
- 7.3.2 Level Measurements 468
- 7.3.3 Flow Measurements 470
- 7.3.4 Chemical Feed Rate 477
- 7.3.5 Process Instrumentation 478
- 7.3.6 Signal Transmitters 479

7.4 Instrumentation 480

- 7.4.1 Primary Elements 480
- 7.4.2 Panel Instruments 480
 - 7.4.2.1 Indicators 480
 - 7.4.2.2 Recorders 481
 - 7.4.2.3 Totalizers 483
 - 7.4.2.4 Alarms 484
- 7.4.3 Automatic Controllers 484
- 7.4.4 Pump Controllers 485
- 7.4.5 Air Supply Systems 487
- 7.4.6 Laboratory Instruments 489
- 7.4.7 Test and Calibration Equipment 489
- 7.4.8 Process Computer Control Systems 491
 - 7.4.8.1 Computer Control System Functions 492

7.5 Operation and Preventive Maintenance 495

- 7.5.1 Indications of Proper Function 496
- 7.5.2 Startup/Shutdown Considerations 496
- 7.5.3 Preventive Maintenance 497
- 7.5.4 Operational Checks 499

7.6 Additional Resources 500

Chapter Review 501

**Chapter 8
Plant Maintenance 505**

8.1 Maintenance Program 506

- 8.1.1 Preventive Maintenance Records 507
- 8.1.2 Lockout/Tagout Procedure 508

8.2 Electrical Equipment 510

- 8.2.1 Electrical Safety Checklist 511
- 8.2.2 Understanding Electricity 512
 - 8.2.2.1 Volts 512
 - 8.2.2.2 Amps 512
 - 8.2.2.3 Direct Current 513
 - 8.2.2.4 Alternating Current 513
 - 8.2.2.5 Power 513
 - 8.2.2.6 Power Requirements 514
 - 8.2.2.7 Conductors and Insulators 514
- 8.2.3 Meters and Testers 515
 - 8.2.3.1 Voltage Testing 515
 - 8.2.3.2 Ammeter 517
 - 8.2.3.3 Megger 522
 - 8.2.3.4 Ohmmeter 523
- 8.2.4 Safety Devices 524
 - 8.2.4.1 Fuses 524
 - 8.2.4.2 Circuit Breakers 524
 - 8.2.4.3 Overload Relays 525
 - 8.2.4.4 Motor Starters 526
- 8.2.5 Electric Motors 528
 - 8.2.5.1 Variable Frequency Drives 532
 - 8.2.5.2 Troubleshooting 533
- 8.2.6 Auxiliary Electrical Power 536
 - 8.2.6.1 Standby Power Generation 539
 - 8.2.6.2 Emergency Lighting 541
 - 8.2.6.3 Batteries 543

- 8.2.7 High Voltage 544
 - 8.2.7.1 Transmission 544
 - 8.2.7.2 Switchgear 544
 - 8.2.7.3 Power Distribution Transformers 545
- 8.2.8 Recordkeeping 545

8.3 Mechanical Equipment 548

- 8.3.1 Lubrication 548
 - 8.3.1.1 Precautions 550
 - 8.3.1.2 Lubrication Schedule 550
 - 8.3.1.3 Pump Lubrication 551
 - 8.3.1.4 Equipment Lubrication 551
- 8.3.2 Pumps 552
 - 8.3.2.1 Centrifugal Pumps 552
 - 8.3.2.2 Positive-Displacement Pumps 558
 - 8.3.2.3 Starting Pumps 561
 - 8.3.2.4 Pump Shutdown 564
 - 8.3.2.5 Pump-Driving Equipment 565
 - 8.3.2.6 Electrical Controls 566
- 8.3.3 Preventive Maintenance 566
 - 8.3.3.1 Pumps, General 566
 - 8.3.3.2 Reciprocating Pumps 570
 - 8.3.3.3 Propeller Pumps 572
 - 8.3.3.4 Progressive Cavity Pumps 572
 - 8.3.3.5 Pump Controls 573
 - 8.3.3.6 Electric Motors 573
 - 8.3.3.7 Belt Drives 574
 - 8.3.3.8 Chain Drives 575
 - 8.3.3.9 Variable-Speed Belt Drives 576
 - 8.3.3.10 Couplings 579
 - 8.3.3.11 Shear Pins 579
 - 8.3.3.12 Troubleshooting 581
- 8.3.4 Compressors 581
- 8.3.5 Valves 587
 - 8.3.5.1 Gate Valves 587
 - 8.3.5.2 Globe Valves 590
 - 8.3.5.3 Eccentric Valves 591
 - 8.3.5.4 Butterfly Valves 592
 - 8.3.5.5 Check Valves 592
 - 8.3.5.6 Automatic Valves 593

8.4 Internal Combustion Engines 597

- 8.4.1 Gasoline Engines 597
 - 8.4.1.1 Starting Gasoline Engines 598
 - 8.4.1.2 Identifying Problems 599

- 8.4.2 Diesel Engines 601
 - 8.4.2.1 Starting Diesel Engines 603
 - 8.4.2.2 Troubleshooting 603
- 8.4.3 Standby Engines 603
- 8.4.4 Cooling Systems 604
- 8.4.5 Fuel Storage 605
 - 8.4.5.1 Diesel Fuel 605
 - 8.4.5.2 Gasoline 605
 - 8.4.5.3 Liquefied Petroleum Gas 606
 - 8.4.5.4 Natural Gas 606

8.5 Chemical Storage Facilities 606

8.6 Chemical Feeders 607

- 8.6.1 Calibrating Chemical Feeders 608
 - 8.6.1.1 Large-Volume Metering Pumps 613
 - 8.6.1.2 Small-Volume Metering Pumps 613
 - 8.6.1.3 Dry Chemical Systems 614
- 8.6.2 Chlorinators 615

8.7 Tanks and Reservoirs 616

- 8.7.1 Steel Tanks 616
 - 8.7.1.1 Cathodic Protection 617
- 8.7.2 Concrete Tanks 617

8.8 Building Maintenance 618

8.9 Additional Resources 618

Chapter Review 619

Chapter 9 Management 623

9.1 Managing Utilities 624

- 9.1.1 Feasibility Analysis Process 625

9.2 Planning 626

9.3 Organizing 627

9.4 Staffing 631

- 9.4.1 Workforce Analysis 631
- 9.4.2 Qualifications Profile 632
- 9.4.3 Applications and the Selection Process 633
- 9.4.4 New Employee Orientation 637

- 9.4.5 Employment Policies and Procedures 638
 - 9.4.5.1 Probationary Period 638
 - 9.4.5.2 Compensation 638
 - 9.4.5.3 Training and Certification 638
 - 9.4.5.4 Performance Evaluation 640
 - 9.4.5.5 Dealing with Disciplinary Problems 643
 - 9.4.5.6 Example Policy: Harassment 645
 - 9.4.5.7 Labor Laws Governing Employer/Employee Relations 649
 - 9.4.5.8 Personnel Records 650

- 9.4.6 Unions 651

9.5 Communication 652

- 9.5.1 Oral Communication 652
- 9.5.2 Written Communication 653

9.6 Conducting Meetings 656

9.7 Public Relations 656

- 9.7.1 Establish Objectives 657
- 9.7.2 Utility Operations 657
- 9.7.3 Mass Media 657
- 9.7.4 Being Interviewed 658
- 9.7.5 Public Speaking 658
- 9.7.6 Telephone Contacts 659
- 9.7.7 Consumer Inquiries 659
- 9.7.8 Plant Tours 660

9.8 Planning for Financial Stability 661

- 9.8.1 Measuring Stability 661
- 9.8.2 Budgeting 662
- 9.8.3 Equipment Repair/Replacement Fund 664
- 9.8.4 Water Rates 665
- 9.8.5 Capital Improvement Program 665

9.9 Operation and Maintenance 668

- 9.9.1 Using Geographic Information Systems 668
- 9.9.2 Types of Maintenance 669
- 9.9.3 Benefits of Managing Maintenance 670
- 9.9.4 SCADA Systems 671
- 9.9.5 Cross-Connection Control Program 674
 - 9.9.5.1 Program Responsibilities 675
 - 9.9.5.2 Water Supplier Program 678

9.10 Emergency Response 679

- 9.10.1 Federal Requirements 679
- 9.10.2 Assessment and Planning 680
- 9.10.3 Security 682
- 9.10.4 Managing Contamination Threats 686
 - 9.10.4.1 Evaluating and Responding to Threats 687
 - 9.10.4.2 *Cryptosporidium* in Water Systems 689

9.11 Safety Program 690

- 9.11.1 Regulatory Agencies 691
- 9.11.2 Managers 691
- 9.11.3 Supervisors 693
- 9.11.4 Operators 694
- 9.11.5 First Aid 694
- 9.11.6 Hazard Communication Standard and Worker Right-To-Know Laws 695
- 9.11.7 Confined Space Entry Procedures 705
- 9.11.8 Reporting 707
- 9.11.9 Training 710
- 9.11.10 Measuring 712
- 9.11.11 Human Factors 715

9.12 Recordkeeping 716

- 9.12.1 Plant Operations Data 717
- 9.12.2 Maintenance 718
 - 9.12.2.1 Procurement 718
 - 9.12.2.2 Inventory 718
 - 9.12.2.3 Equipment 720
- 9.12.3 Computer Recordkeeping Systems 720
- 9.12.4 Retaining Utility Records 720

9.13 Water and Energy Conservation 721

- 9.13.1 Conservation Programs 722
 - 9.13.1.1 Residential Water Surveys 722
 - 9.13.1.2 Residential Plumbing Retrofits 723
 - 9.13.1.3 System Water Audits, Leak Detection, and Repair 723
 - 9.13.1.4 Metering with Commodity Rates 723
 - 9.13.1.5 Large Landscape Conservation Programs 724
 - 9.13.1.6 Public Information Programs 725
 - 9.13.1.7 Commercial-, Industrial-, and Institutional-Sector Programs 725

- 9.13.1.8 Wholesale Agency Assistance Programs 726
- 9.13.1.9 Conservation Pricing 727
- 9.13.1.10 Conservation Coordinator 727
- 9.13.1.11 Water Waste Prohibition 727
- 9.13.1.12 Residential ULFT Replacement Programs 728
- 9.13.1.13 Potential Best Management Practices 728

9.14 Additional Resources 729

Chapter Review 730

Appendix A

Introduction to Basic Math for Operators 733

Introduction 734

Basic Concepts (Sections A.1–A.4) 735

A.1 Numbers and Operations 735

- A.1.1 Addition 735
- A.1.2 Subtraction 735
- A.1.3 Multiplication 736
- A.1.4 Division 736

A.2 Order of Operations 736

- A.2.1 More on Exponents 740

A.3 Basic Algebra (Solving Equations) 740

A.4 Percentages 743

Intermediate Concepts (Sections A.5–A.6) 746

A.5 Units 746

- A.5.1 Distance or Length 746
- A.5.2 Area 747
 - A.5.2.1 Surface Area of a Rectangle 747
 - A.5.2.2 Surface Area of a Triangle 748
 - A.5.2.3 Surface Area of a Trapezoid 749
 - A.5.2.4 Surface Area of a Circle 749
 - A.5.2.5 Surface Area of a Cylinder 750
 - A.5.2.6 Surface Area of a Cone 751
 - A.5.2.7 Surface Area of a Sphere 752

- A.5.3** Volume 752
 - A.5.3.1** Cube 753
 - A.5.3.2** Rectangular Prism 753
 - A.5.3.3** Triangular Prism 754
 - A.5.3.4** Cylinder 754
 - A.5.3.5** Cone 755
 - A.5.3.6** Sphere 755
- A.5.4** Mass and Weight 755
- A.5.5** Density, Specific Weight, and Specific Gravity 756
- A.5.6** Concentration 756
- A.5.7** Velocity and Flow Rate 758
- A.5.8** Force and Pressure 760
- A.5.9** Work, Head, and Power 765

A.6 Metric System 768

- A.6.1** SI Base Units 768
- A.6.2** Measures of Length 770
- A.6.3** Measures of Capacity or Volume 770
- A.6.4** Measures of Weight 770
- A.6.5** Temperature 771

Advanced Concepts (Sections A.7–A.8) 772

A.7 Pumps 772

- A.7.1** Pressure 772
- A.7.2** Work 773
- A.7.3** Power 774
- A.7.4** Horsepower 774
- A.7.5** Head 778

- A.7.6** Pump Characteristics 780
- A.7.7** Evaluation of Pump Performance 782
 - A.7.7.1** Capacity 782
 - A.7.7.2** Efficiency 783
- A.7.8** Pump Speed–Performance Relationships 786
- A.7.9** Friction or Energy Losses 787

A.8 Analysis and Presentation of Data 791

- A.8.1** Causes of Variations in Results 791
 - A.8.1.1** Water or Material Being Examined 792
 - A.8.1.2** Sampling 792
 - A.8.1.3** Testing 792
- A.8.2** Controlling Variation 792
 - A.8.2.1** Reading Charts 794
- A.8.3** Describing Data or Results 794
 - A.8.3.1** Graphs and Charts 795
 - A.8.3.2** Numerical Representation of Data 800
- A.8.4** Moving Averages 807
- A.8.5** More Applications of Graphs 809
 - A.8.5.1** Volume of Sludge in a Digester 809
 - A.8.5.2** Tracking BOD Loading 812
- A.8.6** Regression Analysis (Prediction Equations, Trends, and Correlations) 814
 - A.8.6.1** Correlations 819

Answer Key 821

Glossary 825

Index 855

- A**
- Accessibility, 655
 - Accident prevention, for operator safety
 - noise exposure, 63–66
 - personal protective equipment, 61–63
 - respiratory protection, 60–61
 - training program, 66–68
 - Accountable, 627, 630
 - Accuracy, 452
 - Acetic acid, 101, 103
 - Acids
 - acetic acid, 101, 103
 - hydrochloric acid, 103–105
 - nitric acid, 105
 - phosphoric acid, 105–106
 - sulfuric acid, 106–107
 - Activated alumina
 - configuration, 242
 - definition, 237
 - media availability, 242
 - pH, 240–241
 - spent media, 241
 - wastewater disposal, 241
 - water quality concerns, 241
 - Activated carbon, 119–120, 418
 - Addition, 735
 - Adsorption, 74, 237
 - Advanced concepts, of basic math operations
 - analysis and presentation of data
 - applications of graphs, 809–814
 - controlling variation, 792–794
 - data interpretation, 794–807
 - moving averages, 807–809
 - regression analysis, 814–820
 - variation causes, 791–792
 - pumps
 - characteristics, 780–782
 - friction/energy losses, 787–790
 - head, 778–780
 - horsepower, 774–778
 - performance evaluation, 782–786
 - power, 774
 - pressure, 772–773
 - speed–performance relationships, 786–787
 - work, 773
 - Aeration oxidation, 221–224
 - Air supply systems, 487–489
 - Alarm contacts, 469
 - Alarms, 484
 - Algebra, 740–743
 - Alkalinity
 - definition, 140–141
 - softening chemistry of, 146–149
 - Alternating current (AC), 90, 393, 513
 - Aluminum sulfate, 117
 - Alum salts, 163
 - Alum sludge, 441
 - Americans with Disabilities Act of 1990 (ADA), 650
 - American Water Works Association (AWWA), 279, 406
 - Ammeter, 517–522
 - Amperage, 512
 - Ampere (A), 512
 - Amplitude, 513
 - Analog, 453
 - Analog readout, 453
 - Analyzers, 455
 - Anion-permeable membranes, 387
 - Anions, 140
 - Anthracite filter, 229
 - Antimony, 12
 - Aquifer, 214
 - Arsenic, 12–13
 - Arsenic control
 - alternative treatment, 237
 - chemistry, 236–237
 - monitoring, 247–248
 - recordkeeping and reporting, 249–250
 - reduction or removal, 237–245
 - review of plans and specifications, 246
 - safety, 236
 - Arsenic reduction/removal
 - activated alumina, 240–242
 - engineered blending, 243–245
 - granular ferric hydroxide, 242
 - ion exchange, 238–240
 - operation, 240
 - point-of-use and point-of-entry devices, 242–243
 - Asbestos, 13
 - atm, 364
 - Atomic absorption
 - spectrophotometer, 143
 - Atomic adsorption, 248
 - Authority, 627
 - Automatic controllers, 484–485
 - Automatic valves, 593–597
 - Auxiliary electrical power
 - batteries, 543
 - emergency lighting, 541–543
 - standby power generation, 539–541
 - Avoiding electric shock, 85–87

B

 - Backflow, 222, 674–675, 677
 - Back pressure, 674–675
 - Backsiphonage, 235, 281, 674, 676
 - Backwashing, 230, 346
 - Barium, 14
 - Bases
 - calcium hydroxide, 107–108
 - calcium oxide, 107–108
 - hypochlorite, 109
 - sodium carbonate, 109
 - sodium hydroxide, 108–109
 - Basic math operations
 - advanced concepts
 - analysis and presentation of data, 790–820
 - pumps, 772–790
 - basic algebra, 740–743
 - intermediate concepts
 - metric system, 768–772
 - units, 746–768
 - numbers and operations
 - addition, 735
 - division, 736
 - multiplication, 736
 - subtraction, 735–736
 - order of operations, 736–740
 - percentages, 743–746
 - Batch process, 285
 - Batteries, 543
 - Bench-scale analysis, 214, 346
 - Benzene, 17–18
 - Beryllium, 14
 - Best available technology (BAT), 237
 - Best management practice (BMP)
 - strategies, 722
 - Biochemical oxygen demand (BOD), 403, 421
 - Biofiltration, 266
 - Blending calculations record, 249
 - Body resistances, 86, 87
 - Breakpoint chlorination, 233
 - Bromate, 14
 - Building maintenance, 618
 - Butterfly valves, 592

C

- Cadmium, 14
- Calcium carbonate
 - equilibrium, 159
 - equivalent, 141
 - pH and temperature control, 378
 - scale, 234
- Calcium hardness, 140
- Calcium hydroxide, 107–108, 150.
 - See also* Slaked lime
- Calcium oxide, 107–108
- Calcium sulfate, 378
- Calibrating chemical feeders
 - dry chemical systems, 614–615
 - large-volume metering pumps, 613
 - small-volume metering pumps, 613–614
- Calibration, 452
- Call date, 667
- Capacity, 782–783
- Capital improvement plan (CIP), 665
- Carbonate hardness
 - definition, 140
 - removal, 151
- Carbon dioxide
 - extinguishers, 96
 - gases and vapors, 114
 - removal, 150
- Carbon monoxide, 115–116
- Carbon tetrachloride, 18
- Cardiopulmonary resuscitation (CPR), 75
- Cartridge filters, 377, 379, 392–393
- Catalytic regeneration, 225–226
- Cathodic protection, 617
- Cation-permeable membranes, 387
- Cations, 140
- Caustic soda
 - bases, 108–109
 - chemical reactions, to soften water, 152–153
 - safe handling procedures for, 153
 - soften water, 161–162
- Cavitation, 556
- Cellulose acetate membrane, 366
- Central tendency, 800–804
- Centrifugal pumps, 552–558
- Centrifuges
 - dewatering processes, 435–437
 - of sludge, 424
- Certification examinations, 639
- Chain drives, troubleshooting, 577
- Check valves, 592–593
- Chemical feeder maintenance, 234
- Chemical feeders
 - calibrating, 608–615
 - chlorinators, 615–616
 - fluoridation systems, 281
 - log sheets
 - hydrofluosilicic acid, 314–315
 - sodium silicofluoride, 315–319
 - operation
 - equipment check procedures, 319
 - feed rates and preparing chemical solutions, 295–314
 - startup, 294–295
- Chemical feed rate indicators, 477
- Chemical feed systems, 347
- Chemical flush system, 393–394
- Chemical handling
 - acids
 - acetic acid, 101, 103
 - hydrochloric acid, 103–105
 - nitric acid, 105
 - phosphoric acid, 105–106
 - sulfuric acid, 106–107
 - bases
 - calcium hydroxide, 107–108
 - calcium oxide, 107–108
 - hypochlorite, 109
 - sodium carbonate, 109
 - sodium hydroxide, 108–109
 - chemical storage drains, 120
 - gases and vapors
 - carbon dioxide, 114
 - carbon monoxide, 115–116
 - chlorine, 110–113
 - ethane, 116
 - gasoline vapor, 115
 - hydrogen, 116
 - hydrogen sulfide gas, 116
 - methane gas, 116
 - oxygen, 114–115
 - specific gravity, 110
 - sulfur dioxide, 114
 - hazard communication program, 101, 102
 - labeling on sulfuric acid container, 98
 - powders, 118–120
 - safety data sheet (SDS), 98–101
 - salts
 - aluminum sulfate, 117
 - ferric chloride, 117–118
 - ferric sulfate, 118
 - ferrous sulfate, 118
 - sodium aluminate, 118
 - training, 101
- Chemically enhanced backwash (CEBW), 414
- Chemical oxygen demand (COD), 407
- Chemical reactions, to soften water
 - calculating chemical dosages, 153–157
 - carbonate hardness removal, 151
 - carbon dioxide removal, 150
 - caustic soda softening, 152–153
 - lime, 150
 - noncarbonate hardness removal, 151
 - stability, 151–152
- Chemical storage
 - drains, 120
 - facilities, 606–607
- Chloramination, 28
- Chloramines, 267
- Chloride, 46, 47
- Chlorinators, 615–616
- Chlorine, 110–113
- Chlorine contact chamber, 347
- Chlorine dioxide, 267
- Chlorine oxidation, 224–225
- Chlorite, 14
- Chromium, 14–15
- Circle, 749–750
- Circuit, 510
- Circuit breakers, 524–525
- Circuit testers. *See* Ohmmeter
- Cleaning, 70–71
- Cleaning connections, 373
- Clean-in-place (CIP) process
 - backwashing, 346
 - low-pressure membrane systems, 414
 - membrane regeneration system, 347
- Clean Water Act (CWA), 405
- Clear well, 347
- Closed-loop control system, 292
- CMMS. *See* Computerized maintenance management systems (CMMS)
- Coagulation
 - interactions with, 163
 - mechanical treatment, process wastes, 411–412
- Cocurrent flow, 239
- Code of Federal Regulations (CFR), 4
- Coliform, 20
- Colloids, 210, 377
- Communication
 - oral communication, 652–653
 - written communication, 653–655
- Community water system (CWS), 3
- Competent person, 132
- Compressors, 581–586
- Computer control system, 491–495
- Computer maintenance management systems (CMMS), 507, 668–669
- Computer recordkeeping systems, 720
- Concentrate control valve, 373
- Concentration, 756–757
- Concentration polarization, 368
- Concrete tanks, 617
- Conditioning, of sludge, 424
- Conductors, 514–515
- Cone, 751–752, 755
- Confined spaces
 - checklist and permit, 75, 76
 - dangerous air contamination, 74
 - definition, 73, 705
 - gas-detection and -monitoring devices, 74–75
 - instrumentation and control systems, 462
 - permit-required or non-permit-required, 75
 - procedures, 75, 77
 - steps of, 75
- Conservation pricing, 727

- Conservation programs
 - best management practice strategies, 722
 - commercial-, industrial-, and institutional-sector programs, 725–726
 - commodity rates, 723–724
 - coordinator, 727
 - large landscape conservation programs, 724–725
 - leak detection and repair, 723
 - potential best management practices, 728
 - pricing, 727
 - public information programs, 725
 - residential plumbing retrofits, 723
 - residential ULFT replacement programs, 728
 - residential water surveys, 722–723
 - system water audits, 723
 - water waste prohibition, 727–728
 - wholesale agency assistance programs, 726–727
 - Consumer Confidence Report (CCR) Rule, 6
 - Contactors, 458
 - Contaminant Candidate List (CCL), 2
 - Contaminants
 - inorganic, 3
 - microbial, 3
 - organic, 3
 - public drinking water, 2
 - radiological, 3
 - regulated, 4–5
 - turbidity, 3
 - unregulated, 5–6
 - Continuity, 655
 - Continuous-belt filter presses, 435
 - Continuously regenerated manganese greensand processes, 227–231
 - Continuous regeneration (CR), 225–226
 - Controller, 454
 - Control panels, 90
 - Control systems, 454
 - Cooling systems, 604–605
 - Copper, 15
 - Coprecipitation, 237
 - Corrective maintenance, 506
 - Correlation coefficient, 819–820
 - Countercurrent flow, 239
 - Coverage ratio, 661
 - Crane operation, 72
 - Cross-connection control program
 - backflow, 674–675, 677
 - back pressure, 674–675
 - backsiphonage, 674, 676
 - inspections, 674
 - responsibilities, 675, 677
 - types, 674
 - water supplier program, 678
 - Cross-connections, 567
 - Cross-flow filtration, 340
 - Cryptosporidia*, 689, 690
 - Cryptosporidium*, 23, 25, 689–690
 - CT value, 28, 32–38
 - Cube, 753
 - Current, 512
 - Cycles, 513
 - Cylinder, 750–751, 754
- ## D
- Daily operations log, 249
 - Dangerous air contamination, 74, 462
 - Dateometer, 575
 - Day tank, 285
 - Dead-end filtration, 340
 - Debt service, 661
 - Decant pumps, 429
 - Defensive driving, 81–82
 - Delegation, 627
 - Demineralization, 336
 - Density, 756
 - Department of Health and Human Services, 4
 - Department of Homeland Security (DHS), 684
 - Depreciation, 666
 - Desiccant, 497
 - Detention basin, 222
 - Dewatering sludge, 412, 432–439
 - Diatomaceous earth filters, 412–413
 - 1,2-Dichloroethane, 18
 - 1,1-Dichloroethylene, 18–19
 - Diesel engines, 601–603
 - Diesel fuel, 605
 - Digesters, 809–811
 - Digital, 453
 - Digital readout, 453
 - Direct current (DC), 85, 384, 513
 - Direct dischargers, 403
 - Direct potable reuse, 338
 - Dirty water problems, 234
 - Discharge monitoring reports (DMRs), 408
 - Discrete control, 465
 - Discrete I/O (input/output), 465
 - Disinfectants and Disinfection Byproducts Rules (DBPRs), 42–44, 250
 - Disinfection, 419
 - Disinfection byproducts (DBPs)
 - control strategies, 261–262
 - definition, 210
 - disinfectants, 42–44
 - drinking water standards for, 251
 - evaluating control options, 263–268
 - existing treatment processes, 262
 - formation, 253–255
 - membrane treatment technologies, 336
 - process waste generation, 419
 - production, 256–259
 - regulatory compliance, 250–253
 - sampling, 257–259
 - selecting and implementing, 268–269
 - THM calculations, 259–261
 - Dispersion, 804–807
 - Disposal practices
 - plant wastewaters, 443–444
 - sludges and slurries, 440–443
 - Dissolved air flotation (DAF), 431
 - Dissolved BOD (DBOD), 421
 - Dissolved organic carbon (DOC), 345
 - Dissolved organic matter (DOM), 336
 - Dissolved oxygen (DO), 421
 - Distributed control systems (DCS), 491
 - Distribution system safety
 - lockout/tagout, 125–126
 - lubricants and fuels, storage of, 126
 - pump safety
 - definitions of, 124
 - enclosed guards, 124, 125
 - maintenance and repair, 125
 - safety around water storage facilities
 - confined spaces, 131–132
 - ladders, 128–130
 - slips and falls, 127
 - tank coatings, 130–131
 - safety around wells
 - safety inspection, 121
 - well chemicals, 121–123
 - working around electrical units, 123
 - traffic hazards, 127–128
 - Divalent, 194, 210
 - Division, 736
 - Downflow saturators, 287
 - Drafts, 654
 - Drinking Water Contaminant Candidate List, 4
 - Drinking water regulations
 - CCR Rule, 6
 - contaminants, types of, 3
 - NPDWRs, 2
 - NSDWRs, 2
 - primary drinking water standards (*see* Primary drinking water standards)
 - regulate contaminant, 4–5
 - SDWA, 2
 - secondary drinking water standards
 - monitoring, 46–47
 - secondary contaminants, 47–51
 - secondary MCLs (SMCLs), 46
 - setting standards, 3–4
 - unregulated contaminants, 4–5
 - water systems, types of, 2–3
 - Drinking water standards, for DBPs, 251
 - Drinking Water State Revolving Fund (DWSRF), 406
 - Drowning prevention, 70
 - Dry chemical extinguishers, 96
 - Dry chemical systems, 614–615
- ## E
- Eccentric valves, 591
 - Effective range, 452
 - Efficacy, 655

- Efficiency, of pump, 783–786
 - Electrical energy consumption, 493
 - Electrical equipment safety
 - avoiding electric shock, 85–87
 - control panels, 90
 - current and voltage, 85
 - electric motors, 89
 - electric starters, 89
 - emergency procedures, 88
 - instrumentation, 90
 - lockout/tagout procedure, 90–92
 - safe practices, 85
 - transformers, 88
 - Electrical hazards, 459–460
 - Electrical safety checklist, 511
 - Electrical tools, 78
 - Electricity
 - alternating current, 513
 - amps, 512
 - conductors and insulators, 514–515
 - direct current, 513
 - power, 513–514
 - volts, 512
 - Electric motors
 - electrical equipment safety, 89, 528–539
 - preventive maintenance, 573–574
 - troubleshooting, 533–539
 - variable frequency drives, 532
 - Electric shock, 85–87
 - Electric starters, 89
 - Electrodialysis (ED)
 - anion-permeable membranes, 387
 - cation-permeable membranes, 387
 - chemical flush system, 393–394
 - DC power supply, 393
 - equipment, 391
 - membrane stack, 393
 - multicompartment unit, 387–389
 - operation, 394
 - pretreatment, 391–393
 - principles of, 386
 - pumping equipment and piping, 393
 - safety, 390–391
 - three-cell unit, 387
 - Electrodialysis polarity reversal (EDR)
 - systems, 386, 392, 393
 - Electrolyte, 542
 - Electromedia processes, 231–234
 - Electromotive force (EMF). *See* Voltage (V)
 - Electron, 512
 - Electronic feeder, 283
 - Emergency lighting, 541–543
 - Emergency maintenance, 506
 - Emergency response
 - assessment and planning, 680–682
 - contamination threats, 686–690
 - Cryptosporidium*, 689–690
 - evaluating and responding, 687–688
 - federal requirements, 679
 - security, 682–685
 - Employment policies and procedures
 - compensation, 638
 - discipline problems, 643–645
 - harassment, 645–649
 - labor laws governing employer/employee relations, 649–650
 - performance evaluation, 640–643
 - personnel records, 650
 - probationary period, 638
 - training and certification, 638–639
 - Empty bed contact time (EBCT), 239
 - End bells, 528
 - Endemic brown stain, 276
 - Endocrine effects, 236
 - Energy-isolating device, 91
 - Energy losses, 787–790
 - Energy recovery devices, 374
 - Enhanced Surface Water Treatment Rule (ESWTR), 22
 - Enteric, 24
 - Environmental impacts
 - dechlorination, 444
 - increased oxygen by aeration, 444
 - pH adjustment, 444–445
 - Environmental Protection Agency (EPA)
 - Contaminant Candidate List, 2
 - Information Collection Rule (ICR) data, 42
 - maximum contaminant level (MCL), 4
 - maximum contaminant level goals (MCLGs), 3
 - national drinking water standards, 4
 - no observed adverse effect level (NOAEL), 3
 - public drinking water systems, 2–3
 - of public water systems (PWSs), 3
 - Stage 1 DBPR, 42–43
 - Stage 2 DBPR, 43–44
 - Standardized Monitoring Framework (SMF), 7
 - Unregulated Contaminant Monitoring (UCM) program, 5–6
 - unregulated contaminants, 2
 - Enzyme systems, 378
 - Equipment lubrication, 551–552
 - Equivalent weight, 143
 - Ethane, 116
 - Explosive atmosphere monitoring, 115
 - Explosive gas mixtures, 72–73, 463–464
 - Eye protection, 62
- ## F
- Facility maintenance safety
 - cleaning, 70–71
 - confined spaces, 73–77
 - crane operation, 72
 - explosive gas mixtures, 72–73
 - painting, 71
 - power tools, 77–78
 - safety valves, 80
 - welding, 78, 80
 - Facts, 654
 - Fail-safe, 456
 - Family and Medical Leave Act of 1993 (FMLA), 650
 - Feasibility analysis process, 625–626
 - Federal Register (FR), 4
 - Feedback, 455
 - Feedwater, 354
 - Ferric chloride, 117–118
 - Ferric sulfate, 118
 - Ferrous sulfate, 118
 - Filter backwash, 413
 - Filter effluent, 233
 - Filter presses, 437
 - Filtration, 412–416
 - Financial stability planning
 - budgeting, 662–664
 - capital improvement program, 665–667
 - equipment repair/replacement fund, 664–665
 - stability measurement, 661–662
 - water rates, 665
 - Fire exits, 97
 - Fire extinguisher
 - classifications, 93–95
 - operation and maintenance
 - carbon dioxide, 96
 - foam, 95
 - water, 95
 - Fire hoses, 96
 - Fire prevention and protection
 - fire exits, 97
 - fire extinguishers
 - classification of, 93–95
 - operation and maintenance, 95–96
 - fire hoses, 96
 - plan, 93
 - storage of flammables, 96
 - First aid, 694
 - Flocculation, 411–412
 - Flow measurements, 470–477
 - Flow rate, 758–760
 - Fluoridation
 - chemical feeder operation
 - equipment check procedures, 319
 - feed rates and preparing chemical solutions, 295–314
 - chemical feeder startup, 294–295
 - definition, 276
 - final equipment checkup, 293–294
 - fluoride compounds, 279–281
 - history of, 276
 - log sheets
 - hydrofluosilicic acid, 314–315
 - sodium silicofluoride, 315–319
 - maintenance, 320–321
 - overfeeding prevention, 319
 - programs, 276
 - safety
 - avoid overexposure, 277
 - first aid, 278
 - fluoride poisoning, 278
 - protecting yourself and your family, 279
 - training, 279

shutting down chemical systems, 320
 systems
 chemical feeders, 281
 downflow saturators, 287
 large hydrofluosilicic acid systems, 291–292
 small hydrofluosilicic acid systems, 290–291
 upflow saturators, 288–289
 underfeeding prevention, 320
 Fluoride, 15
 Fluoride poisoning, 278
 Fluorosilicic acid, 279
 Flush connections, 373
 Flux flow, 358
 Foam extinguishers, 95
 Foot protection, 62
 Force, 760–765
 Forklifts, 83
 Free chlorine, 254
 Friction, 787–790
 Fuel storage
 diesel, 605
 gasoline, 605–606
 liquefied petroleum gas, 606
 natural gas, 606
 Fuses, 524

G

Gasoline engines
 problem identification, 599–600
 starting, 598–599
 Gasoline fuel storage, 605–606
 Gasoline vapor, 115
 Gate valves, 586–590
 Geographic information systems (GIS), 668–669
Giardia lamblia, 23
 Giardiasis, 23
 Globally Harmonized System of Classification and Labeling of Chemicals (GHS), 695
 Globe valves, 590–591
 Granular activated carbon (GAC), 43, 262, 418
 Granular ferric hydroxide (GFH), 242
 Gravimetric feeder, 281, 285
 Greensand, 225
 Ground, 511
 Ground-fault circuit interrupter (GFCI), 78
 Groundwater under direct influence (GWUDI), 43

H

Haloacetic acid (HAA), 250
 Handling and disposal, process wastes
 chemical precipitation, 439
 disposal practices, 440–444

draining and cleaning tanks, 428–430
 environmental impacts, 444–445
 monitoring and reporting, 445
 process sludge volumes, 424–428
 sludge dewatering processes, 432–439
 thickening process, 431–432
 Hand-Off-Automatic (HOA), 456, 458
 Hand protection, 62
 Harassment, 645–649
 Hardness, in water, 140
 Hard water, 140–141
 Hazards
 accidents, 54
 communication program, 101, 102
 exposures, 54
 preventive measures, 54, 55
 statement, 701
 work environment or conditions, 54
 Head
 definition, 355, 476, 556
 loss, 226, 413
 protection, 62
 Hertz (Hz), 513
 Heterotrophic plate count (HPC), 27
 Heterotrophs, 27
 High voltage
 power distribution transformers, 545
 switchgear, 544–545
 transmission, 544
 Hollow fiber reverse osmosis module, 376
 Horsepower, 774–778
 Human carcinogens, 3
 Human machine interface (HMI), 491
 Hydrated lime, 107–108, 150
 Hydrochloric acid, 103–105, 121–122
 Hydrofluosilicic acid
 chemical feeders, 314–315
 fluoridation, 279, 280
 large, 291–292
 small, 290–291
 Hydrogen, 116
 Hydrogen sulfide gas
 detectors, 110, 111
 gases and vapors, 116
 Hydrolysis, 366
 Hygroscopic, 606
 Hypochlorite, 109

I

Indicators, 480–481
 Indirect discharger, 403
 Indirect potable reuse, 338
 Induction motors, troubleshooting, 537–539
 Information Collection Rule (ICR), 42
 Initial Distribution System Evaluation (IDSE), 253
 Inorganic chemical contaminants, 405
 Inorganic chemical standards
 antimony, 12
 arsenic, 12–13

asbestos, 13
 barium, 14
 beryllium, 14
 bromate, 14
 cadmium, 14
 chlorite, 14
 chromium, 14–15
 copper, 15
 fluoride, 15
 lead, 15–16
 MCLGs, 7, 13
 MCLs, 7, 13
 nitrate, 16
 nitrite, 16
 primary standards and health concerns, 7–12
 selenium, 16
 thallium, 16–17
 Inorganic contaminants, 3
 Insoluble, 150, 210, 411
 Instrumentation and control systems
 air supply systems, 487–489
 automatic controllers, 484–485
 computer control system, 491–495
 confined spaces, 462
 explosive gas mixtures, 463–464
 falls and associated hazards, 464
 laboratory, 489
 measured variables
 chemical feed rate, 477
 flow measurements, 470–477
 level measurements, 468–470
 pressure measurements, 465–467
 process instrumentation, 478–479
 signal transmitters, 479
 operation and preventive maintenance
 indications of proper function, 496
 operational checks, 499
 preventive maintenance, 497–498
 startup/shutdown considerations, 496–497
 oxygen deficiency, 462
 panel instruments
 alarms, 484
 indicators, 480–481
 recorders, 481–483
 totalizers, 483
 primary elements, 480
 process monitoring and manipulation
 measurements, 451–454
 modulating control systems, 454–455
 motor control station, 456–459
 pump controllers, 485–487
 safety
 electrical hazards, 459–460
 mechanical and pneumatic hazards, 460–462
 sensors, 465–479
 test and calibration equipment, 489–490
 Insulation, 514–515
 Insulators, 514–515
 Integrators, 483

- Interim Enhanced Surface Water Treatment Rule (IESWTR), 22, 23
- Interim regulations. *See* Drinking water regulations
- Interlock, 460
- Intermediate concepts, of basic math operations
- metric system, 768–772
 - length measurement, 770
 - SI base units, 768–769
 - temperature, 771–772
 - volume capacity measurement, 770
 - weight measurement, 770–771
- units, 746–768
- circle surface area, 749–750
 - concentration, 756–757
 - cone surface area, 751–752
 - cylinder surface area, 750–751
 - density, 756
 - distance/length, 746–747
 - force and pressure, 760–765
 - mass and weight, 755
 - rectangle surface area, 747–748
 - sphere surface area, 752
 - trapezoid surface area, 749
 - triangle surface area, 748–749
 - velocity and flow rate, 758–760
 - volume, 752–755
 - work, head, and power, 765–768
- Intermittent regeneration (IR), 225–226
- Internal combustion engines
- cooling systems, 604–605
 - diesel engines, 601–603
 - fuel storage, 605–606
 - gasoline engines, 597–600
 - standby engines, 603–604
- Ion exchange
- arsenic concentration, 238
 - competing ions, 238
 - configuration of columns or vessels, 238
 - definition, 221
 - flow direction of, 239
 - mechanical treatment, process wastes, 417–418
 - number of units, 239
 - pH, 238
 - process wastes, 408
 - removal, 221
 - resins, 172, 221
 - type, 238
- Ion exchange softening
- blending, 192–194
 - calculations, 185–191
 - control testing, 178–179
 - definition, 142
 - limitations caused by iron and manganese, 179
 - maintenance, 180–182
 - operation, 174–178
 - spent brine disposal, 179–180
 - startup and shutdown, 184–185
 - troubleshooting, 182–183
- Ions, 140
- Iron and manganese control
- arsenic control
 - alternative treatment, 237
 - chemistry, 236–237
 - monitoring, 247–248
 - recordkeeping and reporting, 249–250
 - reduction/removal, 237–245
 - review of plans and specifications, 246
 - safety, 236
 - chemical feeder maintenance, 234
 - disinfection byproducts (DBPs) control
 - control strategies, 261–262
 - evaluating control options, 263–268
 - existing treatment processes, 262
 - formation, 253–256
 - production, 256–259
 - regulatory compliance, 250–253
 - selecting and implementing, 268–269
 - THM calculations, 259–261
 - measurements of, 211–212
 - red water complaints, 234–235
 - remedial action, 213–234
- Iron bacteria, 210–211
- Iron salts, 163
- J**
- Jar tests
- calculating chemical feeder settings, 169–171
 - definition, 166
 - examples, 167–169
- K**
- Kjeldahl nitrogen, 422
- L**
- Laboratory instruments, 489
- Ladders, 128–130
- Lag time, 458
- Langelier Index (LI)
- membrane treatment technologies, 386
 - softening, 146
- Large hydrofluosilicic acid systems, 291–292
- Large-volume metering pumps, 613
- Lateral surface area, 750
- Lead, 15–16, 513
- Level measurements, 468–470
- Lime
- application of, 157
 - chemical reactions, 150
 - handling of, 157
 - sludge water treatment plant, 441
 - softening, 158, 417, 441
 - storage of, 157
- Lime–soda ash softening, 161
- Lime–soda sludges, discharge of, 441
- Lime–soda softening, 149
- Linear alkylbenzene sulfonate (LAS), 48
- Linearity, 452
- Liquefied petroleum gas (LPG), 606
- Locational running annual average (LRAA), 44, 251
- Lockout device, 91
- Lockout switches, 294
- Lockout/tagout procedure, 90–92, 125–126, 508–510
- Log sheets
- hydrofluosilicic acid, 314–315
 - sodium silicofluoride, 315–319
- Long Term 1 Enhanced Surface Water Treatment Rule (LT1ESWTR), 22, 23
- Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR), 22
- Lower explosive limit (LEL), 72, 463
- Lubrication
- equipment, 551–552
 - precautions, 550
 - pump, 551
 - schedule, 550
- M**
- Magnesium hardness, 140
- Magnetic starters, troubleshooting, 529–531
- Management
- communication
 - oral communication, 652–653
 - written communication, 653–655
 - conduct meetings, 656
 - emergency response
 - assessment and planning, 680–682
 - contamination threats, 686–690
 - federal requirements, 679
 - security, 682–685
 - financial stability planning
 - budgeting, 662–664
 - capital improvement program, 665–667
 - equipment repair/replacement fund, 664–665
 - stability measurement, 661–662
 - water rates, 665
 - operation and maintenance
 - benefits, 670–671
 - cross-connection control program, 674–678
 - effective programs, 668
 - geographic information systems, 668–669
 - SCADA systems, 671–673
 - types, 669–670
 - organizing, 627–630
 - planning, 626–627
 - public relations
 - being interviewed, 658
 - consumer inquiries, 659–660

- establish objectives, 657
- mass media, 657–658
- plant tours, 660
- public speaking, 658
- telephone contacts, 659
- utility operations, 657
- recordkeeping
 - computer systems, 720
 - essential records, 716–717
 - maintenance, 718–720
 - plant operations data, 717–718
 - retaining utility records, 720–721
 - types, 716
 - uses, 717
- safety program
 - confined space entry procedures, 705–706
 - effectiveness, 690
 - first aid, 694–695
 - Hazard Communication Standard, 695–705
 - human factors engineering, 715–716
 - managers, 691–693
 - measuring, 712–715
 - operators, 694
 - regulatory agencies, 691
 - reporting, 707–709
 - supervisors, 693–694
 - training, 710–711
 - worker Right-To-Know (RTK) laws, 695–705
- staffing
 - applications, 633–637
 - employment policies and procedures, 638–650
 - legislation, legal requirements of, 631
 - new employee orientation, 637
 - qualifications profile, 632–633
 - responsible, 631
 - selection process, 633–637
 - unions, 651–652
 - workforce analysis, 631–632
- utilities
 - environmental field, 624
 - feasibility analysis process, 625–626
 - manager functions, 624
 - organizing, 624
 - planning, 624
 - staffing, 625
 - water treatment facility self-assessment, 625
- water and energy conservation
 - best management practice strategies, 722
 - commercial-, industrial-, and institutional-sector programs, 725–726
 - commodity rates, 723–724
 - coordinator, 727
 - large landscape conservation programs, 724–725
 - leak detection and repair, 723
 - potential best management practices, 728
 - pricing, 727
 - public information programs, 725
 - residential plumbing retrofits, 723
 - residential ULFT replacement programs, 728
 - residential water surveys, 722–723
 - system water audits, 723
 - water waste prohibition, 727–728
 - wholesale agency assistance programs, 726–727
- Manganese greensand
 - filters, 225–226
 - iron and manganese removal process, 229
 - potassium permanganate, 225
 - troubleshooting, 232
- Manganese zeolite, 225
- Mass media, 657–658
- Mass spectrometry (MS), 248
- Maximum contaminant level (MCL)
 - definition, 4, 236, 276, 405
 - disinfection byproducts, 42–43
 - inorganic chemical, 7, 13
 - organic chemical, 17–20
 - radiological contaminants, 45
 - Revised Total Coliform Rule (RTCR), 22
 - Total Coliform Rule (TCR), 21
 - turbidity, 26
- Maximum contaminant level goal (MCLG)
 - definition, 3, 251
 - disinfection byproducts, 42–43
 - inorganic chemical, 7, 13
 - organic chemical, 17–20
 - Revised Total Coliform Rule (RTCR), 22
 - Total Coliform Rule (TCR), 21
- Maximum residual disinfectant level goals (MRDLGs), 42
- Maximum residual disinfectant levels (MRDLs), 42
- MCL. *See* Maximum contaminant level (MCL)
- MCLG. *See* Maximum contaminant level goal (MCLG)
- Measured variables
 - chemical feed rate, 477
 - definition, 465
 - flow measurements, 470–477
 - level measurements, 468–470
 - pressure measurements, 465–467
 - process instrumentation, 478–479
 - signal transmitters, 479
- Mechanical equipment
 - compressors, 581, 584–586
 - lubrication, 548–552
 - preventive maintenance, 566–584
 - pumps, 552–566
 - valves, 586–597
- Mechanical hazards, 460–462
- Mechanical maintenance, 506
- Mechanical treatment, process wastes
 - activated carbon, 418
 - coagulation, 411–412
 - disinfection, 419
 - filtration, 412–416
 - flocculation, 411–412
 - ion exchange, 417–418
 - organic matter and oxygen, 421
 - precipitative softening, 416–417
 - presedimentation, 410
 - sedimentation, 411–412
- Median, 802
- Megger, 522–523
- Megohm, 523
- Membrane cleaning, 383–384
- Membrane damage, 383
- Membrane equipment, 350
- Membrane filters, 346, 413
- Membrane filtration/separation, 414–416
- Membrane fouling, 345
- Membrane process problems, 350
- Membrane treatment technologies
 - corrective maintenance, 353
 - demineralizing processes, 354–355
 - electrodialysis (ED)
 - anion-permeable membranes, 387
 - cation-permeable membranes, 387
 - chemical flush system, 393–394
 - DC power supply, 393
 - equipment, 391
 - membrane stack, 393
 - multicompartment unit, 387–389
 - operation, 394
 - pretreatment, 391–393
 - principles of, 386
 - pumping equipment and piping, 393
 - safety, 390–391
 - three-cell unit, 387
 - membrane flow systems, 340–342
 - membrane fouling, 350–351
 - operation and maintenance
 - bench-scale analysis, 345–346
 - membrane performance monitoring, 349
 - operational procedures, 348–349
 - pilot-scale studies, 345–346
 - pretreatment, 344–346
 - SCADA system, 343
 - typical plant components, 346–348
 - pressure vessels, 339–340
 - preventive maintenance, 352–353
 - recordkeeping, 351–352
 - reverse osmosis
 - chemical safety, 357
 - components, 371–376
 - electrical safety, 357
 - flux, 359–360
 - hydraulic safety, 357
 - membrane cleaning, 383–384
 - mineral rejection, 361–364
 - performance and properties, 364–367
 - plant operation, 379–383

- Membrane treatment technologies
 - (*continued*)
 - pretreatment, 376–379
 - recovery, 367–370
 - structure and composition, 357–359
 - routine maintenance, 352
 - submerged flow, 339–340
 - troubleshooting, 350–351
 - Meniscus, 793
 - Meters and testers
 - ammeter, 517–522
 - megger, 522–523
 - ohmmeter, 523
 - voltage testing, 515–517
 - Methane gas, 116
 - Methylene blue active substance (MBAS), 48
 - Methyl orange alkalinity, 146
 - Metric system
 - length measurement, 770
 - SI base units, 768–769
 - temperature, 771–772
 - volume capacity measurement, 770
 - weight measurement, 770–771
 - Microbial contaminants, 3
 - Microbial standards
 - Revised Total Coliform Rule (RTCR), 21–22
 - Surface Water Treatment Rule (SWTR), 22–28
 - Total Coliform Rule (TCR), 21
 - Microbiological contamination, 42
 - Microbiological organisms, 378–379
 - Microfiltration (MF), 336
 - Mineral rejection, 361–364
 - Modulating control systems, 454–455
 - Molecular weight, 143, 298
 - Monthly summary form, 249
 - Motor control circuit operation, 458–459
 - Motor control station, 456–459
 - Motor starters, 526–528
 - Multimedia filters, 413
 - Multiplication, 736
- N**
- Nameplates, 512
 - Nanofiltration (NF), 264, 336
 - National Academy of Sciences, 4
 - National Association of Counties (NACo), 406
 - National Contaminant Occurrence Database (NCOD), 5
 - National Electrical Code (NEC), 544
 - National Fire Protection Association Standard 820 (NFPA 820), 73
 - National Pollutant Discharge Elimination System (NPDES) permit, 180, 403
 - National Primary Drinking Water Regulations (NPDWR), 2
 - National Rural Water Association (NRWA), 406
 - National Secondary Drinking Water Regulations (NSDWR), 2, 45
 - National Terrorism Advisory System (NTAS), 685
 - Natural gas, 606
 - Natural organic matter (NOM), 254, 336
 - Nitrate, 16
 - Nitric acid, 105
 - Nitrite, 16
 - Noise exposure
 - advantages/disadvantages, 66
 - earplug, insertion type, 65
 - fatigue, 64
 - full earmuff type, 65
 - meters, 63
 - permissible, 64, 65
 - Noise reduction rating (NRR), 66
 - Noncarbonate hardness
 - hardness, 140
 - removal, 151
 - Noncarcinogens, 3
 - Nonconserving pricing, 727
 - Non-membrane filtration, 413–414
 - Non-transient non-community water system (NTNCWS), 3
 - No observed adverse effect level (NOAEL), 3
 - Numbers and operations, of basic math
 - operations
 - addition, 735
 - division, 736
 - multiplication, 736
 - subtraction, 735–736
- O**
- Occupational Safety and Health Act of 1970 (OSH Act of 1970), 691
 - Occupational Safety and Health Administration (OSHA), 52, 64, 75, 83, 509
 - Offset, 458
 - Ohm, 512
 - Ohmmeter, 523
 - Olfactory fatigue, 72
 - On-the-job training (OJT), 67
 - Operating ratio, 661
 - Operation and maintenance (O&M)
 - benefits, 670–671
 - cross-connection control program
 - backflow, 674–675, 677
 - back pressure, 674–675
 - backsiphonage, 674, 676
 - inspections, 674
 - responsibilities, 675, 677
 - types, 674
 - water supplier program, 678
 - effective programs, 668
 - geographic information systems, 668–669
 - membrane treatment technologies
 - bench-scale analysis, 345–346
 - membrane performance monitoring, 349
 - operational procedures, 348–349
 - pilot-scale studies, 345–346
 - pretreatment, 344–346
 - SCADA system, 343
 - typical plant components, 346–348
 - preventive
 - indications of proper function, 496
 - operational checks, 499
 - preventive maintenance, 497–498
 - startup/shutdown considerations, 496–497
 - SCADA systems, 671–673
 - types, 669–670
 - Operator interface, 453
 - Operator safety, 2
 - Oral communication, 652–653
 - Organic chemical standards
 - benzene, 17–18
 - carbon tetrachloride, 18
 - 1,2-dichloroethane, 18
 - 1,1-dichloroethylene, 18–19
 - para-dichlorobenzene, 19
 - 1,1,1-trichloroethane, 19
 - trichloroethylene (TCE), 19
 - vinyl chloride, 19–20
 - Organic compounds, 254
 - Organic contaminants, 3
 - Organizing
 - definition, 624
 - management, 627–630
 - Orifice, 476
 - OSHA. *See* Occupational Safety and Health Administration (OSHA)
 - Osmosis, 355
 - OUCH principle, 636, 637
 - Overfeeding prevention, 319
 - Overload relays, 525–526
 - Oxygen, 114–115
 - Oxygen deficiency, 114, 462
 - Oxygen enrichment, 114
- P**
- Painting, 71
 - Panel instruments
 - alarms, 484
 - indicators, 480–481
 - recorders, 481–483
 - totalizers, 483
 - Para-dichlorobenzene, 19
 - Parts per million (ppm), 103
 - Percentages, of basic math operations, 743–746
 - Peristaltic feeder, 283
 - Permanent hardness, 140. *See also* Noncarbonate hardness
 - Permanganate oxidation
 - continuously regenerated manganese greensand processes, 227–231
 - iron and manganese control, 225–231

- Permeate
 definition, 365
 drawback tank, 373–374
 rinse, 373
- Permissible noise exposure, 64, 65
- Permit-required confined space, 705
- Personal flotation device (PFD), 70
- Personal protective equipment (PPE)
 eye protection, 62
 foot protection, 62
 hand protection, 62
 head protection, 62
 SCBA, 60
- pH
 activated alumina, 240–241
 adjustment, 420, 444–445
 chemistry of softening, 145–146
 definition, 211
 feedwater temperature and, 366
 of fluoride, 277
 ion exchange, 238
 process wastes, 422
 secondary contaminants, 50
 secondary maximum contaminant levels (SMCLs), 46, 50
 softening, 145–146
 and temperature control, 378
- Phenolphthalein alkalinity, 146
- Phosphate treatment, 214–220
- Phosphoric acid, 105–106
- Physical separation, 237
- picoCurie, 45
- Pictogram, 701
- Pilot-scale study, 346
- Piping, reverse osmosis, 372
- Planning, 624
- Plant management, 626–627
- Plant maintenance
 building maintenance, 618
 chemical feeders
 calibrating, 608–615
 chlorinators, 615–616
 chemical storage facilities, 606–607
 electrical equipment
 auxiliary electrical power, 536, 539–543
 electrical safety checklist, 511
 electricity, 512–515
 electric motors, 528–539
 high voltage, 544–545
 meters and testers, 515–523
 recordkeeping, 545–547
 safety devices, 524–528
 internal combustion engines
 cooling systems, 604–605
 diesel engines, 601–603
 fuel storage, 605–606
 gasoline engines, 597–600
 standby engines, 603–604
 mechanical equipment
 compressors, 581–586
 lubrication, 548–552
 preventive maintenance, 566–581
 pumps, 552–566
 valves, 586–597
 program
 lockout/tagout procedure, 508–510
 preventive maintenance records, 507–508
 tanks and reservoirs
 concrete tanks, 617
 steel tanks, 616–617
 Plant operating records
 blending calculations record, 249
 daily inspection form, 249
 daily operations log, 249
 monthly summary form, 249
 Plant operations data, 717–718
 Pneumatic hazards, 461–462
 Pneumatic tools, 78
 Point-of-use/point-of-entry (POU/POE), 242, 336
 Polychlorinated biphenyls (PCBs), 130
 Polyphosphate treatment, 218
 Polyvinyl chloride (PVC), 372
 Portable multi-gas monitor, 74
 Positive-displacement pumps, 281, 282, 558–560
 Potable water, 130, 181, 404
 Potassium permanganate, 225–227
 Powdered activated carbon (PAC), 262, 265, 418
 Powders, 118–120
 Power, 513–514
 Power distribution transformers, 545
 Power factor (PF), 514
 Power requirements, 514
 Power tools, 77–79
 PPE. *See* Personal protective equipment (PPE)
 Precautionary statements, 701
 Precipitation, 140
 Precipitative softening, 409, 416–417
 Precision, 452
 Predictive maintenance, 506
 Presedimentation, 410
 Present worth, 666
 Pressure filters, 412
 Pressure, force and, 760–765
 Pressure measurements, 465–467
 Pressure vessels
 housings, 373
 submerged flow, 339–340
 Pressure pumps, 772–773
 Pressurization pump, 371–372
 Pretreatment for reverse osmosis (RO)
 microbiological organisms, 378–379
 other potential scalants, 378
 pH and temperature control, 378
 removal of turbidity and suspended solids, 377
 requirements, 377
 Preventive maintenance
 belt drives, 574–575
 chain drives, 575–577
 couplings, 579
 definition, 506
 electric motors, 573–574
 progressive cavity pumps, 572–573
 propeller pumps, 572
 pump controls, 573
 pumps, general, 566–570
 reciprocating pumps, 570–572
 records, 507–508
 shear pins, 579–581
 troubleshooting, 581–584
 variable-speed belt drives, 576–579
- Primacy, 7
- Primary contaminants, 3
- Primary Drinking Water Regulations, 47
- Primary drinking water standards
 disinfectants and disinfection byproducts, 42–44
 inorganic chemical standards
 antimony, 12
 arsenic, 12–13
 asbestos, 13
 barium, 14
 beryllium, 14
 bromate, 14
 cadmium, 14
 chlorite, 14
 chromium, 14–15
 copper, 15
 fluoride, 15
 lead, 15–16
 MCLGs, 7, 13
 MCLs, 7, 13
 nitrate, 16
 nitrite, 16
 selenium, 16
 thallium, 16–17
 microbial standards
 Revised Total Coliform Rule (RTCR), 21–22
 Surface Water Treatment Rule (SWTR), 22–28
 Total Coliform Rule (TCR), 21
 organic chemical standards
 benzene, 17–18
 carbon tetrachloride, 18
 1,2-dichloroethane, 18
 1,1-dichloroethylene, 18–19
 para-dichlorobenzene, 19
 1,1,1-trichloroethane, 19
 trichloroethylene (TCE), 19
 vinyl chloride, 19–20
 radiological standards, 44–45
- Primary elements, 465, 480
- Prime, 557
- Process instrumentation, 478–479
- Process variable, 452
- Process wastes
 contaminants removed, regulation, 402–404
 handling and disposal
 chemical precipitation, 439
 disposal practices, 440–444

- Process wastes (*continued*)
- draining and cleaning tanks, 428–430
 - environmental impacts, 444–445
 - monitoring and reporting, 445
 - process sludge volumes, 424–428
 - sludge dewatering processes, 432–439
 - thickening process, 431–432
- mechanical treatment
- activated carbon, 418
 - coagulation, 411–412
 - disinfection, 419
 - filtration, 412–416
 - flocculation, 411–412
 - ion exchange, 417–418
 - organic matter and oxygen, 421
 - precipitative softening, 416–417
 - presedimentation, 410
 - sedimentation, 411–412
- other chemical additions
- corrosion and scale control, 420
 - pH adjustment, 420
 - solids removal using sequestering agents, 420
 - water additives, 420–421
- other pollutants in water treatment plants
- chloride, 422
 - nitrogen, 422
 - pH, 422
 - phosphorus, 422
 - radionuclides, 422
- source water pollution prevention, 404–406
- wastes produced by source water treatment, 407–409
- Programmable logic controller (PLC), 491
- Progressive cavity pumps, 572–573
- Propeller pumps, 572
- Protective safety gear, 62
- Prussian blue, 589
- Public information programs, 725
- Publicly owned treatment works (POTW), 403
- Public relations
- being interviewed, 658
 - consumer inquiries, 659–660
 - establish objectives, 657
 - mass media, 657–658
 - plant tours, 660
 - public speaking, 658
 - telephone contacts, 659
 - utility operations, 657
- Public safety, 2
- Public water systems (PWSs)
- Community water system (CWS), 3
 - Disinfectants and Disinfection Byproducts Rules (DBPRs), 250
 - drinking water regulations, 2
 - human consumption, 3
 - Non-transient non-community water system (NTNCWS), 3
 - Transient non-community water system (TNCWS), 3
- Pump
- calculating performance, 772–790
 - characteristics, 780–782
 - friction/energy losses, 787–790
 - head, 778–780
 - horsepower, 774–778
 - performance evaluation, 782–786
 - power, 774
 - pressure, 772–773
 - speed–performance relationships, 786–787
 - work, 773
 - centrifugal, 552–558
 - controllers, 485–487
 - controls, 573
 - driving equipment, 565
 - electrical controls, 566
 - lubrication, 551
 - positive-displacement, 558–560
 - progressive cavity, 572–573
 - propeller, 572
 - reciprocating, 570–572
 - safety
 - definitions of, 124
 - enclosed guards, 124, 125
 - maintenance and repair, 125
 - shutdown, 564–565
 - starting, 561–563
 - troubleshooting, 582–584
- PWSs. *See* Public water systems (PWSs)
- Q**
- Qualification profile, of staff, 632–633
- Quicklime, 107–108, 150
- R**
- Radiological contaminants, 3
- Radiological standards, 44–45
- Radionuclides Rule, 44–45
- Range, 452, 796
- Rapid sand filters, 412
- Raw water pump station, 346
- Raw water source, 346
- Reaction basin, 222
- Readouts, 453
- Recarbonation, 152
- Receiver, 469
- Reciprocating pumps, 570–572
- Recorders, 481–483
- Recordkeeping
- computer systems, 720
 - electrical equipment, 545–547
 - essential records, 716–717
 - maintenance
 - equipment, 720
 - inventory, 718–719
 - procurement, 718, 719
 - management, 716–721
- plant operations data, 717–718
- retaining utility records, 720–721
- softening, 194
- types, 716
- uses, 717
- Rectangle, 747–748
- Rectangular prism, 753–754
- Red water complaints, 234–235
- Reference, 453
- Regression analysis, 814–820
- Regulated contaminants, 4–5
- Regulatory compliance
- Stage 1 regulatory requirements, 251–253
 - Stage 2 regulatory requirements, 253
- Remedial action, iron and manganese
- aeration oxidation, 221–224
 - alternate source, 214
 - chlorine oxidation, 224–225
 - electromedia processes, 231–234
 - ion exchange removal, 221
 - operating filters, 231
 - permanganate oxidation, 225–231
 - phosphate treatment, 214–220
- Remote terminal unit (RTU), 491
- Representative sample, 257, 791
- Resistance, 512
- Responsibility, 627, 630
- Reverse osmosis (RO)
- chemical safety, 357
 - cleaning connections, 373
 - components of, 371–376
 - concentrate control valve, 373
 - definition, 336
 - electrical safety, 357
 - energy recovery devices, 374
 - flush connections, 373
 - flux, 359–360
 - hollow fiber module, 376
 - hydraulic safety, 357
 - membrane cleaning, 374, 383–384
 - mineral rejection, 361–364
 - performance and properties, 364–367
 - permeate drawback tank, 373–374
 - permeate rinse, 373
 - piping, 372
 - plant operation, 379–383
 - pressure vessel housings, 373
 - pressurization pump, 371–372
 - pretreatment, 376–379
 - recovery, 367–370
 - sample valves, 373
 - spiral-wound module, 375
 - structure and composition, 357–359
- Revised Total Coliform Rule (RTCR), 21
- Rotameters, 472
- Rotor, 528
- S**
- Sacrificial anodes, 617
- Safe Drinking Water Act (SDWA), 2, 4, 254, 404

- Safety
- accident prevention, for operator
 - noise exposure, 63–66
 - personal protective equipment, 61–63
 - respiratory protection, 60–61
 - training program, 66–68
 - devices, in electrical equipment
 - circuit breakers, 524–525
 - fuses, 524
 - motor starters, 526–528
 - overload relays, 525–526
 - distribution system (*See* Distribution system safety)
 - electrical equipment
 - avoiding electric shock, 85–87
 - control panels, 90
 - current and voltage, 85
 - electric motors, 89
 - electric starters, 89
 - emergency procedures, 88
 - instrumentation, 90
 - lockout/tagout procedure, 90–92
 - safe practices, 85
 - transformers, 88
 - electrical safety checklist, 511
 - electrodialysis (ED), 390–391
 - facility maintenance
 - cleaning, 70–71
 - confined spaces, 73–77
 - crane operation, 72
 - explosive gas mixtures, 72–73
 - painting, 71
 - power tools, 77–78
 - safety valves, 80
 - welding, 78, 80
 - fluoridation
 - avoid overexposure, 277
 - first aid, 278
 - fluoride poisoning, 278
 - protecting yourself and your family, 279
 - training, 279
 - instrumentation and control systems
 - electrical hazards, 459–460
 - mechanical and pneumatic hazards, 460–462
 - management program
 - confined space entry procedures, 705–706
 - effectiveness, 690
 - first aid, 694–695
 - Hazard Communication Standard, 695–705
 - human factors engineering, 715–716
 - managers, 691–693
 - measuring, 712–715
 - operators, 694
 - regulatory agencies, 691
 - reporting, 707–709
 - supervisors, 693–694
 - training, 710–711
 - worker Right-To-Know (RTK) laws, 695–705
 - program
 - confined space entry procedures, 705–706
 - effectiveness, 690
 - first aid, 694–695
 - Hazard Communication Standard, 695–705
 - human factors engineering, 715–716
 - managers, 691–693
 - measuring, 712–715
 - operators, 694
 - regulatory agencies, 691
 - reporting, 707–709
 - supervisors, 693–694
 - training, 710–711
 - worker Right-To-Know (RTK) laws, 695–705
 - protective safety gear, 62
 - pump
 - definitions of, 124
 - enclosed guards, 124, 125
 - maintenance and repair, 125
 - softening, 162–163
 - workplace (*see* workplace safety)
 - Safety data sheet (SDS), 98–101, 351, 695
 - Salinity, 339
 - Salts
 - aluminum sulfate, 117
 - ferric chloride, 117–118
 - ferric sulfate, 118
 - ferrous sulfate, 118
 - sodium aluminate, 118
 - Sample valves, 373
 - Sand drying beds, 433–435
 - Sanitary surveys, 24
 - Saturators
 - definition, 277
 - downflow, 287
 - upflow, 288–289
 - Scale, 453
 - Scatter plots, 798–800
 - Screw press, 439
 - Secondary drinking water standards
 - monitoring, 46–47
 - secondary contaminants
 - aluminum, 47
 - chloride, 47
 - color, 47
 - copper, 48
 - corrosivity, 48
 - fluoride, 48
 - foaming agents, 48
 - iron, 48–49
 - manganese, 48–49
 - odor, 49
 - pH, 50
 - silver, 50
 - sulfate, 50
 - total dissolved solids (TDS), 50–51
 - zinc, 51
 - secondary MCLs (SMCLs), 46
 - Secondary maximum contaminant levels (SMCLs)
 - chloride, 46, 47
 - color, 46, 47
 - copper, 46, 48
 - foaming agents, 46, 48
 - iron, 46, 49
 - manganese, 46, 49
 - odor, 46, 49
 - pH, 46, 50
 - silver, 46, 50
 - TDS, 50–51
 - zinc, 51
 - Sedimentation, 411–412
 - Selection process, of staff
 - advertise a job opening, 633–634
 - interview applicants, 634
 - objectivity, 637
 - OUCH principle, 637
 - paper screening, 634
 - preemployment inquiries, 635–636
 - select qualified candidate, 636
 - Selenium, 16
 - Self-contained breathing apparatus (SCBA), 52, 60, 112, 113
 - Semiliquid residuals, 245
 - Sensitivity, 452
 - Sensor, 465
 - Septic, 443
 - Set point, 455
 - Shear pins, 91, 571, 579–581
 - Sheave, 561
 - Shim, 572
 - SHMP. *See* Sodium hexametaphosphate (SHMP)
 - Short-circuiting, 222
 - Signal transmitters, 479
 - Signal word, 701
 - Single-phase power, 513
 - Single-stage pumps, 558
 - Slaked lime, 150
 - Slips and falls, 127
 - Slow sand filters, 412
 - Sludge dewatering processes
 - centrifuges, 435–437
 - continuous-belt filter presses, 435
 - filter presses, 437
 - sand drying beds, 433–435
 - screw press, 439
 - storage ponds and lagoons, 432–433
 - thermal drying, 439
 - vacuum filter, 437–439
 - Sludges
 - production factors, 426
 - recirculation and disposal, 165–166 and slurries, 440–443
 - Slurries, 440–443
 - Small hydrofluosilicic acid systems, 290–291
 - Small-volume metering pumps, 613–614
 - SMCLs. *See* Secondary maximum contaminant levels (SMCLs)

- Sodium aluminate, 118
 - Sodium carbonate, 109
 - Sodium hexametaphosphate (SHMP), 378
 - Sodium hydroxide, 108–109
 - Sodium polymetaphosphate, 122
 - Sodium silicofluoride, 315–319
 - Softening
 - application, 157
 - caustic soda softening, 161–162
 - chemical reactions
 - calculating chemical dosages, 153–157
 - carbonate hardness removal, 151
 - carbon dioxide removal, 150
 - caustic soda softening, 152–153
 - lime, 150
 - noncarbonate hardness removal, 151
 - stability, 151–152
 - chemistry of
 - alkalinity, 146–149
 - hardness, 142–145
 - pH, 145–146
 - definition, 141–142
 - handling, 157
 - lime–soda ash softening, 161
 - lime softening, 158
 - recordkeeping of, 194
 - safety of, 162–163
 - sludge, 417
 - split lime treatment, 159–161
 - stability of, 163–165
 - storage of lime, 157
 - Span, 452
 - Specific gravity, 110, 314, 756
 - Sphere, 752, 755
 - Spiral-wound reverse osmosis module, 375
 - Split lime treatment, 159–161
 - Split samples, 248
 - Stability, of softening, 163–165
 - Staffing
 - applications, 633–637
 - employment policies and procedures
 - compensation, 638
 - discipline problems, 643–645
 - harassment, 645–649
 - labor laws governing employer/employee relations, 649–650
 - performance evaluation, 640–643
 - personnel records, 650
 - probationary period, 638
 - training and certification, 638–639
 - legislation, legal requirements of, 631
 - new employee orientation, 637
 - qualifications profile, 632–633
 - responsible, 631
 - selection process
 - advertise a job opening, 633–634
 - interview applicants, 634
 - objectivity, 637
 - OUCH principle, 637
 - paper screening, 634
 - preemployment inquiries, 635–636
 - select qualified candidate, 636
 - unions, 651–652
 - workforce analysis, 631–632
 - Standardization, 452
 - Standardized Monitoring Framework (SMF), 7
 - Standards, 452
 - Standby engines
 - generator, 348
 - internal combustion engines, 603–604
 - Standby power generation, 539–541
 - Starting gasoline engines, 598–599
 - Starting pumps, 561–563
 - State revolving fund (SRF) programs, 667
 - Stator, 528
 - Steel tanks, 616–617
 - Stethoscope, 575
 - Storage ponds and lagoons, 432–433
 - Submerged flow, 339–340
 - Subtraction, 735–736
 - Sulfamic acid, 122
 - Sulfur dioxide, 114
 - Sulfuric acid, 106–107
 - Sump, 433
 - Supernatant, 432
 - Supersaturated, 150
 - Supervisory control and data acquisition (SCADA) system, 343, 491, 671–673
 - Surface Water Treatment Rule (SWTR)
 - CT values, 28, 32–38
 - filtered systems, 27
 - filtration and disinfection, 31–32
 - Interim Enhanced Surface Water Treatment Rule (IESWTR), 23
 - log removal efficiency, 31, 32
 - Long Term 1 Enhanced Surface Water Treatment Rule (LT1ESWTR), 23
 - Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR), 25
 - pathogenic organisms, 27
 - turbidity measurements, 23
 - unfiltered surface water systems, 26–27
 - Surfactants, 48
 - Switchgear, 544–545
 - SWTR. *See* Surface Water Treatment Rule (SWTR)
 - Synthetic organic chemical (SOC), 17, 405
 - Synthetic resins, 266
- T**
- Tailgate safety meetings, 67–68
 - Tank coatings, 130–131
 - Tank loss gals, 314
 - Tanks and reservoirs
 - concrete tanks, 617
 - steel tanks, 616–617
 - Temporary hardness, 140. *See also* Carbonate hardness
 - Thallium, 16–17
 - Thermal drying, 439
 - Thickening, sludge, 412
 - THM precursors
 - definition, 254
 - remove, 263–264
 - Three-phase electric motors, 528
 - Threshold odor number (TON), 49
 - Time-weighted average (TWA), 66
 - Titrate, 143
 - Total chlorine residual, 403
 - Total Coliform Rule (TCR), 21
 - Total dissolved solids (TDS)
 - general permits, 403
 - membrane treatment technologies, 336
 - secondary contaminants, 50–51
 - water quality, 241
 - Total dynamic head (TDH), 780
 - Total hardness, 140
 - Totalizers, 483
 - Total organic carbon (TOC), 43, 252, 419
 - Total suspended solids (TSS), 403
 - Tours, of water treatment plants, 660
 - Toxic chemicals, 674
 - Toxic effect, 236
 - Toxic gases, 390
 - Toxic, in lead, 15
 - Toxic level, 179
 - Toxic metals, in water, 409
 - Traffic control zones, 127
 - Traffic hazards, 127–128
 - Transducer, 474
 - Transformers, 88
 - Transient non-community water system (TNCWS), 3
 - Transmission, 544
 - Trapezoid, 749
 - Treated water pump station, 347–348
 - Triangle, 748–749
 - Triangular prism, 754
 - 1,1,1-Trichloroethane, 19
 - Trichloroethylene (TCE), 19
 - Trihalomethanes (THMs)
 - adsorption, 265–266
 - aeration, 264–265
 - biofiltration, 266
 - calculations, 259–261
 - contaminant types, 3
 - definition, 250
 - membrane treatment technologies, 364
 - oxidation, 264
 - remove, 264–266
 - wastes produced by source water treatment, 407
 - Troubleshooting
 - chain drives, 577
 - electric motors, 534–536
 - induction motors, 537–539
 - magnetic starters, 529–531
 - manganese greensand systems, 232
 - membrane damage, 383
 - membrane equipment and process problems, 350
 - pumps, 582–584

Trust for Public Lands (TPL), 406
 TTHM formation potential (TTHMFP), 256
 Turbidity, 3, 404
 Turbidity unit (TU), 24, 377, 425

U

Ultrafiltration (UF), 336
 Ultra-low-flush toilets (ULFTs) replacement programs, 728
 Units, of basic math operations
 circle, 749–750
 concentration, 756–757
 cone, 751–752
 cylinder, 750–751
 density, 756
 distance/length, 746–747
 force and pressure, 760–765
 mass and weight, 755
 rectangle, 747–748
 sphere, 752
 trapezoid, 749
 triangle, 748–749
 velocity and flow rate, 758–760
 volume, 752–755
 work, head, and power, 765–768
 Unregulated Contaminant Monitoring (UCM) program, 5
 Unregulated contaminants, 5–6
 “Unslaked” lime, 150.
 See also Quicklime
 Upflow saturators, 288–289
 Uplift force, 428
 Upper explosive limit (UEL), 72, 463
 Upward flow, 239
 US Environmental Protection Agency (EPA), 2
 Utility management. *See* Management

V

Vacuum filter, 437–439
 Valves
 automatic, 593–597
 butterfly, 592
 check, 592–593
 eccentric, 591
 gate, 586–590
 globe, 590–591
 safety, 80
 Variable frequency drives (VFDs), 532
 Vehicle maintenance, 83–84
 Vehicle operation
 defensive driving, 81–82
 forklifts, 83

Velocity, 758–760
 Venturi meter, 315
 Vinyl chloride, 19–20
 Viscosity, 218, 549
 Volatile compounds, 263
 Volatile organic compounds (VOCs), 17, 405
 Voltage (V)
 definition, 512
 testing, 515–517
 Volt-ohm-milliammeter (VOM), 490
 Volume
 cone, 755
 cube, 753
 cylinder, 754
 rectangular prism, 753–754
 sphere, 755
 triangular prism, 754
 Volumetric feeder, 281, 284

W

Wastewater disposal, 241
 Water and energy conservation, 721–728
 Water extinguishers, 95
 Water flux, 365
 Water hammer, 561
 Water meter totalizer, 315
 Water quality, 241
 Watershed management, 405
 Water storage facilities, safety around
 confined spaces, 131–132
 ladders, 128–130
 slips and falls, 127
 tank coatings, 130–131
 Water treatment facilities, discharge permits, 408–409
 Welding, 78, 80
 Wells, safety around
 safety inspection, 121
 well chemicals, 121–123
 working around electrical units, 123
 Wholesale agency assistance programs, 726–727
 Workplace safety
 accident prevention (*See* Accident prevention, for operator safety)
 chemical handling
 acids, 101, 103–107
 bases, 107–109
 chemical storage drains, 120
 gases and vapors, 110–116
 hazard communication program, 101, 102
 labeling on sulfuric acid container, 98
 powders, 118–120
 safety data sheet (SDS), 98–101

 salts, 116–118
 training, 101
 distribution system safety
 (*see* Distribution system safety)
 electrical equipment safety
 avoiding electric shock, 85–87
 control panels, 90
 current and voltage, 85
 electric motors, 89
 electric starters, 89
 emergency procedures, 88
 instrumentation, 90
 lockout/tagout procedure, 90–92
 safe practices, 85
 transformers, 88
 emergency preparedness and response, 68–69
 facility maintenance safety
 cleaning, 70–71
 confined spaces, 73–77
 crane operation, 72
 explosive gas mixtures, 72–73
 painting, 71
 power tools, 77–78
 safety valves, 80
 welding, 78, 80
 fire prevention and protection
 extinguishers classification of, 93–96
 fire exits, 97
 plan, 93
 storage of flammables, 96
 management’s responsibilities, 52
 safety around water-filled structures, 69–70
 safety program
 emergency plans, 58
 hazards, types of, 54–56
 operator, 53–54
 reporting incidents, 56–58
 utilities, 53
 vehicle maintenance, 83–84
 vehicle operation
 defensive driving, 81–82
 forklifts, 83
 Work zones, 127–128
 Written communication, 653–655

Z

Zeolites
 fluoridation, 286
 potassium permanganate, 225
 process waste generation, 417
 sodium ion exchangers, 171
 Zinc, 51