Contents

List of Figures xvii
List of Tables xxi
Preface xxxiii

Chapter 1 Introduction 1
1.0 OVERVIEW 1
2.0 GUIDE TO THE MANUAL 2

Chapter 2 Station Capacity 5
1.0 SANITARY WASTEWATER FLOW 6
1.1 Engineering Report 6
1.2 Design Life 7
1.3 Population Growth Projection 7
1.4 Land Development 9
1.5 Quantity of Available Water 9
1.6 Quantity of Wastewater Flow 9
1.7 Additional Contributors 10
1.7.1 Commercial 10
1.7.2 Industrial 11
1.7.3 Institutional 11
1.7.4 Infiltration and Inflow 11
1.8 Peak Hourly Wastewater Flowrate 12
2.0 STORMWATER FLOWS 15
2.1 Inflow Hydrograph 16
2.2 Methods of Developing Inflow Hydrographs 16
2.2.1 Rational Method 16
2.2.2 Curve Number Method (Natural Resources Conservation Service Method) 24
2.2.2.1 Rainfall 24
2.2.2.2 Runoff Volume Parameters 24
2.2.2.3 Time Parameters 25

2.2.2.4 *Determination of Runoff Volume* 2
2.2.2.5 *Time of Concentration, Travel Time, and Lag* 2
2.2.2.6 *Peak Discharge* 2
2.2.3 *Computerized Runoff Models* 2
2.2.3.1 *Planning Models* 2
2.2.3.2 *Design Models* 2
2.2.3.3 *Operational Models* 2
2.2.3.4 *Sensitivity Analysis* 2
3.0 COMBINED FLOW SYSTEMS 2
4.0 FLOW REGULATION 2
5.0 QUALITY OF INFLUENT 2
6.0 REFERENCES 3

Chapter 3 Station Configuration and Design 33
1.0 LOCATION CONSIDERATIONS 34
2.0 STATION TYPES 36
2.1 Ranges of Flow 36
2.2 Vertical Pumps 45
2.3 Submersible Pumps 45
2.4 Centrifugal Pumps 46
2.5 Horizontal Pumps 46
3.0 WET WELL CONSIDERATIONS 46
4.0 AESTHETIC AND SAFETY CONSIDERATIONS 49
5.0 ARCHITECTURAL DESIGN CONSIDERATIONS 50
6.0 STRUCTURAL DESIGN CONSIDERATIONS 51
7.0 REFERENCE 53
8.0 SUGGESTED READINGS 53

Chapter 4 Pumping Systems 55
1.0 WASTEWATER AND STORMWATER PUMPING STATIONS 56
2.0 PUMPING SYSTEM HYDRAULICS AND DEFINITIONS 58
2.1 Capacity 59
2.2 Head 59
2.3 Pump Efficiency and Power Requirements 61

3.0 PUMPS 62
4.0 CENTRIFUGAL PUMPS 62
4.1 Pump Classification 63
4.2 Impellers 67
4.3 Pump Characteristic Curves 67
4.4 Cavitation and Net Positive Suction Head 69
4.5 Pump Operating Range 72
4.6 Affinity Laws 73
4.7 Pump Construction 76
4.7.1 Radial-Flow Volute Pumps 76
4.7.2 Axial-Flow Column Pumps 83
4.7.3 Construction Materials 84
5.0 POSITIVE DISPLACEMENT PUMPS 85
5.1 Archimedes Screw Pumps 85
5.2 Pneumatic Ejectors 88
5.3 Airlift Pumps 89
5.4 Progressive Cavity Pumps 89
6.0 FORCE MAINS 89
7.0 WET WELLS 90
8.0 PUMP DRIVES 90
8.1 Electric Motors 91
8.2 Variable-Speed Motor Operation 93
8.2.1 Variable-Frequency Drive. 93
8.2.2 Wound-Rotor Motor Variable Speed 94
8.2.3 Variable-Voltage Motors 95
8.2.4 Variable-Speed Clutches 95
8.3 Internal Combustion Engines 95
9.0 PUMP SELECTION 98
9.1 System Design Considerations 98
9.1.1 Flowrates 98
9.1.2 System Head-Capacity Curve 99
9.1.3 Station Location and Area Served 101
9.1.4 Force Main 101
9.2 Selection Procedure 101
9.2.1 System Head-Capacity Curve Characteristics 101

9.2.2 Preliminary Selection of Pumps 104
9.2.3 Preparation of System Curves 105
9.2.4 Analyzing System Curves 106
10.0 EXAMPLES OF PUMP SELECTION 106
10.1 High Friction Head System 106
10.1.1 On–Off Operation of Single Speed Pumps 107
10.1.2 Two-Speed Operation of Pumps 107
10.1.3 Variable-Capacity Operation of Pumps 109
10.1.4 Power Consumption 109
10.2 High Static Head System 110
10.2.1 On–Off Operation of Constant Speed Pumps 115
10.2.2 Two-Speed Operation of Pumps 115
10.2.3 Variable-Speed Operation of Pumps 116
10.2.4 Power Consumption 116
10.3 Large Pumping Station System 117
11.0 SPECIFYING PUMP PERFORMANCE 120
12.0 REFERENCE 121
13.0 SUGGESTED READINGS 121

Chapter 5 Piping Systems 123
1.0 GENERAL DESIGN CRITERIA 124
1.1 Piping 124
1.2 Valves 125
1.3 Maintenance 126
1.4 Force Mains 126
2.0 FLUID FLOW FUNDAMENTALS 128
2.1 System Curve 129
2.2 Equations 130
2.3 Pipe Flow Parameters 131
2.4 Pipe-Fitting Parameters 132
2.5 Station Piping 135
2.6 Discharge Line Piping 136
3.0 WATER HAMMER AND SURGE 137
3.1 Surge Pressure Limits 138

3.2 Checklist for Surge Problems 138
3.3 Rigid Water Column Theory 140
3.4 Pressure Wave Velocity 145
3.5 Negative Surge Pressure 146
3.6 Operational Changes to Reduce Water Hammer by Design 146
3.7 Surge Attenuating Devices 147
3.8 Closing Check Valve or Pump Control Valve 147
3.9 Combination Air Vent and Vacuum Break Valves 149
3.10 Pressure Surge Relief Valves 150
3.11 Surge Accumulator Tanks 151
3.12 Surge Towers 152
3.13 Bypass Check Valves 152
3.14 Pump Flywheels 153
3.15 Surge Analysis Software 153
4.0 PIPING MATERIAL AND FITTINGS 156
4.1 Pipe Joints and Connections 156
4.2 Pipe Supports for Static Loads 157
4.3 Pipe Supports for Dynamic Loads 157
5.0 VALVES 160
5.1 Valve Types 160
5.2 Valve Actuation 163
5.3 Valve Applications 164
6.0 FLOW METERS 164
7.0 REFERENCES 164
8.0 SUGGESTED READINGS 165

Chapter 6 Electrical Design 167
1.0 RELIABILITY AND REDUNDANCY 168
2.0 VOLTAGE CONSIDERATIONS 169
3.0 SUBSTATIONS 171
4.0 TRANSFORMERS 172
5.0 SWITCHGEAR 173
6.0 CONDUIT AND WIRE 176

7.0 LIGHTNING PROTECTION 177
8.0 STANDBY POWER 178
9.0 ADJUSTABLE-SPEED DRIVES 180
9.1 Matching Variable-Frequency Drives and Motors 180
9.2 Variable-Frequency Drive Interfaces 181
9.3 Some Problems With Variable-Frequency Drives 182
10.0 POWER FACTOR 182
11.0 ARC FLASH HAZARD ANALYSIS 183
12.0 REFERENCES 183
13.0 SUGGESTED READINGS 185

Chapter 7 Instrumentation and Control Systems 187
1.0 PROCESS AND INSTRUMENTATION DIAGRAMS 188
2.0 LEVEL MEASUREMENT 190
2.1 Float Switches 190
2.2 Bubbler Systems 191
2.3 Ultrasonic Sensors 192
2.4 Radar Level Sensors 193
2.5 Submersible Level Sensors 195
3.0 FLOW MEASUREMENT 196
3.1 Magnetic Flow Meters 197
3.2 Ultrasonic Flow Meters 200
3.3 Differential Producers 200
3.4 Open Channel Flow Meters—Primary Devices 201
3.5 Open Channel Flow Meters—Secondary Devices 203
3.6 Open Channel Flow Meters—Accuracy 205
3.7 Ancillary Flow Meters 210
4.0 PRESSURE MEASUREMENT 210
5.0 ALARMS AND INDICATION 211
5.1 Alarm 211
5.2 Equipment Status Indication 212
5.3 Process Variable Indication 213
6.0 OPERATOR INTERFACES 214

6.1 Control Panels 217
6.2 Ancillary Instrumentation 219
7.0 CONTROL SYSTEMS 220
7.1 Conventional Control Relays 220
7.2 Programmable Logic Controllers 220
7.3 Single-Loop Digital Controllers and Other Devices 221
8.0 CONTROL ALGORITHMS 222
8.1 All Constant-Speed Pumps 223
8.2 All Variable-Speed Pumps 223
8.3 Combination of Constant- and Variable-Speed Pumps 224
8.4 Alternation 227
8.5 Abnormal Operating Conditions 228
9.0 VARIABLE-SPEED DRIVES 229
10.0 MISCELLANEOUS 230
10.1 Installation 230
10.2 Seal Water 231
10.3 Surge Suppression 232
10.4 Contract Document Coordination 232
10.5 Training and Maintenance 233
11.0 TELEMETRY SYSTEMS 233
11.1 User Needs 234
11.2 System Types 234
11.3 Supervisory Control and Data Acquisition Systems 236
11.4 Communication Links 237
11.5 Remote Terminal Units 240
12.0 RELIABILITY 241
12.1 Level Sensing Elements 241
12.2 Control Hardware and Algorithms 241
12.3 Control Power 242
12.4 Pumps and Drives 242
13.0 TESTING 242
14.0 REFERENCES 244
15.0 SUGGESTED READINGS 245

Chapter 8 Appurtenances 247
1.0 SCREENING 248
1.1 Types of Screens 249
1.1.1 Trash Racks 249
1.1.2 Manually Cleaned Screens 249
1.1.3 Basket Screens 251
1.1.4 Mechanically Cleaned Screens 252
1.1.4.1 Multi-Rake, Chain-Driven Screens 252
1.1.4.2 Reciprocating Rake Screens 254
1.1.4.3 Catenary Screens 254
1.1.4.4 Continuous Self-Cleaning Screens 257
1.1.4.5 Overhead Trash Rakes 258
1.1.5 Comminutors or Grinders 258
1.2 Screenings 259
1.2.1 Quantities of Screenings 259
1.2.2 Characteristics of Screenings 260
1.2.3 Handling of Screenings 260
1.2.4 Design Practice 262
1.2.5 Installation 262
1.2.6 Design 263
1.2.7 Instrumentation 264
1.2.8 Hydraulics 264
1.2.9 Grit Removal 266
2.0 ODOR CONTROL 266
2.1 Nature and Origins of Odor 266
2.2 Odor Control Practices 268
2.2.1 Pumping Station Design and Operation 268
2.2.2 Odor Prevention 270
2.2.2.1 Flushing/Pigging 270
2.2.2.2 Air/Oxygen Injection 270
2.2.2.3 Chemical Addition 272
2.2.2.3.1 Chlorination 273
2.2.2.3.2 Hydrogen Peroxide 273

2.2.2.3.3 *Potassium Permanganate* 274
2.2.2.3.4 *pH Adjustment* 274
2.2.2.3.5 *Metal Salts* 275
2.2.3 *Odor Treatment* 275
2.2.3.1 *Wet Chemical Scrubbing* 275
2.2.3.2 *Activated Carbon Adsorption* 276
2.2.3.3 *Dry Chemical Scrubbers* 277
2.2.3.4 *Ozone* 277
2.2.3.5 *Organic Media Biofilters* 277
2.2.3.6 *Biotrickling Filters* 278
2.2.3.7 *Odor Modification, Counteraction, and Masking* 279
3.0 NOISE CONTROL 280
3.1 Noise Characteristics and Sources 280
3.2 Applicable Codes 280
3.3 Noise Reduction Measures 281
4.0 BUILDING SERVICES 281
4.1 Heating, Ventilating and Cooling 281
4.1.1 *Codes and Standards* 282
4.1.2 *Cooling Systems* 282
4.1.3 *Ventilation Systems* 283
4.1.4 *Heating Systems* 283
4.1.5 *Wet Wells* 283
4.1.6 *Dry Wells* 284
4.2 Electrical Design 284
4.3 Plumbing Design 285
4.3.1 *Water Supply* 285
4.3.2 *Interior Sanitary Drainage* 287
4.4 Site Storm Drainage 288
4.5 Utilities 288
4.5.1 *Electric Utility* 288
4.5.2 *Telephone Utility* 289
4.5.3 *Gas Company* 289

5.0 OTHER APPURTENANCES 289
5.1 Hoists 289
5.2 Safety Features 290
6.0 REFERENCES 293
7.0 SUGGESTED READINGS 293

Index 295