

Analysis of Woodlands Village's Wastewater Treatment Facility and Why O&M Manuals for WWTFs Rarely Meet Operators' Needs

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DUST-COVERED OPERATIONS AND MAINTENANCE MANUALS:

Why O&M Manuals for Wastewater Treatment Facilities Rarely
Meet Operators' Needs

By
Abbegail Nack

Abstract

Operation and maintenance (O&M) manuals are crucial to the safe and economical operation of wastewater treatment facilities, but often do not meet operators' needs because they are inaccurate, overly general, highly technical, and poorly organized. Unfortunately, guidance on preparing O&M manuals from the Massachusetts Department of Environmental Protection (MassDEP) fails to address many of the problems common to O&M manuals. This report examines why many O&M manuals are inadequate and proposes revisions to MassDEP's guidance document that address these issues.

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Table of Contents

Abstract.....	i
Acknowledgements.....	ii
Table of Contents.....	iii
List of Figures.....	iv
List of Tables.....	v
1 Introduction.....	1
2 Overview of Operations and Maintenance Manuals.....	3
2.1 What are Operations and Maintenance Manuals?.....	3
2.2 What Information do O&M Manuals Contain?.....	4
2.3 Who Writes and Uses O&M Manuals?.....	7
2.3.1 Authors: Engineering Consultants.....	7
2.3.2 Multiple Audiences.....	8
3 Why O&M Manuals Rarely Meet Operators' Needs.....	12
3.1 Dust-Covered O&M Manuals.....	12
3.2 Infrequently Used, but Still Important.....	13
3.3 Common Deficiencies of O&M Manuals.....	14
3.3.1 Accuracy of Content: Current vs. Outdated.....	15
3.3.2 Level of Detail: Site-Specific vs. Overly General.....	17
3.3.3 Organization: Well Organized vs. Disorganized.....	22
3.3.4 Style & Diction: Layman's Terms vs. Engineering Jargon.....	25
4 Improving MassDEP's O&M Manual Guidance.....	32
4.1 Insufficient MassDEP O&M Manual Guidance.....	32
4.2 Review of Other O&M Manual Guidance.....	34
4.2.1 O&M Manual Guidance from Environmental Protection Agency.....	34
4.2.2 O&M Manual Guidance from Other State's Environmental Regulatory Agencies.....	38
4.2.3 O&M Manual Guidance from Other Sources.....	43
4.3 Revision of MassDEP O&M Manual Guidelines.....	44
4.3.1 Acknowledging the Pressures of Multiple Audiences.....	44
4.3.2 Establishing the Importance of O&M Manuals.....	46
4.3.3 Providing Writing Advice.....	47
4.3.4 Integrating of Writing Advice Throughout Guidelines.....	50
4.3.5 Discussion the Advantages of Electronic O&M Manuals.....	54
5 Conclusion.....	55
References.....	57

List of Figures

Figure 1: Authors and Audiences of O&M Manuals	7
Figure 2: Reasons for Common Deficiencies Found in O&M Manuals	15
Figure 3: Excerpt from Woodlands Village's 1999 O&M Manual	18
Figure 4: Excerpt from Woodlands Village's Revised 2016 O&M Manual.....	19
Figure 5: Proper Revision of O&M Manuals Made Using Templates	22
Figure 6: Comparison of Poorly Organized and Well Organized Tables of Content	24
Figure 7: Excerpt from Sawyer Hill's O&M Manual at an 8 th Grade Reading Level	29
Figure 8: Excerpt from Sawyer Hill's O&M Manual at a College Reading Level	30
Figure 9: Example Provided in EPA's O&M Manual Guidance.....	36
Figure 10: Discussion of Level of Detail and Purpose in EPA's O&M Manual Guidance	37
Figure 11: Discussion of Timeliness and Organization in New Jersey's O&M Manual Guidance	39
Figure 12: An In-Depth Overview of O&M Manuals.....	45
Figure 13: Discussion of Multiple Audiences	46
Figure 14: The Importance of O&M Manuals.....	47
Figure 15: General Writing Advice	47
Figure 16: Advice on Accuracy and Relevance of Content	48
Figure 17: Advice on Level of Detail.....	49
Figure 18: Advice on Organization	49
Figure 19: Advice on Language & Style.....	50
Figure 20: Original Description of Operation and Control of WWTFs	51
Figure 21: Revised Description of Operation and Control of WWTFs	53
Figure 22: Discussion of the Advantages of Electronic O&M Manuals.....	54

List of Tables

Table 1: MassDEP Guidance on the Content and Purpose of Each Section in an O&M Manual.....	5
Table 2: Flesch Reading Ease Scores	26
Table 3: Seven Popular Readability Tests	27
Table 4: Comparison of O&M Manual, Operator Training Manual, and College Text Readability	28
Table 5: Writing Advice Provided in MassDEP's O&M Manual Guidelines.....	33
Table 6: Writing Advice Provided in Minnesota's O&M Manual Guidance.....	40
Table 7: Writing Advice Provided in Tennessee's O&M Manual Guidance.....	41
Table 8: Writing Advice Provided in Oregon's O&M Manual Guidance	41
Table 9: Writing Advice Contained in New Jersey's O&M Manual Guidance.....	42
Table 10: Writing Advice Provided in Virginia's O&M Manual Guidance.....	42
Table 11: Writing Advice about O&M Manuals Provided in MOP 11.....	44

1 Introduction

Imagine this scenario: A retirement community hires a new third-party operating company to run their small wastewater treatment facility. Since much of the facility is underground (the norm with many treatment facilities), the new operator cannot see a substantial portion of the system's innerworkings. On his first day, the operator quickly flips through the system's operations and maintenance (O&M) manual. Since he has worked on a similar system before, he assumes that he knows how to operate this treatment facility. However, he does not know that a pipe leaving the bioreactor contains a filter, which must be cleaned monthly to prevent it from clogging. Even if he had read through the O&M manual more carefully, there was no mention of the filter. This is because the manual was written for the original treatment system nearly 20 years ago, and has not been updated since the filter was installed.

Six months after the new operating company takes over, an engineer from the Massachusetts Department of Environmental Protection (MassDEP) inspects the facility. The engineer discovers that due to the clogged filter, wastewater has bypassed the treatment system and is spilling over into a nearby wetland. The wetland is adjacent to a public water supply. As a result, the operating company and owner of the treatment facility are fined thousands of dollars for endangering a public drinking water supply, contaminating wetlands, and violating the conditions of their operating permit.

Although infrequent, environmental disasters like the hypothetical scenario described above do occur. I witnessed a similar situation – though one far less severe – while working with a team to analyze the wastewater treatment system serving Woodlands Village at Hickory Hills Lake condominium, a 46-unit lakeside community. In 2013, an inspector from MassDEP discovered that wastewater was ponding on top of the facility's trickling filters because a cap on one of the filter's inspection ports had fallen off, allowing wastewater to escape from the filter (R. Kimball, personal communication, June 4, 2013; Waste Water Environmental Management, personal communication, June 10, 2014). The facility's operator at the time did not know that the inspection ports existed. During the inspection, the facility's O&M manual could not be found onsite. When the manual was found, MassDEP required Woodlands Village to rewrite their O&M manual because it had not been updated since 1999 (R. Kimball, personal communication, June 4, 2013). There was no mention of the inspection ports in the 1999 version of Woodlands Village's O&M manual. For allowing waste to bypass the treatment system and for failing to maintain a current O&M manual at the facility, MassDEP fined the condominium \$2,000 (Executive Office of Energy and Environmental Affairs, 2013). Fortunately, the breakout of wastewater at Woodlands Village was confined and did not pose a significant environmental threat.

In such situations, had the O&M manual adequately described the treatment process and maintenance procedures, a serious public health and environmental hazard could have been avoided. This illustrates that O&M manuals are a crucial tool for the safe and economical operation of wastewater treatment facilities, especially during staff turnover and equipment malfunctions. The Massachusetts Department of Environmental Protection (MassDEP) believes that O&M manuals are so critical to the successful operation of wastewater treatment facilities that the state's environmental regulations require facilities to "prepare, adopt, and keep current an operation and maintenance manual" (314 CMR 12.04 (1)). Unfortunately, many O&M manuals sit on a shelf at the treatment facility, collecting dust. In some instances, a facility's operations and maintenance manual is not even located on the premises. This

report examines why such seemingly important documents go unused by domestic wastewater treatment plant operators in Massachusetts.

To understand why operations and maintenance manuals rarely meet operators' needs, I interviewed design engineers who write O&M manuals, operators who use (or at least should use) the manuals, owners of a wastewater treatment facility, and an employee at the MassDEP who reviews O&M manuals. These first-hand accounts were necessary because limited literature is available on the genre of operations and maintenance manuals, especially those written for wastewater treatment facilities (WWTFs). From these conversations, I discovered that the common deficiencies of O&M manuals do not result from any single cause, but from a complex web of constraints and challenges imposed on authors such as budgets, regulations, and pressures exerted from multiple audiences.

Some guidance to assist authors as they write O&M manuals has been published by a few individuals, state environmental agencies, and the EPA. However, the only guidance that pertains to O&M manuals for WWTFs in Massachusetts (other than the state's regulations themselves) is a nine-page section within MassDEP's *Guidelines for the Design, Construction, Operation, and Maintenance of Small Wastewater Treatment Facilities with Land Disposal*. Unfortunately, this guidance largely fails to help authors negotiate problems common to O&M manuals. Based on my interviews and analysis of other guidance on O&M manuals, I revised MassDEP's guidelines to help authors write more useful O&M manuals, which could help prevent predicaments like the scenarios described above.

2 Overview of Operations and Maintenance Manuals

2.1 What are Operations and Maintenance Manuals?

In the most general sense, operations and maintenance (O&M) manuals are written documents that contain all of the information required to run, maintain, and repair a facility, process, or piece of equipment. However, O&M manuals created by manufacturers for individual pieces of equipment differ significantly from those written for entire facilities that operate as an integrated system (Tidwell, 2000). As a result, this paper will focus (most broadly) on operations and maintenance manuals for facilities such as drinking water and wastewater treatment plants. These treatment facilities are complex operations involving several different processes and hundreds of equipment pieces.

For all treatment facilities, the purpose of the O&M manual is to provide the facility's operator(s) with "the proper understanding of recommended operating techniques and procedures" (MassDEP Division of Watershed Permitting, 2014). The manual must also contain all of the reference material required to efficiently and economically operate and maintain the facility's collection, treatment, and disposal/distribution systems in accordance with all applicable laws, operating permits, and regulations (Santos, 2016; MassDEP Division of Watershed Permitting, 2014).

The successful operation of drinking and wastewater treatment plants is paramount to the protection of public health and the environment; improper operation can lead to the contamination of drinking water supplies, outbreak of disease, or a shortage of potable water. Therefore, it is essential that these facilities have the tools necessary for continuous and successful operation. According to Tidwell (2000), an O&M manual is "one of the most fundamental tools a utility has for day-to-day decision making" (p. vii). The sentiment is also held by several environmental regulatory agencies. For example, the Massachusetts Department of Environmental Protection (MassDEP) believes that O&M Manuals are critical to the successful operation of wastewater treatment facilities. Consequently, MassDEP's Division of Water Pollution Control mandates that persons operating wastewater treatment facilities must "prepare, adopt, and keep current an operation and maintenance manual" (314 CMR 12.04 (1)). A hard copy of this manual must be kept at treatment facility at all times (MassDEP Division of Watershed Permitting, 2014).

To a small extent, the regulations set forth by each states' environmental regulatory agency dictate the content and the organization of O&M manuals for wastewater treatment facilities. Due to the particular nature of these regulations and to narrow the scope of this paper, this discussion will be limited to operations and maintenance manuals written for wastewater treatment facilities in Massachusetts.

The Massachusetts Department of Environmental Protection broadly defines the operations and maintenance manual as "all information needed by the operator of the treatment works to properly operate and maintain said treatment works in accordance with the requirements of 314 CMR 12.00" (314 CMR 12.04). In 314 CMR 5.10 (1), the O&M manual is further described as a plan of "how the permittee intends to operate, maintain, and staff the facility" pursuant to the facility's permit and applicable regulations.

According to consulting engineer Tim Santos of Holmes & McGrath, an O&M manual for a wastewater treatment facility serves as “guidance for the continuing and economical operation and maintenance” of a wastewater treatment facility (Santos, 2016). As Santos writes in the revised 2016 O&M manual for Woodlands Village condominium, O&M manuals are “intended to serve as a training manual for the inexperienced operator or operators unfamiliar with RUCK CFT technology operation and functions” (p. 1). While the MassDEP defines the manual as containing all of the information required to operate a treatment facility, Santos hedges that the O&M manual “is not intended to be the single source of information regarding the operation and maintenance of this facility” (Santos, 2016, p. 1).

2.2 What Information do O&M Manuals Contain?

O&M manuals should include all of the information that an operator needs to “properly operate and maintain the collection, treatment, and disposal systems” (MassDEP Division of Watershed Permitting, 2014). This includes a description of the facility; a discussion of the wastewater’s characteristics; an overview and description of all of the processes at the facility; and procedures for start-up, shutdown, day-to-day, and emergency operations. A preventative maintenance program should be incorporated into the manual “to ensure that all equipment is kept in reliable condition” (314 CMR 5.10 (8)(j)1). Recordkeeping techniques are also included because tracking and reviewing historical records can help operators identify common equipment failures and prevent future malfunctions or injury (Santos, 2016). Additionally, the manual ought to include important contact information, such as the phone number for the local fire department, police station, poison control center, Regional Office of MassDEP, and Board of Health. The manual should also contain all of the system’s design specifications and manufacturer’s manuals for each piece of equipment in case the equipment needs repair or replacement. Lastly, the manual must describe the number, qualifications, and responsibilities of the facility’s staff.

Massachusetts’s environmental regulations mandate that an O&M manual for a wastewater treatment facility contain the following 14 sections (314 CMR 12.04 (1)):

- a) Introduction;
- b) Permits and Standards;
- c) Description, Operation and Control of Wastewater Treatment Facilities;
- d) Description, Operation and Control of Sludge Handling Facilities;
- e) Description, Operation, Control and Testing of the Chemical Addition and Monitoring System;
- f) Personnel;
- g) Sampling and Laboratory Analysis;
- h) Records and Reporting;
- i) Maintenance;
- j) Emergency Operating and Response Program;
- k) Safety;
- l) Utilities and Energy Requirements;
- m) Infiltration and Inflow Removal;
- n) Emergency Notification Procedures for overflows or bypasses in accordance with 314 CMR 12.03(8).

Pursuant to 310 CMR 15.021, the state must provide the owner or operator of wastewater treatment facilities with an operation and maintenance guide. This 157-page document—*Guidelines for the Design, Construction, Operation, and Maintenance of Small Wastewater Treatment Facilities with Land Disposal* (2014)—provides technical guidance for small treatment facilities with a sewage flow between 10,000 and 150,000 gallons per day (GPD) that discharge into the ground. The document also summarizes MassDEP regulations, policies, and standards related to the construction, design, and use of small wastewater treatment facilities in Massachusetts.

Buried within this large document, is a nine-page section, “Operation and Maintenance Plan,” which describes the content that should be found in an O&M manual. Besides the state’s environmental regulations themselves, these nine pages are the only guidance provided by the MassDEP on writing O&M manuals for wastewater treatment facilities. For the remainder of the report, this document will be referred to as “MassDEP’s O&M Manual Guidelines”.

Interestingly, MassDEP’s O&M Manual Guidelines only discuss 11 of the 14 mandated sections of the O&M manual. The following table briefly summarizes the purpose and/or content of each section according to the guidance document (MassDEP Division of Watershed Permitting, 2014).

Table 1: MassDEP Guidance on the Content and Purpose of Each Section in an O&M Manual

	Section	Content/Purpose of Section
a	Introduction	Provides a general description of the facility and its location
b	Permits and Standards	Describes the permit Describes the responsibilities of the owner, operator, and consulting engineer
c	Description, Operation, and Control of Wastewater Treatment Facilities	The “meat” of the O&M manual Gives detailed instructions on how to operate each component of the treatment system in sequential order Includes manufacturer O&M manuals/instructions for all equipment pieces (can be appendices) Provides detailed instruction on chemical storage and handling, standard and optional operating modes, process controls, process testing, and safeguards Includes the name, address, and number of chemical suppliers
d	Description, Operation, and Control of Sludge Handling Facilities	Describes the how solid wastes are handled, stored, and removed and the frequency of sludge removal Includes the name and number of the septage hauler and sludge disposal facility
e	Description, Operation, Control and Testing of the Chemical Addition and Monitoring System	Not described
f	Personnel	Contains the facility’s Staffing Plan, which describes the hours that the facility is staffed, the number and qualifications of the staff, duties of the staff, and emergency operating personnel Includes the Approved Service Contact with a licensed operator

g	Sampling and Laboratory Analysis	Describes all sampling needed to comply with permit conditions Details the frequency and mode of testing Includes sampling, storage, transportation, and analysis protocol
h	Records and Reporting	Lists all recordkeeping and reporting requirements Describes the location of records and method of recordkeeping Describes events that require reporting to MassDEP
i	Maintenance	Contains a spare parts list and itemized list of equipment Includes a list of all maintenance actions and the frequency of those actions
j	Emergency Operating and Response Program	Details what to do in the event of an emergency, including who should be notified and when Includes emergency contact information Describes procedures for following-up emergency situations
k	Safety	Describes how to properly handle materials Provides an itemized list of safety and first aid equipment and instructions for its use Details training requirements of staff Includes all Material Safety Data Sheets (MSDS)
l	Utilities and Energy Requirements	Lists the names and notification requirements for all utilities
m	Infiltration and Inflow Removal	Not described
n	Emergency Notification Procedures for Overflows or Bypasses in Accordance with 314 CMR 12.03(8)	Not described

The guidance provided by the MassDEP is purely content-oriented; the document almost exclusively discusses what information should be contained in each section. There is no discussion of the O&M manual's multiple audiences and purposes. The guidelines also say nothing regarding sentence-style or the technicality of the language that should be used in an O&M manual. There are only three brief mentions about the appropriate level of detail that should be employed, which are found in the "Introduction," "Permits and Standards" and "Description of Operation and Control of Wastewater Treatment Facilities" sections. Lastly, other than dictating the sections that must be addressed and which components can be attached as appendices, there is little guidance on how to structure the O&M manual.

Without extensive guidance on how to write O&M manuals, the authors of these manuals may fail to recognize their target audience's needs, the appropriate level of vocabulary, or the best way to organize the manual, among other things. However, before discussing these issues in greater detail, it is important to first understand who writes O&M manuals, who uses O&M manuals, and how each audience uses the manual.

2.3 Who Writes and Uses O&M Manuals?

Operations and maintenance manuals for wastewater treatment facilities are written by the system's design engineers and are used by three distinct audiences. The operators who run the wastewater treatment plant are the primary audience. The secondary audiences are the regulatory agency that reviews the manual as part of the permit-granting process and the permittee who is legally responsible for the treatment facility. The following figure illustrates who is involved in the creation and use of O&M manuals for wastewater treatment facilities.

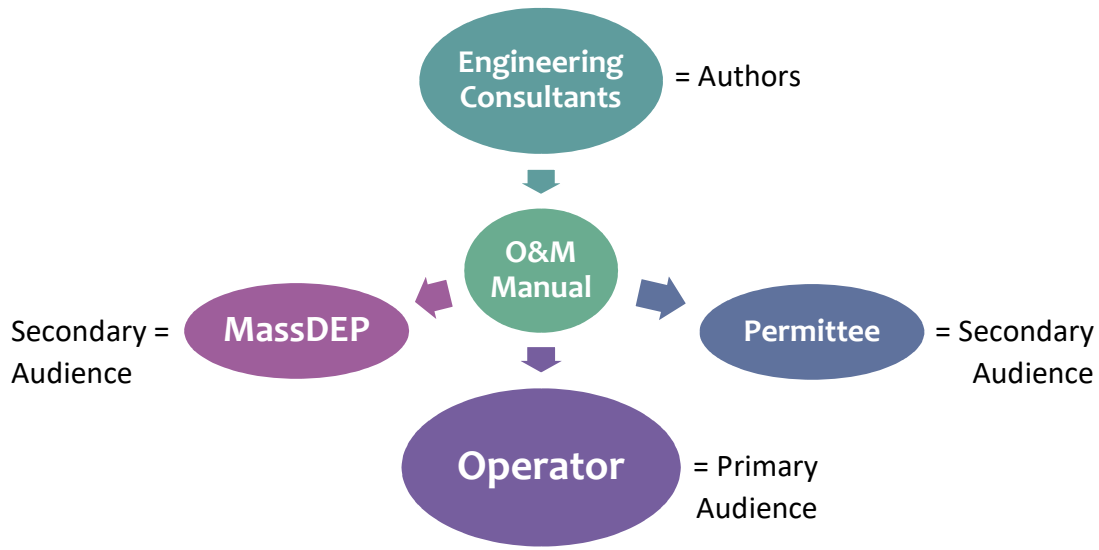


Figure 1: Authors and Audiences of O&M Manuals

The following sections describe how each of the above groups are involved in the writing and use of O&M manuals. Each section discusses the education-level, training, and occupation of the authors and audiences because the expertise and responsibilities of each group place constraints on the content, style, and organization of the O&M manual. Before discussing the O&M manual's multiple audiences, I will first describe the engineering consultants who write O&M manuals.

2.3.1 Authors: Engineering Consultants

Operations and maintenance manuals are typically written by the engineers who design wastewater treatment facilities (Tidwell, 2000). Most often, these design engineers possess a Bachelor's or Master's degree in civil, environmental, or chemical engineering and work at an environmental consulting firm. These firms range from large, national companies such as CH2M, CDM Smith, Black & Veatch, to small regional firms such as Tighe & Bond, Weston & Sampson, and Woodard & Curran.

According to MassDEP's O&M Manual Guidelines, an O&M manual for a wastewater treatment facility must be "prepared and stamped by a registered Professional Engineer." While there are different ways to become a registered Professional Engineer (PE) in Massachusetts, registered Professional Engineers must typically have a Bachelor's of Science in Engineering, pass a preliminary Fundamentals of Engineering (FE) Exam, have at least 4 years of engineering experience under a PE, and then pass a second Principles and Practice of Engineering (PE) Exam ("250 CMR 3.00: The Registration Process",

2017). However, the actual task of producing the O&M manual may be delegated to an entry-level engineer and later approved by a registered Professional Engineer. For smaller systems, the O&M manual may be created by a single engineer. Typically, for large and complex treatment facilities, several engineers team together to produce the O&M manual (W. Bates, personal communication, Nov. 21, 2016; G. Grissop, personal communication, Feb. 15, 2017).

2.3.2 Multiple Audiences

The engineers who write O&M manuals must contend with the challenge of communicating information to three distinct audiences: the operator(s), the permittee, and the regulatory agency. Addressing three audiences simultaneously is complicated. Each audience has different needs and expectations based on their education-level and purposes for reading the manual, some of which can be conflicting. The most important audience of the O&M manual is the operator. It is imperative that the O&M manual be primarily catered to the needs of operators who will reference the manual when operating a wastewater treatment facility. However, the O&M manual must also satisfy the needs of the MassDEP and the permittee.

2.3.2.1 Primary Audience: Operators

All wastewater treatment systems in Massachusetts are operated by licensed technicians. To acquire a license, an operator must pass an exam. Prior to taking the exam, operators typically take training courses provided by the New England Interstate Water Pollution Control Commission (NEIWPC) ("The Roadmap to Certification", 2013). Additionally, operators may possess an associate's degree or have completed a certificate program. Wastewater treatment plant operators acquire most of their technical knowledge through on-the-job training and apprenticeships. According to the U.S. Bureau of Labor Statistics, the typical highest achieved education level of a wastewater treatment plant operator is a high school diploma or equivalent ("Water and Wastewater Treatment Plant and System Operators", 2017).

Wastewater treatment plant operators are responsible for managing the day-to-day operations of the treatment facility. Operators are primarily responsible for monitoring the quality and characteristics of the effluent, such as pH, turbidity, and color. As part of this monitoring, operators take samples from the facility's influent and effluent. Based on the samples, they make adjustments to the concentrations of chemicals added to the system (J. Corrigan, personal communication, Dec. 12, 2016). Operators are also responsible for inspecting equipment for leaks, excessive noise, and abnormalities (J. Corrigan, personal communication, Dec. 12, 2016). While operators may make small equipment repairs, large repairs are often contracted out to another company. Some large treatment facilities have their own maintenance team that is separate from their operating staff (M. Johnson & K. Sangrey, personal communication, Feb. 3, 2017). For the purposes of this report, the term "operator" refers to both operators and maintenance personnel.

According to consulting engineer Tim Santos (2016), each operator should read the O&M manual thoroughly and understand the function of every component. However, operators primarily use the operations and maintenance manual for two reasons: if they are new to the system or if a malfunction occurs at the treatment facility (J. Corrigan, personal communication, Dec. 12, 2016; D. Langford, personal communication, Dec. 15, 2016). According to John Corrigan, an operator at EST Associates,

most experienced operators only rely on the O&M manual during the first month at an unfamiliar facility; after about a month, the operators acclimate to the system and do not need to consult the manual (personal communication, Dec. 12, 2016). Typically, once an operator learns the idiosyncrasies of a facility, he or she only references the manual when there is an equipment failure (J. Corrigan, personal communication, Dec. 12, 2016). According to Georgine Grissop, a consulting engineer at CDM Smith, the O&M manual is often used by upper-level operators to develop training materials for new hires, but the new hires do not read through the whole manual themselves (personal communication, Feb. 15, 2017). Presumably, this way of using the O&M manual only occurs at larger facilities that have multiple operators.

2.3.2.2 Secondary Audience: Permittee (Management/Owner)

At large municipal wastewater treatment facilities, the company who owns and operates the WWTS may be the same entity. For small communities or companies using decentralized wastewater treatment plants, the company or association that owns the wastewater treatment system does not necessarily operate the system. Instead, operation of the treatment plant is contracted out to a third-party that specializes in operating and maintaining wastewater treatment facilities.

By law, all wastewater treatment facilities discharging more than 15,000 GPD of sanitary wastewater or any amount of industrial wastewater must have a groundwater discharge permit issued by the Massachusetts Department of Environmental Protection (MassDEP). The MassDEP issues this permit to the owner of the treatment facility, not to the operator. Therefore, even though the owner (or permittee) does not run the treatment system, the owner is ultimately responsible for the successful operation of the facility. The permittee may be a management association, a board of trustees, or a company. The permittee has a vested interest in the proper operation of their facility; if the wastewater treatment facility violates its groundwater discharge permit, the permittee will be fined by the MassDEP (although in some cases, the operating company will be fined too).

Why must the permittee need to be able to use and the O&M Manual? In a perfect world, the permittee could allow the operator free reign to run the system, putting full faith into the operator's knowledge and good will. Unfortunately, such blind faith can have economic consequences. Some operating or repair companies could exploit the permittee's lack of knowledge and charge them excessively for unnecessary repairs, chemicals, or labor. The permittee must be able to have intelligent and informed conversations with the operators and repair companies they are hiring to run and maintain their system.

While the intended audience of the O&M manual is the operator, the manual is essential for the permittee so that they can properly oversee the treatment facility (E. Weksner & B. Pease, personal communication, Dec. 9, 2016). The O&M manual is an important tool that allows the permittee to gain a rudimentary understanding of the system, details their responsibilities as the permittee, and describes the responsibilities of their operator. The permittee can use the O&M manual as a way to hold their operators accountable (E. Weksner & B. Pease, personal communication, Dec. 9, 2016). In theory, since the operator cannot make changes to the O&M manual without letting the permittee know, the O&M manual serves as a way of ensuring that the operator keeps the permittee informed about changes to the wastewater treatment facility. Without an O&M manual, the permittee is essentially at the mercy of the operator, leaving the permittee in a vulnerable position (E. Weksner & B. Pease, personal

communication, Dec. 9, 2016). According to MassDEP's O&M Manual Guidelines, the O&M manual should be reviewed by the owner of the treatment facility at least every two years.

The O&M manual is also important for a company or association when there is a change in management (E. Weksner & B. Pease, personal communication, Dec. 9, 2016). The manual allows new managers, trustees, or anyone else who is a new permittee to become acquainted with the facility and understand their responsibilities. The manual should include all contact information pertinent to the operation of the treatment facility, which may be essential information for a new permittee during a transition in management.

In the case of Woodlands Village condominium, the permittee (the trustees of the condominium) were unusually involved in the revisions of their O&M manual (E. Weksner & B. Pease, personal communication, Dec. 9, 2016). One trustee, Bob Pease, conducted extensive research to understand the system so that he could identify how exactly the manual was lacking and make an informed decision when hiring a new consulting engineer. To Bob Pease, it is important that the Woodlands Villages' newest O&M manual institutionalizes all of the information he has collected on the system for future trustees (personal communication, Dec. 9, 2016).

2.3.2.3 Secondary Audience: Regulatory Agency: MassDEP

As previously discussed, the Massachusetts Department of Environmental Protection (MassDEP) believes that operations and maintenance manuals are so crucial to the successful operation of wastewater treatment facilities that they are required by law. However, it is not enough for a treatment facility to produce an O&M manual; the O&M manual must be submitted, reviewed, and approved by the MassDEP before the plant can begin operation.

The O&M manual must be submitted to the MassDEP at least 90 days before the plant begins operation or 45 days before the facility's permit takes effect, whichever occurs last (314 CMR 5.10 (1)). However, according to MassDEP's O&M Manual Guidelines, "the manual must be submitted for approval at least thirty days prior to scheduling with MassDEP the clear water hydraulic test of the facility." While the guidelines seem to contradict the regulations, the guidelines better corroborate with existing protocol. According to Andrew Osei, an Environmental Engineer for the Bureau of Water Resources at MassDEP's Central office, MassDEP requires the O&M manual to be submitted 30 days before the clear water test (personal communication, Nov. 18, 2016). However, the agency is not very strict with this rule; the permittee can submit generic O&M manual information 30 days prior to the clear water hydraulic test, but is expected to submit a complete O&M manual as soon as the facility passes the test. MassDEP must approve the manual before operation can begin. It is important to recognize that a facility's O&M manual must be produced and submitted to the MassDEP *before* the treatment facility even begins operation.

A revised O&M manual must be submitted to the MassDEP for review whenever there are proposed changes to the treatment facility, its standard operating procedures, or its staffing plan (314 CMR 5.10 (3)). The proposed modifications may only be implemented if the revised manual is approved by the agency (314 CMR 5.10 (4)). The O&M manual must also be revised and resubmitted if that facility is noncompliant with their permit (A. Osei, personal communication, Nov. 18, 2016).

According to Andrew Osei, the O&M manual serves as a safety measure to build confidence in the operator. The O&M manual is used by the MassDEP as a means of holding the operators and permittees accountable for the facility's proper operation. Therefore, the MassDEP reviews manuals to ensure that they outline the duties of the operators and permittee so that they can be held responsible if the facility violates the conditions of its Groundwater Discharge Permit. When reviewing an O&M manual, the MassDEP is also checking to make sure that it contains all the information that they believe an operator needs to run a wastewater treatment facility (A. Osei, personal communication, Nov. 18, 2016). To an extent, what a reviewer considers to be essential information may vary since the regulations that dictate the O&M manual's content are rather open-ended and subject to interpretation. Some reviewers will consider certain components of the O&M manual that are not specifically required by the regulations – such as a Preventative Maintenance Schedule or discussion of lift stations – to be essential information and will reject a manual without these components.

At MassDEP, O&M manuals are reviewed by environmental engineers, such as Andrew Osei. Osei joined MassDEP right after graduating from Worcester Polytechnic Institute about 2 years ago. Osei is the youngest staff member at the Bureau of Water Resources; he works with several other environmental engineers who have worked for the department for many years. When asked about his training concerning O&M manuals, Osei stated that his job training did not include formal instruction on how to review O&M manuals. Instead, Osei gained his knowledge about what is needed in an O&M manual through inspecting wastewater treatment facilities, by seeing what is expected of operators, and by reading through the environmental regulations. This experience gave him the ability to know which tasks must be performed in order for a treatment facility to run smoothly. Osei was under the impression that other reviewers at the agency also have not had specific training on the O&M approval process in a very long time (A. Osei, personal communication, Nov. 18, 2016).

From his experience reviewing many O&M manuals, Andrew Osei has found that the usefulness and quality of operations and maintenance manuals is highly variable. He explained that, for a number of reasons, many operators never even glance at their facility's O&M manual. This phenomenon observed by Osei is discussed at-length in the following section.

3 Why O&M Manuals Rarely Meet Operators' Needs

3.1 Dust-Covered O&M Manuals

Many O&M manuals go unused, collecting dust on a shelf. In the case of Woodlands Village's wastewater treatment facility, at one point, the O&M manual could not even be found on the treatment facility's premises. According to Upper Blackstone Water Pollution Abatement District's (UBWPAD) head engineers, Karla Sangrey and Mark Johnson, even though their O&M manual is technically accurate and a "wonderful piece of prose," no one uses it (personal communication, Feb. 3, 2017). This claim was verified by the pristine condition of the facility's hardcopy manual; the document did not contain a single earmark, crinkle, or annotation. So why do these seemingly important manuals go unused?

While the goal of author is (or at least should be) to produce a document that is frequently used and an integral part of everyday operations, this is easier said than done (Tidwell, 2000). Sangrey explained that even though she believed UBWPAD's manual was well-written, she and her colleagues struggle to incorporate it into the daily activities of UBWPAD's operators (personal communication, Feb. 3, 2017). O&M manuals are large, bulky documents that cannot be easily carried around a facility. For smaller treatment facilities, manuals are usually 300 – 400 pages. For large facilities, the O&M manual might be upwards of 1000 pages (G. Grissop, personal communication, Feb. 15, 2017).

Despite their bulkiness, rarely do O&M manuals have the level of detail that allows an operator to actually run a process step-by-step (M. Johnson & K. Sangrey, personal communication, Feb. 3, 2017). Even when manuals contain sufficiently detailed step-by-step operating procedures, the manual is often ignored because more accessible procedures can be found elsewhere. At UBWPAD, procedural descriptions are included in the facility's control system (M. Johnson & K. Sangrey, personal communication, Feb. 3, 2017). Their supervisory control and data acquisition (SCADA) system incorporates standard operating procedures (SOPs) into the user interface so that operators can access procedures on computers located throughout the facility. Therefore, they have no need to consult the O&M manual in day-to-day activities. Similarly, Darren Langford, a senior operator at Worcester's drinking water treatment facility, explained that operators at the treatment plant do not consult an O&M manual. Instead, they consult a binder of SOPs that operators can remove and bring with them as they perform a task (personal communication, Dec. 15, 2016).

Even new hires who are more likely to reference the O&M manual do not rely exclusively on the document to learn about a system. Especially at large treatment facilities, many operators primarily gain knowledge through observing senior operators and hands-on experience, rather than by consulting the O&M manual. In addition, many new hires will rely substantially on experience at other treatment facilities. As Karla Sangrey put it, "like you can't read a book to become a surgeon," you cannot simply read an O&M manual to become an operator (personal communication, Feb. 3, 2017). Sangrey contends that operators are not inclined to sit down and read through hundreds of pages to learn about a system. Instead, they learn through observation, practice, and application of past experiences to new contexts (personal communication, Feb. 3, 2017).

However, for small treatment facilities without SCADA systems and multiple operators who can help train new hires, the O&M manual is more critical. At small facilities with only one operator, learning

through observation of other operators is not an option. For example, at Woodlands Village, one operator visits the site for two hours a day, five days a week. When the condominium hired a new operating company, the new operator only had the O&M manual and his previous experience to immediately begin operating the system (wastewater treatment systems can never stop operating).

Given that O&M manuals are especially crucial to new operators, the aging population of operators will make O&M manuals even more important. Since a substantial portion of operators are reaching retirement age, MassDEP reviewer Andrew Osei predicts that there will soon be an influx of new, young, and inexperienced operators (personal communication, Nov. 18, 2016). These new operators will not be able to rely on decades of experience to run a new system. Instead, they will rely much more heavily on the O&M manual to become educated about a system (A. Osei, personal communication, Nov. 18, 2016). Grissop, a consultant at CDM Smith agrees, suggesting that as the shortage of wastewater treatment operators becomes more critical, the O&M manual will be an important tool in capturing and preserving the knowledge of retiring operators for use by the incoming generation of inexperienced operators (personal communication, Feb. 15, 2017).

3.2 Infrequently Used, but Still Important

Even though O&M manuals are used infrequently, almost all players involved in the production, review, and use of O&M manuals contend that they are important. Nearly everyone who was interviewed - engineering consultants, operators, permittees, and a reviewer at MassDEP- said they believe that a wastewater treatment facility should have an O&M manual even if it were not required by regulations. When questioned about this apparent contradiction between the lack of use of O&M manuals and their perceived importance, Georgine Grissop explained that O&M manuals are “like owner’s manual for car, which stays in the glove box until you need to reference it” (personal communication, Feb. 15, 2017).

A typical car owner may leaf through the owner’s manual when they first purchase the car. Other than that, a car owner will probably only consult the manual if warning lights appear on their dashboard. In an ideal world, the car owner would never need to consult the manual because warning lights would never appear. In reality, at some point most car owners will need to reference their car’s owner manual, and when they do, they most certainly want it to be understandable and useful.

In the same way, most operators only reference the O&M manual when equipment has malfunctioned. When a process at a wastewater treatment facility is disrupted, the health of waterbodies receiving treated wastewater and consequently the public’s safety is put at risk. Therefore, when operators do need to consult the manual, it is essential that the document is easy to use and understand. Guidance on O&M manuals published by New Jersey Department of Environmental Protection states that O&M manuals are important because, “the O&M Manual can provide the WWTP with a level of security during times of crisis and staff turnover by providing consistent guidance to responsible operators” (p. 3). According to the US EPA, the adequacy of a wastewater treatment plant’s O&M manual plays a significant role in determining how well the facility operates.

3.3 Common Deficiencies of O&M Manuals

Unfortunately, as Tidwell (2000) states, “many facility operators find their operations and maintenance (O&M) manuals either outdated, inaccurate, too technical, or difficult to understand – in other words: useless” (p.1). Similarly, O&M manual guidance from Minnesota Pollution Control Agency states that, “past studies have shown O&M manuals often to be inadequate for operating personnel” (Minnesota Pollution Control Agency, 2000, p. 1). In his interview, John Corrigan, an operator at EST Associates, said that although most manuals are useful, almost all manuals could be *more* useful (personal communication, Dec. 12, 2016). From conversations with professionals representing each of the O&M manual’s three audiences, it is apparent that many O&M manuals do not meet operators’ needs because they are inaccurate, overly general, highly technical, and poorly organized.

Why are these deficiencies so common in O&M manuals? During the earliest stages of this research project, I hypothesized that the regulations set forth by MassDEP limited the effectiveness of O&M manuals by dictating the manual’s content and organization. The question was: is it possible to write a useful, concise document that still adheres to the law? The answer, seemingly, is yes. MassDEP’s regulations have little impact on how the manual is written and structured; the regulations only dictate what information must be included in the manual. All persons interviewed either believed that the regulations did not negatively impact the effectiveness of the O&M manual or did not comment on the topic. Several interviewees contended that the regulations give the writer boundaries to work within and help keep the manual organized (W. Bates, personal communication, Nov. 21, 2016; M. Johnson & K. Sangrey, personal communication, Feb. 3, 2017). Andrew Osei, a reviewer at MassDEP, asserted that it is definitely possible for the O&M manual to meet MassDEP’s requirements and be useful; in fact, to be useful, the manual must go above the requirements (personal communication, Nov. 18, 2016).

Maybe the right question to ask is: are the regulations constraining *enough*? Do the regulations provide enough structure to guide (or compel) the writer to produce a useful document? From a legal perspective, there is no incentive to create a well-written O&M manual. Nothing in Massachusetts regulations insist that the manual must be readable, only that it must contain all information needed to operate and maintain the facility. To Osei’s frustration, even when a manual is really difficult to read, but fulfills the regulatory requirements, he has no choice but to approve the manual (personal communication, Nov. 18, 2016). Issues with organization, diction, and style alone are not grounds for returning the manual for revision; in order to be rejected, the manual must be technically deficient. According to operator John Corrigan, an operator might work at three different facilities and each facility’s manual could have a very different level of quality (personal communication, Dec. 12, 2016). The regulations allow for such variation in quality. Perhaps if the regulations were more constraining and provided greater impetus for the manual to be well-written, manuals of greater quality would be produced.

However, even if engineers were compelled by law to “write better,” that does not necessarily mean they have the training, ability, or resources to do so. There are several constraints and challenges relating to authors’ writing-process that result in inadequate manuals. In creating the O&M manual, writers must contend with pressures from multiple audiences. Due to differences in occupation and expertise, each audience has different requirements and expectations, which makes it difficult for writers to determine the appropriate content and style of the manual (Tidwell, 2000). The engineers

who write O&M manuals are not usually trained as technical writers. Therefore, without adequate guidance, they may not be predisposed to consider their audiences or may not have the tools to communicate information to readers who are not fellow engineers (Beer and McMurrey, p. 48). Constraints such as time, budgets, regulations, and the inherent differences between those who write and use O&M manuals also impact the quality of O&M manual. The following graphic summarizes common deficiencies of O&M manuals and the probable reasons for these weaknesses:

Reasons for Deficiencies		Common Deficiencies of O&M Manuals			
		Poorly Organized	Engineering Jargon	Overly General	Inaccurate & Outdated
Reasons Related to the Writing Process	Authors Fail to Consult with the Operator	✓	✓	✓	✓
	Authors Are Not Trained as Technical Writers	✓	✓		
	Misuse of Templates			✓	✓
	Insufficient Guidance	✓	✓	✓	✓
Procedural/ Regulatory Constraints	Author Did Not Design the WWTF			✓	✓
	Authors Lack Experience as Operators		✓	✓	
	Timeline of Review by MassDEP				✓
	Time/Budgetary Constraints	✓			✓

Figure 2: Reasons for Common Deficiencies Found in O&M Manuals

The following sections further explain how challenges related to the writing process and procedural or regulatory constraints interfere with O&M manuals meeting their audiences' needs.

3.3.1 Accuracy of Content: Current vs. Outdated

Operations and maintenance manuals should be accurate, living documents (D. Langford, personal communication, Dec. 15, 2016; Tidwell, 2000; Santos, 2016; G. Grissop, personal communication, Feb. 15, 2017). This sentiment was repeated in nearly every interview conducted and was shared among operators, O&M manual writers, permittees, and the MassDEP. Tidwell (2000) states that “most will agree that an O&M Manual is virtually worthless if not used and updated regularly” (p. 1). Despite the

benefits of maintaining an updated manual, there is little incentive to update the O&M manual to reflect actual operations once the manual has been approved and operations begins. Revisions to the manual only cost the permittee more money. This budgetary deterrent, coupled with a lack of enforcement by MassDEP, results in technically deficient and outdated O&M manuals.

As previously discussed, the operations and maintenance manual for a new facility must be produced and submitted for review by MassDEP *before* the plant actually begins operating. However, according to operator John Corrigan, facilities never run the way they are designed; it is impossible to anticipate the idiosyncrasies of a system before it begins operating (personal communication, Dec. 12, 2016). As a result, the O&M manual that is submitted to MassDEP 30 days before startup will not accurately reflect how the system actually runs, limiting its effectiveness. This is especially true for O&M manuals that are written according to engineer's design memos, since how the facility is actually constructed rarely matches the engineer's original designs perfectly.

For that reason, an O&M manual should not be completed until after a system is running (J. Corrigan, personal communication, Dec. 12, 2016). Additionally, as any change is made to the treatment facility, the O&M manual should be updated accordingly by the operator, no matter how minor the change (J. Corrigan, personal communication, Dec. 12, 2016; Santos, 2016; G. Grissop, personal communication, Feb. 15, 2017). In fact, regulations mandate that the O&M manual should be revised and resubmitted to MassDEP for approval *before* the installation of retrofits, the modification of operating procedures, or changes in staff (314 CMR 5.10 (3)). By law (and in theory), any proposed modifications may only be implemented if MassDEP approves the O&M manual's revisions.

In reality, small modifications (and sometimes even substantial changes) are often not updated in the manual (J. Corrigan, personal communication, Dec. 12, 2016). Changes to small pieces of equipment, such as probes, or staffing changes, frequently fail to be reflected in an O&M manual. For example, Woodlands Village did not update their O&M manual, which was originally written in 1999, until 2013, despite numerous changes to equipment, operational procedures, and staffing. In many cases, the first draft of the O&M manual is the only draft.

This is because in practice, it is difficult to enforce the MassDEP regulations that require manuals to be continuously updated (A. Osei, personal communication, Nov. 18, 2016). This is especially true for minor modifications such as switching chemical additives or staffing changes (A. Osei, personal communication, Nov. 18, 2016). Unless a permittee notifies MassDEP of any changes to their treatment facility, the only way for MassDEP to learn if there have been any modifications to a plant's equipment, operations, or maintenance plan is through an inspection of the facility. Regularly scheduled inspections of wastewater treatment facilities are not frequent, especially for small facilities. Most facilities with a design flow between 10,000 – 15,000 GPD are inspected by MassDEP every 5 years unless there is a change in ownership or an expansion of the facility (310 CMR 15.301 (6)). In general, the only other time MassDEP will inspect a facility is if the permittee reports effluent characteristics in their monthly Discharge Monitoring Reports (DMR) that violate the limits set by their Groundwater Discharge Permit. In other words, unless a facility is caught for being non-compliant with their permit, it is easy to get away with not updating the manual.

MassDEP *will* enforce that a facility revise and submit their O&M manual if the facility is noncompliant with their permit. If a facility then submits a technically deficient revision (one that does not contain all of the information required by regulations), MassDEP will return the manual to the permittee for additional revisions. However, once the manual is returned for revisions, there is no enforceable timeline for when those revisions must be made (A. Osei, personal communication, Nov. 18, 2016). Typically, while the O&M manual is being revised, the facility is allowed to continue operating (A. Osei, personal communication, Nov. 18, 2016). As a result, some facilities take over a year to return the revised the O&M manual (A. Osei, personal communication, Nov. 18, 2016).

However, MassDEP's policies are not the norm. In other states, wastewater treatment facilities are required to submit two "final" versions of their O&M manual. For example, in Minnesota, a final O&M manual must be submitted to the Minnesota Pollution Control Agency for review. The manual must be complete, void of spelling and grammatical errors, include all figures, diagrams, tables, page numbers, design information, etc. (Minnesota Pollution Control Agency, 2000). Like in Massachusetts, the treatment facility cannot begin operating until the agency approves the manual. However, in Minnesota, a second revised final O&M manual must be submitted for review 11 months after the facility begins operation. As stated in Minnesota's O&M manual guidance, "the revised manual is an updated final manual that includes revisions based on actual plant operation" and recommends that the revisions be a collaborative effort between the consulting engineer and the operator(s) (Minnesota Pollution Control Agency, 2000, p. 2).

3.3.2 Level of Detail: Site-Specific vs. Overly General

According to Tidwell (2000), defining the level of detail, or the "amount and type of information" (p. 14), is a critical step in manual planning that should not be taken lightly by the manual's author. While an O&M manual that contains excessive and unnecessary detail is not an effective tool, a manual that is not sufficiently specific, will be equally as useless to an operator (Tidwell, 2000).

Ideally, an O&M manual should allow someone who has never worked on a particular wastewater treatment system to operate it, but this level of detail is rare (J. Corrigan, personal communication, Dec. 12, 2016). According to Corrigan, O&M manuals are often written for the general operation of a wastewater treatment plant and describe treatment processes broadly (personal communication, Dec. 12, 2016). Manuals that are written from the engineer's designs plans are not specific enough; two wastewater treatment systems that are identical on paper will operate in very different ways depending on the facility's location and the wastewater's characteristics (J. Corrigan, personal communication, Dec. 12, 2016; D. Langford, personal communication, Dec. 15, 2016). For example, on paper, the design of a WWTF for an office complex and a nursing home could be identical. However, the nursing home's effluent would contain more non-dissolved toilet paper and wipes (rags), which would significantly impact how frequently pumps should be inspected for buildup of rags. The office complex would have much greater variations in effluent flowrate throughout the day, which would affect chemical dosing patterns more significantly. Therefore, an O&M manual should reflect how the treatment facility actually operates, taking into account all of the system's idiosyncrasies.

According to MassDEP reviewer Andrew Osei, engineers frequently omit important information and include unnecessary information in the O&M manuals they submit to the agency (personal

communication, Nov. 18, 2016). Osei claimed that good O&M manuals include pragmatic information such as when alarms should be checked, when tanks should be pumped of sludge, emergency contact information, and sludge hauler contact information (personal communication, Nov. 18, 2016). Unfortunately, consultants often forget to include content such as emergency procedures, utilities information, backup generator descriptions, locations of process sampling, spare parts lists, third-party operator contacts, and who performs lab testing and analysis (A. Osei, personal communication, Nov. 18, 2016). John Corrigan contends that although many manuals contain the manufacturer's manual for each piece of equipment, this alone is not sufficient (personal communication, Dec. 12, 2016). The O&M manual should include where each equipment piece was purchased to make replacing damaged parts easier (J. Corrigan, personal communication, Dec. 12, 2016). Operators are generally required to do in-house lab testing to monitor and adjust a system. Frequently, the chemical formulas and descriptions of bench testing procedures are not included in the manual, even though Corrigan believes they should be (personal communication, Dec. 12, 2016).

Although O&M manuals should be comprehensive, inclusion of certain content detracts from the manual's effectiveness. For example, Osei has received some O&M manuals containing scenic pictures, which serve no purpose other than to increase the length of the document (personal communication, Nov. 18, 2016). In Osei's opinion, poorly-written O&M manuals often contain too much information on the system's design. An operator does not need to understand *why* a plant was designed a certain way; information about other systems or technologies that were considered and justifications for the final design are not necessary (personal communication, Nov. 18, 2016). While design specifications should be included in the manual, specs are only useful to consultants redesigning the facility or when making a repair. Therefore, these specifications should be attached as appendices rather than constitute a main portion of the manual's body.

While many manuals contain extraneous information, more often than not, O&M manuals are insufficiently detailed. For example, the following passage from Woodlands Village's original 1999 O&M manual that describes the facility's carbon-based chemical feed system is far too brief to be of use to an operator (Holmes and McGrath, 1999).

The carbon source is in the rear of the garage. Two small diaphragm pumps dose the soap like compound from 55 gallon drums to the mixing chamber. The carbon pumps are controlled by a series of electrical relays. There are settings in the interior of the control box which have been set by the engineer. These controls normally will not be altered except by the engineer. If the final effluent contains elevated levels of BOD, then the carbon pumps may need to be adjusted. The fresh water pumps draw fresh water from a tank and flushes the soap like compound into the mixing chamber.

Figure 3: Excerpt from Woodlands Village's 1999 O&M Manual

While this passage is full of technical language, the description of the chemical dosing system is not adequately detailed for the purposes of operation. The excerpt instructs the operator to adjust the carbon pumps when the final effluent contains high BOD, but does not describe how the carbon dose should be adjusted, what constitutes as "high" BOD, or what BOD means. In fact, the manual does not

even give the name of the chemical compound used as a carbon source. An operator could not possibly operate a treatment facility for the first time with such limited information. The following passage from the revised Woodlands Village O&M manual (written in 2016) is a revision to the *same section* of the O&M manual. This passage is much more detailed (Santos, 2016):

3.3.4 Denitrification

Denitrification starts to take place within the 1,500 gallon heating tank and two 4,000 gallon detention tank when the mixture of carbon and nitrate combine in an anaerobic environment (no air). During this process, all of the elements for denitrification are present. Those elements are nitrate, a carbon source (Methanol-20%), anoxic conditions (no air), and a large and hungry biomass.

The methanol being used at this time will be 20% dilution and stored within drums within a spill containment area. The methanol is stored within the old large wastewater treatment plant building and is further protected from spillage due to the concrete floor within the building. Methanol at this dilution is not considered a flammable/explosive material but must still be treated with caution as per the MSDS sheets for the material (see Appendix C). The methanol is being fed to the discharge side of the heating tank prior to the denitrification tanks. Methanol dosages of approximately 4 mg/l per mg/l of nitrogen to be removed are typical. The chemical feed pumps should be calibrated to determine the proper output established for the facility. Maximum daily usage of methanol can be estimated by the following:

$$45 \text{ mg/l NH}_4 \times 4 \text{ mg/l methanol} = 180 \text{ mg/l} \times 0.011 \text{ Mgd} \times 8.34 = 16.5 \text{ lbs. methanol/day} / 6.6 \text{ lbs/gal} = 2.5 \text{ gallons per day}$$

$$20\% \text{ Methanol} = 5 \times 2.5 \text{ gallons per day} = 12.5 \text{ gpd}$$

This calculation is based on a typical influent ammonia (NH₄), it will need to be monitored and adjusted accordingly. The chemical feed pump will then need to be adjusted to deliver the appropriate amount of methanol as required. The methanol is currently being feed continuously to the heating tank. Refer to Appendix G for specifications.

Figure 4: Excerpt from Woodlands Village's Revised 2016 O&M Manual

Unlike the 1999 version, this passage explains what chemical is used as a carbon source (20% methanol) and where to find it, provides the formula that should be used to estimate the chemical dose, and directs the reader to appendices with more detailed information. It is also important that the passage explains the role of the carbon source in context of the treatment process (as an element required for denitrification) and indicates the hazards associated with handling flammable methanol. This level of detail is much more specific to the Woodlands Village treatment facility and provides the operator with a better understanding of how to monitor the dose of the carbon-based chemical.

Failure to provide the appropriate level of detail, shown by 1999 example, may stem from the writer's lack of experience with operating wastewater treatment systems (J. Corrigan, personal communication, Dec. 12, 2016; M. Johnson & K. Sangrey, personal communication, Feb. 3, 2017). Corrigan believes that engineers who write O&M manuals tend to generalize process descriptions and operating procedures because they have never operated a wastewater treatment facility (personal communication, Dec. 12, 2016). Mark Johnson of UBWPAD contends that the process of writing an O&M manual is "automatically disconnected because the person designing it isn't the operator" (personal communication, Feb. 3, 2017). Since many consultants who write O&M manuals have never operated a facility or needed to use an O&M manual, they do not really understand what information is needed by operators from the manual.

However, in some cases, the engineers who write O&M manuals are indeed operators. For example, the consultants who wrote the 1999 and 2016 versions of Woodlands Village's O&M manual, Holmes and McGrath, advertise their experience operating wastewater treatment facilities. The following quote can be found on Holmes & McGrath's website (*Wastewater Treatment Operations*, 2017):

"The fact that design engineers are also operators brings a different depth to the design of treatment facilities. Our engineers have operated almost every small-scale onsite treatment technology available as well as a variety of large-scale systems."

The consultant who wrote UBWPAD's O&M manual, Georgine Grissop, is a Grade 7 operator (G. Grissop, personal communication, Feb. 15, 2017). This is the highest wastewater treatment facility operating license available in Massachusetts, which can only be obtained after many years of operating a large municipal plant. According to head engineer Karla Sangrey, UBWPAD benefits from Grissop's hands-on experience as an operator. She believes that if the author of their O&M manual had not been an operator, the manual would probably be a lot worse (personal communication, Feb. 3, 2017). In her interview, Grissop stated repeatedly that it is important to "practice what she preaches" and that she would not want to coauthor an O&M manual with someone who has not been involved in operations (personal communication, Feb. 15, 2017).

Failure to provide appropriate and accurate content at the correct level of detail may also stem from a lack of communication between consultants and operators. Corrigan contends that unless consultants include the operator in the writing process by discussing and revising the manual together, consultants will not know what their primary audience needs (personal communication, Dec. 12, 2016). Therefore, Corrigan suggests that the people who write O&M manuals should "go out and work in the field" (personal communication, Dec. 12, 2016). Tidwell (2000) emphasizes the value in collaborating with the end-user, stating that "the best way to get constructive feedback from the end-users is to communicate directly with them" (p. 15). Wayne Bates, a Principal Engineer at Tighe & Bond (a consulting firm), also highlighted importance of communicating with the operator; consulting the system's operator to better understand how it works is a fundamental part of his writing process (personal communication, Nov. 21, 2016). When an engineer has never operated a WWTF before, is it especially important that he or she at least communicate with the operator, but even authors who have worked as operators should consult with the operator of the particular facility described in the O&M manual. Unfortunately, this communication does not always happen. Corrigan stated that he had never been consulted by a consultant who was in the process of producing an O&M document for a facility that he operated

(personal communication, Dec. 12, 2016). To ensure that authors communicate with operators, some states require that the O&M manual be submitted with a cover letter that includes the signature of treatment plant operator or superintendent to “ensure proper input by the operating staff” (Minnesota Pollution Control Agency, 2000). Massachusetts, however, does not require authors to receive input from operators.

Despite the obvious benefit of consulting with operators, it rarely happens due to tight deadlines and budgets. Besides limiting authors’ ability to consult with operators, time constraints also significantly impact authors’ ability to research a facility and revise the O&M manual. This in turn negatively affects the manual’s scope, content, and level of detail (Tidwell, 2000). Producing an O&M manual can be significant undertaking, especially for large treatment facilities (Tidwell, 2000). Wayne Bates, a Principal Engineer at Tighe & Bond, claims that an O&M manual takes between 60 – 80 hours and \$5,000 - \$7,500 to produce depending on the size and complexity of the system (personal communication, Nov. 21, 2016). O&M manual author Georgine Grissop contends that this process is even longer and may take upwards of one year (personal communication, Feb. 15, 2017). The engineering consultants who write O&M manuals are under pressure to provide a quality O&M manual within a set budget (Tidwell, 2000). Since consultants typically bill their client by the hour, if their budget is defined, so is the time they can allot to producing the manual. Because the O&M manual must be submitted before the plant can begin operation, writers also face tight deadlines. Consequently, the writers of O&M manuals “often find themselves bogged down by unrealistic deadlines, inadequate budgets, poorly defined scopes of work, and procedural red tape” (Tidwell, 2000). These constraints can tempt consultants to do the bare minimum that is required by MassDEP’s regulations, since taking considerable time to consult with the operator, fact-check, and revise ultimately costs more money.

To combat time constraints, the engineers who write O&M manuals often use a template produced by their company (G. Grissop, personal communication, Feb. 15, 2017; W. Bates, personal communication, Nov. 21, 2016). In many instances, the equipment installed at one wastewater treatment facility has already been installed and discussed in an O&M manual for another facility. As a result, engineering firms gather a library of process descriptions that can be refined and reused (G. Grissop, personal communication, Feb. 15, 2017). This is especially true in large engineering firms that have a network of offices with several people writing O&M manuals who can share bits and pieces of hundreds of O&M manuals. According to Grissop, the reuse of parts of previous manuals, which she jokingly referred to as “gratuitous internal plagiarism,” is efficient and important in minimizing the cost of producing O&M manuals (personal communication, Feb. 15, 2017).

However, there is a caveat when reusing information from other O&M manuals: it is extremely important to modify the text to correctly reflect operations at the treatment facility. When writing O&M manuals, Grissop keeps any text borrowed from another manual in red until she verifies the information out in the field (personal communication, Feb. 15, 2017). Figure 5 shows an example of revisions made by Grissop when using text borrowed from another O&M manual. She identified that a section called “Zeta Potential” did not apply to facility that this O&M manual was describing (personal communication, Feb. 15, 2017).

When not used appropriately, templates can lead to overly-generalized information about processes or even result in including information that does not apply to a particular facility. All too often, consultants who cut and paste sections of another manual fail to appropriately revise the sections (E. Weksner & B. Pease, personal communication, Dec. 9, 2016; A. Osei, personal communication, Nov. 18, 2016). For example, a 2013 version of Woodlands Village’s O&M manual states that (Mount Hope Engineering, 2013):

“The system recently installed ultraviolet disinfection to follow the secondary and tertiary treatment system and to provide disinfection prior to discharge to the subsurface leaching fields.”

However, the system never included an ultraviolet disinfection system. This description was clearly copied and pasted from a passage written for another treatment facility.

Lastly, O&M manuals that are written or revised by an engineer who did not design the facility are usually too general or inaccurate. In this instance, the consulting engineer may not be knowledgeable enough about the system to effectively summarize it and to respond to MassDEP’s concerns about the content of the O&M manual during the approval process (Tidwell, 2000). While MassDEP’s environmental engineers are very knowledgeable about wastewater treatment systems, they cannot know every detail about the hundreds of systems installed in Massachusetts. For example, MassDEP insisted that Woodlands Village’s O&M manual should be revised to require the operator to wash down media in one of the treatment tanks. However, washing down the media would destroy essential microbial colonies living on the media and negatively impact biological treatment (E. Weksner & B. Pease, personal communication, Dec. 9, 2016). One Woodlands Village trustee commented that a reviewer at MassDEP “had unfeasible requests [for revisions to the O&M Manual] because he didn’t understand the system” (E. Weksner & B. Pease, personal communication, Dec. 9, 2016). Unfortunately, the engineer writing the O&M manual also did not understand the system well enough to address MassDEP’s concerns when the agency requested these erroneous revisions (E. Weksner & B. Pease, personal communication, Dec. 9, 2016).

3.3.3 Organization: Well Organized vs. Disorganized

An O&M manual should be well-organized so that an operator can easily and intuitively locate information in the manual (Tidwell, 2000). This is especially important when operators need to find

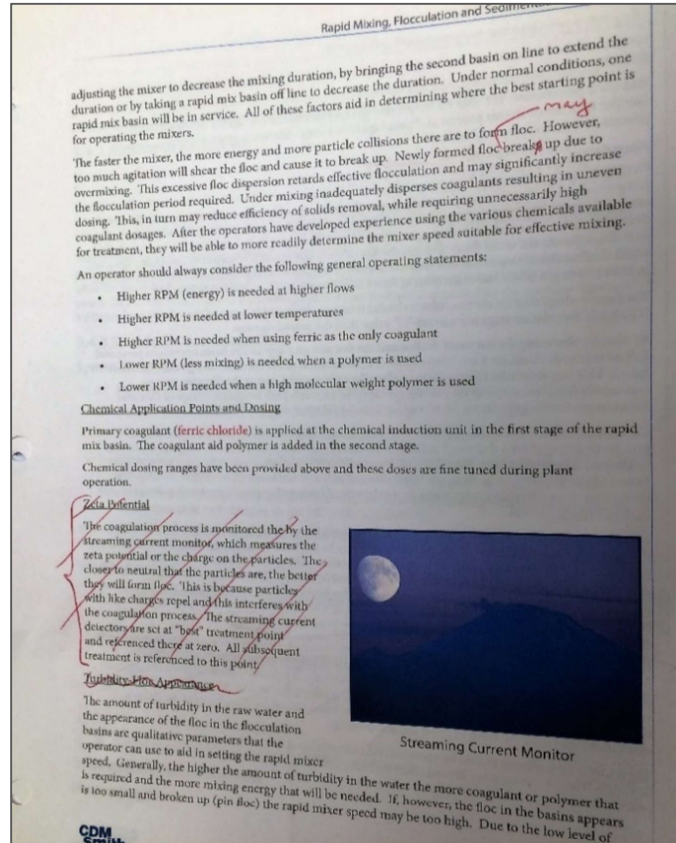


Figure 5: Proper Revision of O&M Manuals Made Using Templates

information quickly to remedy a time-sensitive equipment malfunction. Well organized O&M manuals are also easier to revise and continuously update (Tidwell, 2000).

To be easy to use, O&M manuals should have a simple structure (Tidwell, 2000). Principal Engineer Wayne Bates contends that the best O&M manuals organize information into tables instead of lengthy paragraphs, which enhances operators' ability to find information quickly (personal communication, Nov. 21, 2016). MassDEP reviewer Andrew Osei agrees with this sentiment; he believes that operators are unlikely to read through several lines of text (personal communication, Nov. 18, 2016). Ideally, O&M manuals should convey a substantial portion of information through visuals including tables, figures, lists, and drawings (Tidwell, 2000). Especially important information should be emphasized through bolding, italicizing, underlining and/or highlighting (A. Osei, personal communication, Nov. 18, 2016). As stated in Oregon's guidance on O&M manuals, "an operator looking for a specific piece of information should not have to read an essay to find it" (Oregon Department of Environmental Quality, 2012, p. 2).

Effectively organized manuals have a consistent and logical layout with multiple levels of section headings (A. Osei, personal communication, Nov. 18, 2016; Tidwell, 2000). To present information in a logical order, processes should be discussed following the path of wastewater through the system (A. Osei, personal communication, Nov. 18, 2016). Information should also be presented with a gradually increasing level of detail because beginning with detailed explanations may confuse or intimidate the reader (Tidwell, 2000). Within each section, a more general description should introduce a concept. After providing an overview, the manual should delve into specifics (A. Osei, personal communication, Nov. 18, 2016). Headings allow the reader's eyes to rest and make it easier to locate specific topics.

An operator will rarely read a O&M manual from cover to cover. Instead, operators use O&M manuals as a reference and only consult sections relevant to their inquiry. Due to the nature of how O&M manuals are used, almost every person interviewed stressed that a well-constructed and accurate table of contents is critical to the ease with which a manual can be used (J. Corrigan, personal communication, Dec. 12, 2016; A. Osei, personal communication, Nov. 18, 2016). Similarly, an index can "make or break" an O&M manual in terms of its usefulness (Tidwell, 2000). Sections labeled with color-coded tabs can further enhance the manual's navigability (D. Langford, personal communication, Dec. 15, 2016; Tidwell, 2000).

Andrew Osei contends that the best O&M manuals are divided into two main parts (personal communication, Nov. 18, 2016). The first half of the document (approximately 50 pages) should contain the most important information that is used by the operator. This includes a description of all the processes and maintenance activities that must be performed by the operator. The second half of the document should be more technical and contain the information that will only be referenced in the event of equipment failure or redesign, such as design specs. Most of this information should be in the appendices.

The emergence of electronic O&M manuals has helped improve the ease with which operators can locate information. Searchable PDF versions of O&M manuals allow operators to use key words to find specific information. The table of contents can be hyperlinked so that operators can quickly reach sections of interest. Hyperlinks can also be used to link to definitions, images, more detailed standard operating procedures, reference materials, or other related sections. Digital documents are also less clunky and take up less space. Grissop explained that operators are more likely to carry around a digital

copy on a small tablet than a large, bulky, 1000+ page book (personal communication, Feb. 15, 2017). According to Osei, digital copies submitted to the DEP are becoming more popular (personal communication, Nov. 18, 2016).

Despite the organizational advantages afforded by electronic O&M manuals, both electronic and hardcopy O&M manuals are often extremely disorganized. Even when a manual contains all the information needed by an operator, that information is often buried within hundreds of pages. According to Tidwell (2000), most authors do not use enough headings to break up sections of text. John Corrigan stated that the difficulty of finding answers is a major problem with O&M manuals (personal communication, Dec. 12, 2016). Poor organization frequently hinders a manual’s usefulness and ultimately leads to O&M manuals being shelved and never used (Tidwell, 2000).

During his interview, Osei provided examples of high and poor-quality O&M manuals and explained what made the manuals effective and ineffective. When describing the poor-quality manual, one of the most notable features of the manual that Osei repeatedly identified was the lack of effective organization (personal communication, Nov. 18, 2016). The image below compares the second page of two O&M manuals. The left-hand side is from the poor O&M manual provided by Osei (*Amphidrome*, n.d.). The right-hand side is a much more effective table of contents found in the 2016 revision of Woodlands Village’s O&M manual (Santos, 2016).

INDEX	Table of Content
1. INTRODUCTION <ul style="list-style-type: none"> ▪ AMPHIDROME® O&M ▪ EQUIPMENT WARRANTY ▪ OPERATOR'S REPORTS 	1.0 Introduction..... 1 <ul style="list-style-type: none"> 1.1 Existing Site Conditions 2
2. WASTEWATER PUMPS <ul style="list-style-type: none"> ▪ A SERIES: REVERSE FLOW/BACKWASH, FINAL DISCHARGE ▪ TP SERIES: PLUS FEED, PLUS BACKWASH 	2.0 Permits and Standards..... 2
3. CHEMICAL FEED SYSTEMS <ul style="list-style-type: none"> ▪ CHEMICAL FEED PUMPS ▪ SAFETY WAND ▪ AGITATOR ▪ STORAGE TANK 	3.0 Description, Operation and Control of Wastewater Treatment Operations 3 <ul style="list-style-type: none"> 3.1 Design Flows 3 3.2 Effluent Quality Criteria 3 3.3 Treatment Process..... 4 <ul style="list-style-type: none"> 3.3.1 Anoxic and Equalization Pretreatment 4 3.3.2 Nitrification..... 5 3.3.3 Intermediate Pump Station 5 3.3.4 Denitrification..... 6 3.3.5 Leaching System..... 7 3.3.6 Treatment Plant Support Room 7 3.3.7 Flow Monitoring 8 3.3.8 pH Monitoring 8
4. PACKAGED AIR SYSTEM <ul style="list-style-type: none"> ▪ BLOWERS ▪ VARIABLE FREQUENCY DRIVES 	4.0 Sludge Handling 8 <ul style="list-style-type: none"> 4.1 Septage Removal 8
5. FLOW MEASURING EQUIPMENT <ul style="list-style-type: none"> ▪ FLOW METER ▪ CHART RECORDER 	5.0 Personnel..... 9 <ul style="list-style-type: none"> 5.1 General..... 9 5.2 Facility Classification 9 5.3 Certified Operator Requirements..... 10 5.4 Operator Coverage and Effort 10 <ul style="list-style-type: none"> 5.4.1 Staffing Plan 10
6. ANCILLARY EQUIPMENT <ul style="list-style-type: none"> ▪ FLOATS AND BRACKETS ▪ VALVES <ul style="list-style-type: none"> ▪ CHECK VALVES ▪ ELECTRICALLY ACTUATED VALVE ▪ SOLENOID VALVE ▪ STILLING WELL 	6.0 Sampling and Laboratory Analysis 11 <ul style="list-style-type: none"> 6.1 Overview..... 11 6.2 Permit Sampling Requirements 11 <ul style="list-style-type: none"> 6.2.1 Monitoring & Sampling Requirements 11 6.3 Sampling Techniques..... 12 <ul style="list-style-type: none"> 6.3.1 Sample Types..... 13
7. AMPHIDROME® REACTORS	
8. CONTROL SYSTEM <ul style="list-style-type: none"> ▪ AUTODIALER ▪ CONTROL PANELS <ul style="list-style-type: none"> ▪ KAESER FAN PANEL ▪ TREATMENT PLANT PANEL 	

Figure 6: Comparison of Poorly Organized and Well Organized Tables of Content

The table of contents (mislabeled as an “Index”) from the manual provided by Osei is utterly useless without page numbers. Although the “Index” has multiple levels of headings, the order and hierarchy is illogical. For example, an introduction to the entire manual should not include an equipment warranty and the order of the eight main sections is seemingly arbitrary (the sections are not presented in the order that wastewater flows). The inaccurately labeled table of contents reflects the poor organization within the document. The actual headings within the manual do not correspond to those found in the table of contents; the first three headings in the manual are “Touch Screen Options,” “Main Screen,” and “Reactor Screen.” Three important tables (“Daily Operations/Maintenance Checklist,” “Field Water Analysis,” and “Scheduled Preventative Maintenance”) are included after the equipment warranty, but there is no indication that these tables exist in the table of contents. After page 31 of the 527 pages, the O&M manual is just an assortment of equipment O&M manuals, which is not indicated in the table of contents.

The table of contents on the right-hand side from Woodlands Village’s 2016 O&M manual is much more effective. The various levels of headings are clearly identified, reflect the actual headings within the document, and correspond to page numbers. The section on treatment processes logically follows the flow of wastewater through the system. However, the organization of the 2016 revision of Woodlands Village’s manual could be improved. For example, the subsections under “Treatment Processes” are inconsistently organized. Sections 3.3.1, 3.3.2, and 3.3.4 are organized around a treatment process, whereas sections 3.3.3, 3.3.5, 3.3.7, and 3.3.8 are focused on a component of the system. Only one table and eight lists are used throughout the main body of the manual. No images or schematics are provided. The majority of the document consists of large, bulky paragraphs.

Although not all O&M manuals are as ineffectively organized as the left-hand example provided by Osei, MassDEP receives many poorly organized manuals for numerous reasons. Determining the most effective organization of an O&M manual can be challenging. Manuals for large, complex facilities with several simultaneous processes can be difficult to organize, especially because the wastewater may not follow one linear path. Although well-revised templates can significantly enhance the organization of an O&M manual, the best way to organize an O&M manual is specific to a facility (Tidwell, 2000). Therefore, use of a template that effectively organized an O&M manual for one facility may be inadequate for another facility’s manual. The end-user (operators) should be consulted when determining the final organization of the manual to ensure that information is in a format that is accessible to them, but as previously discussed, this rarely happens (Tidwell, 2000). MassDEP’s regulations also place constraints on the O&M manual’s organization by dictating the 14 main sections that must be included.

Many of the above challenges with producing effectively organized O&M manuals could be overcome if the author spent considerable time consulting with the end-user and revising the document. However, as previously discussed, consultants are under pressure to deliver manuals within a set budget and by a tight deadline.

3.3.4 Style & Diction: Layman’s Terms vs. Engineering Jargon

One significant issue with O&M manuals is the technicality of the manual’s language (J. Corrigan, personal communication, Dec. 12, 2016). The O&M manual is frequently written using engineering jargon by a designer with several years of college education and engineering experience (J. Corrigan,

personal communication, Dec. 12, 2016; Tidwell, 2000). However, on an educational level, most operators are high school graduates. As a result, operators can perceive the O&M manual’s language as confusing and pretentious (Tidwell, 2000). The use of highly technical language can prevent operators from understanding equipment specifications and process descriptions and make reading the manual a laborious, unpleasant task (Tidwell, 2000). According to operator John Corrigan, O&M manuals need to be “dumbed down” and written in layman’s terms (personal communication, Dec. 12, 2016). Darren Langford, an operator at Worcester’s drinking water treatment facility, contends that O&M manuals should be somewhat conversational and written at a “3rd grade level” (personal communication, Dec. 15, 2016). While this may be an exaggeration, O&M manuals should at least be written clearly and concisely at the level of the operator (Tidwell, 2000). Grissop of CDM Smith suggests that through her experience working with operators, the O&M manual should be written at an 8th -10th grade level (G. Grissop, personal communication, Feb. 15, 2017).

However, it is difficult to accurately ascribe a reading level to a text to ensure that an O&M manual is not overly-complex. There are numerous readability formulas and charts that attempt to quantify the readability of a passage including the Flesch Reading Ease Score, the Flesch-Kincaid Grade Level, Gunning FOG, the Coleman-Liau Index, the SMOG Index, the Automated Readability Index, the Linsear Write Formula, the Fry Graph, the Raygor Estimate Graph, the Dale-Hall Readability Calculator, the Spache Readability Calculator, the Powers-Sumner-Kearl Readability Formula, and others.

One of the most commonly used and oldest readability formulas is the Flesch Reading Ease Score. In the 1940’s, Dr. Rudolf Flesch developed a readability formula based on sentence length and the number of syllables in each word (Wydick, 1980; Flesch, 2017). Despite numerous critics, this metric has been widely used to measure how difficult an English passage is to understand. The formula is based on the idea that short words and short sentences are easier to understand than long ones (Wydick, 1980). Longer sentences are more likely to be complex, with more subordinate clauses and prepositional phrases, which entails more work for the reader (Flesch, 2017). Similarly, multi-syllabic words are generally more difficult to comprehend (Flesch, 2017). The formula results in a score between 0 and 100 (although technically, negative scores can be produced). A score of 100 indicates extremely easy text, whereas a text scoring 0 is essentially unreadable. The following table describes the reading materials and grade levels (U.S) associated with a range of Flesch Reading Ease scores:

Table 2: Flesch Reading Ease Scores

Score	Grade Level	Level of Difficulty	Examples
100 - 90	5 th	Very Easy	Comics
90 – 80	6 th	Easy	Consumer Ads in Magazines
80 – 70	7 th	Fairly Easy	
70 – 60	8 th - 9 th	Plain English	Seventeen Magazine, Reader’s Digest, Sports Illustrated
60 – 50	10 th – 12 th	Fairly Difficult	Time Magazine, Newsweek
50 - 30	College	Difficult	Wall Street Journal, Harvard Business Review, New York Times
30 – 0 (or below)	College Graduate	Very Difficult	Standard Auto Insurance Policy, Internal Revenue Code

Flesch (2017) gives the following examples of increasingly difficult sentences and their associated score:

“John loves Mary.”
(Score of 91-92, very easy to read)

John has a profound affection for Mary.
(Score of 67, plain English)

“Even though John is not normally given to a display of his deeper emotions, he allegedly has developed a profound affection for Mary, as compared to the more equable feelings he seems to have for Lucy, Fran and, to a lesser extent, Sue.”
(Score of 31-32, difficult)

A score between 70 – 60 indicates “plain English” (Wydick, 1980). According to Georgine Grissop, based on her 30 years of experience working with operators, O&M manuals should be written at approximately this readability level (8th to 10th U.S. grade level) (personal communication, Feb. 15, 2017).

Like the Flesch Reading Ease Score, several readability formulas determine a passage’s grade level from the average sentence length and average syllables per word. Others base their formula on the number of words containing three or more syllables or the number or characters per word (Free Readability Formulas Tools, 2017). The following table summarizes seven readability formulas that were collectively used to assess the average grade level of passages from several O&M manuals, college textbooks on wastewater treatment, and a training manual written specifically for operators.

Table 3: Seven Popular Readability Tests (Free Readability Formulas Tools, 2017)

Test	Criteria	Use
Flesch Reading Ease Score	Average sentence length and average syllables per word	Used by that U.S Department of Defense. Florida requires life insurance policies to have a Flesch score above 45.
Gunning Fog	Average sentence length and percentage of hard words (words with 3+ syllables, excluding compound words, familiar jargon, proper nouns, and common suffixes)	N/A
Flesch-Kincaid Grade Level	Average sentence length and average syllables per word	Used by the U.S. Army to determine the difficulty of technical manuals. Pennsylvania requires automobile insurance policies to be at 9 th grade level or lower
Coleman-Liau Index	Average characters per word and number of sentences	N/A
SMOG Index	Number of sentences and number of words with 3+ syllables	Widely used for checking consumer-oriented healthcare material.
Automated Readability Index	Average letters per word and words per sentence	N/A
Linsear Write Formula	Number of words with 3+ syllables	Purportedly developed for the U.S. Airforce to measure the readability of technical manuals.

A major limitation of all readability formulas is that they do not consider a word’s degree of abstraction and level of familiarity to the reader (Wydick, 1980). Many technical terms found in O&M manuals that would be unfamiliar to the average 8th grade-level reader are familiar to operators. Readability formulas also do not take into account how certain elements of a text, such as use of varied sentence length and active voice, can improve clarity. However, readability formulas are useful as a crude metric to evaluate readability.

To demonstrate that O&M manuals are frequently written with highly technical language, the above seven readability formulas were used to assess the grade level of four O&M manuals. To demonstrate the relative “readability” of the O&M manuals, the grade levels of the O&M manuals were compared to two college textbooks assessed by the same formulas. The four O&M manuals were also compared to text from a widely-used training program developed for operators studying to obtain their operating license published by California State University, Sacramento. For consistency, all passages were about primary treatment.

Table 4: Comparison of O&M Manual, Operator Training Manual, and College Text Readability

Text	Type	Average Grade Level
UBWPAD Wastewater Treatment Operation and Maintenance Manual (p. 3-61)	O&M Manual	14 (college)
Wastewater Treatment System Operation and Maintenance Manual for The Woodlands Village at Hickory Hills Lake (2016) (Section 3.3.1)	O&M Manual	12
Supplemental Operations and Maintenance Manual for Woodlands Village at Hickory Hills Lake (2013) (p. 4)	O&M Manual	12
Sawyer Hill On-Site Wastewater Treatment Facility Operation and Maintenance Manual (p. 14)	O&M Manual	13 (entry-level college)
California State University, Sacramento Operation of Wastewater Treatment Plants: A Field Training Guide (p. 109)	Operator Training Textbook	13 (entry-level college)
Wastewater Engineering: Treatment and Reuse by Metcalf & Eddy (p. 396)	College Textbook	15 (graduate)
Theory and Practice of Water and Wastewater Treatment by Droste (p. 323)	College Textbook	12

When compared to the college-level textbooks, all four O&M manuals were characterized as having at least some passages that were approximately the same grade level (between 12th grade and college graduate level). While these four manuals are by no means an exhaustive representation of all O&M manuals, it is interesting that all of the manuals I analyzed were considered to be at the reading level of a high-school senior or college student. This is clearly not an isolated problem.

Interestingly, the text developed specifically for operators who are studying for the operator licensing exam was also assessed as a college-level, difficult to read text. I had assumed that this text developed specifically for operators would be at a lower reading level. In part, this may be due to the terminology used by operators; lingo such as sedimentation, pretreatment, and clarifier are multisyllabic terms that will naturally make the text seem more complicated.

It is important to note that the grade level of different sections of the manuals may vary. For instance, the discussion of primary treatment in chapter 4 of Sawyer Hill’s O&M manual (p. 14) is rated as college-

level. In contrast, the following description of primary treatment in chapter 3 of Sawyer Hill's O&M manual (p. 12) is rated at an 8th grade level (Coughlin Environmental Services, 2016):

After settling in the primary septic tank, cleaner water will flow to the FET. Two alternate pumps will pump the wastewater to the split box and equally distribute wastewater to the two trains of Bioclere. The dosing rate will be set at 35 gpm. At the design flow rate, the pumps will be set to run about 8 minutes and rest for about 4 minutes. In the early stage when the plant does not receive full design flow, this setting may need to be modified to have flow more uniformly delivered. The Bioclere will be set to recycle about 50% of average daily flow. The sludge removed during the process will be recycled back to the pretreatment tank.

Figure 7: Excerpt from Sawyer Hill's O&M Manual at an 8th Grade Reading Level

This passage falls right in line with the 8th – 10th grade reading level suggested by Grissop. The paragraphs contain short, concise sentences (an average of 17 words per sentence) and many monosyllabic words (on average 1 syllable per word). Due to short reader attention span, when the average sentence length exceeds 20 words, readers often become overwhelmed by information and lose interest. However, the sentence length of this passage varies between 9 and 26 words. Stylistically, this variation in length is preferable because short sentences engage the reader, but too many short sentences are jarring (Newell, 2017). In terms of diction, most of these terms should be familiar to an operator reading this manual. Lengthier words such as “septic,” “sludge,” and “pretreatment” are terms that operators should learn before taking their operating license exam; these three words are included in the summary of “Wastewater Words” provided in the by University of California, Sacramento training program text. Bioclere is simply the name of the system. According to Grissop, the entire O&M manual should be entirely at this level (personal communication, Feb. 15, 2017).

Unfortunately, other sections within Sawyer Hill's O&M manual are not so “readable.” The following paragraph from page 14 of Sawyer Hill's O&M manual is rated at 13 (college-level) (Coughlin Environmental Services, 2016).

To ensure that the septic tank is adequately maintained, the bottom sludge thickness can be monitored with a "sludge judge" or other suitable sampling device, which would preserve the water column separation existing in the tank. Alternately, a conservative pump schedule can be developed to ensure proper tank operation. The outlet tee extends 34 inches below the liquid level. Ideally, the sludge level should not be within 12 inches of the tee base, and scum layers should not be within two inches of the tee top; thus, the maximum sludge depth should not exceed 46 inches in the tank at any time. Given the interior dimension of the tank, this equates to approximately 1470 cubic feet of sludge storage. To reduce odor production, more frequent pumping of the solids would be beneficial, so a target maximum sludge level of 36 inches is recommended. Generally, various reference documents indicate that one person can contribute up to about 3 cubic feet of sludge per year to a septic tank system. Based upon full residential occupancy and assuming one person per bedroom, the development could have a population of 158 people resulting in an annual sludge production of about 474 cubic feet per year. On this

basis, and assuming some degradation of the sludge over time, the tank could operate for almost three years without requiring any pumping. When one also considers the waste sludge from the treatment process, a minimum annual pumping schedule is recommended for the system. Initially the operator should check the tanks semi-annually to track sludge production. If solids are detected to be escaping the tank, as a result of excessive turbulence at the inlet or otherwise, the inlet tee can be reconfigured or the outlet tee can be fitted with a screening device (effluent filter) to better ensure solid capture. It may also be necessary to adjust or increase the tank pumping frequency to further enhance solids capture.

Figure 8: Excerpt from Sawyer Hill's O&M Manual at a College Reading Level

This paragraph contains much longer, more complex sentences. The average sentence length of 25 exceeds the recommended average sentence length of 15 to 20 words for clear writing (Cutts, 2013). While the sentence length does vary between 10 and 44 words, there are two sentences longer than 40 words. The average syllables per word is 2 and 25% of the words have three or more syllables compared to 11% in the previous sample. This is an indicator of more complex vocabulary.

All too often, entire O&M manuals are written with overly technical diction and complicated syntax, like the passage from page 14 of Sawyer Hill's manual. This is because many authors have poor communication skills, especially when trying to communicate to audiences who are not fellow engineers. Beer & McMurrey (2009) begin the first chapter of A Guide to Writing as an Engineer with the quote that, "poor communication skill is the Achilles' heel of many engineers, both young and experienced" (p. 1). It is important to note that the engineers who write O&M manuals are (usually) not trained as technical writers (Tidwell, 2000). Beer and McMurrey (2009) claim that "few engineering colleges offer adequate (if any) courses in technical writing" (p. 2) and by the time students graduate, what writing skills they may have learned are rusty from lack of use. Beer and McMurrey (2009) also state that, "most engineering programs devote less than 5% of their curriculum to communication" (p. 2). However, it is inaccurate to say that all engineers who write O&M manuals have never received formal training in technical writing (G. Grissop, personal communication, Feb. 15, 2017). For instance, Georgine Grissop of CDM Smith was required to pass a technical writing class to obtain her B.S. in Environmental Science and her M.S. in Civil Engineering at Northeastern. Yet, one or two classes in technical writing may not provide adequate training in the discipline of technical writing.

Much of the challenge that engineers face in creating technical documents stems from misunderstanding the needs of the audience. In technical writing, it is essential that the work bridges the gap between the writer and the target audience that is generated by discrepancies in ability, knowledge, or interest (Beer and McMurrey, 2009, p. 48). To bridge this gap, the writer must know who the audience is and "have a clear idea of their technical knowledge, expectations, and attitude towards the subject" (pg. 49). Unfortunately, "engineers often write without taking adequate time initially to consider the nature, needs, interest, levels of expertise, or possible reaction of those who must read their work" (Beer and McMurrey, 2009, p. 48).

According to the Insider's Guide to Technical Writing, "engineers, developers, and other technical specialists often have one thing in common: their high level of expertise makes it difficult for them to think and communicate at a level all users understand" (Van Laan, 2012, n.p.). Because engineers are so

familiar with their own design and technology, they often do not realize they are leaving out critical information in their writing for customers. Often times, engineers incorrectly assume that readers possess the knowledge to understand the assumptions made by the engineer, which makes it difficult for a typical user to follow their logic (Van Laan, 2012; Beer & McMurrey, 2009). Alternatively, engineers may use terminology that is common within their discourse community of fellow engineers, but unfamiliar to operators. As a result, the O&M manual is frequently written in technical language that is too complicated for operators (J. Corrigan, personal communication, Dec. 12, 2016). This is why, according to Tidwell (2000), the importance of understanding the audience of the O&M manual cannot be overstated.

Due to pressures from multiple audiences, consultants often confuse the primary audience of an O&M manual. One could contend that the existence of the regulations themselves cause this “audience confusion” because the desire to satisfy the MassDEP’s requirements obscures the fact that the manual should be useful to the operator. When the writing engineer focuses on producing a document that fulfills the regulatory requirements, they can throw everything together in a way that meets requirements, but is in no way useful to the operator.

Alternatively, even when consultants have identified the correct target audience, the imagined purpose of the O&M manual does not align with the needs of the target audience. According to Principal Engineer Wayne Bates, while the manual is written for the operator, it is 70-80% tailored to meet the MassDEP’s regulations (personal communication, Nov. 21, 2016). Many consultants share this seemingly contradictory sentiment that you write an O&M manual for the operator, but its purpose is to meet the regulations. This misguided strategy stems from the belief that the O&M manual is just another task to cross off the “to-do” list in order to obtain the Groundwater Discharge Permit (W. Bates, personal communication, Nov. 21, 2016; M. Johnson & K. Sangrey, personal communication, Feb. 3, 2017). Authors who perceive the O&M manual as “just another task” will tailor the O&M manual more to satisfying the MassDEP’s requirements than to what the operator needs (W. Bates, personal communication, Nov. 21, 2016; A. Osei, personal communication, Nov. 18, 2016). Depending on the consultant’s familiarity with a MassDEP reviewer, the O&M manual may even be geared towards what that specific reviewer wants (A. Osei, personal communication, Nov. 18, 2016). According to MassDEP reviewer Andrew Osei, most consultants produce an O&M manual that meets the bare minimum of what is required by the MassDEP (personal communication, Nov. 18, 2016).

4 Improving MassDEP's O&M Manual Guidance

4.1 Insufficient MassDEP O&M Manual Guidance

Thus far, I have discussed issues that are prevalent in O&M manuals - inaccuracy of content, over-generalization, poor organization, and use of technical jargon – and explained why these issues are so common. Some of these reasons, such as the timeline for review by MassDEP, the writer's budgetary constraints, and writer's lack of experience out in the field, would require broad procedural or regulatory changes that cannot be easily implemented. Other reasons behind problems frequently found in O&M manuals are related to the writing process. For example, consultants who write O&M manuals often fail to recognize the needs of the operators or communicate with them. Without technical writing training, it seems that engineers may be predisposed to ignore their audience.

Perhaps, with adequate guidance, consultants could be encouraged to more carefully consider the needs of operators instead of focusing on satisfying MassDEP's requirements. However, Massachusetts lacks a guidance document that adequately addresses the specific challenges of writing O&M manuals for wastewater treatment facilities in the state. Therefore, I revised MassDEP's O&M Manual Guidelines to include more advice concerning the common deficiencies of O&M manuals and the reasons for those deficiencies. It is my hope that the revised guidelines will better assist authors of O&M manuals. Before revising MassDEP's O&M Manuals Guidelines, I first analyzed the document's weaknesses, which are described below.

As briefly discussed in the beginning of this report, the only guidance document that pertains to O&M manuals for WWTFs in Massachusetts (other than the regulations themselves) is within MassDEP's *Guidelines for the Design, Construction, Operation, and Maintenance of Small Wastewater Treatment Facilities with Land Disposal* (2014). The nine-page section called "Operation and Maintenance Plan" primarily describes what content should be included in the O&M manual. This document is marginally useful to first-time writers of an O&M manual for a wastewater treatment facility in Massachusetts because the document is more specific about MassDEP's expectations than the regulations. Unfortunately, for any consultant, it might not be obvious that this guidance on O&M manuals is buried within a much larger 157-page document.

MassDEP's O&M Manual Guidelines are not well-organized. Section "Operation and Maintenance Plan" is not complete because it only discusses 11 of the 14 sections mandated by MassDEP. One redeeming feature of the guidance document's organization is that 11 of the 14 sections are discussed individually in the order that is dictated by the regulations. However, the "Personnel" section contains a disproportionately long description of personnel and staffing requirements, responsibilities of the staff, and how to calculate minimum operator coverage. Unlike every other section, the description of this section provides a detailed explanation of the regulations rather than informing the reader what content is appropriate to include under "Personnel." It appears as if this section did not have a place elsewhere in the larger 157-page document and was inserted haphazardly into the discussion of O&M manuals. In the "Maintenance" section, there is a random warning that "only equipment or materials associated with the treatment plant are allowed to be stored within the confines of the WWTP" (MassDEP Division of Watershed Permitting, 2014, p. 123). This is not relevant to the content that should be incorporated into the "Maintenance" portion of an O&M manual.

Other than dictating the 14 sections that must be addressed and their order, there is little guidance as to how to structure the document within the sections. The only mention of organizational structure within a section can be found in “Description, Operation and Control of Wastewater Treatment Facilities,” which states that “each component [of the treatment process] should be presented in a sequential order and discussed individually” (MassDEP Division of Watershed Permitting, 2014, p. 116).

MassDEP’s O&M Manual Guidelines focus on what content to include in an O&M manual. The guidelines say little-to-nothing regarding sentence-style, level of detail, or the technicality of the language used. With regard to level of detail, the guidance briefly mentions whether a description should be “detailed” or “general” three times, which are found in the “Introduction,” “Permits and Standards” and “Description of Operation and Control of Wastewater Treatment Facilities” sections. The only comment with regard to style is that the “Description, Operation and Control of Wastewater Treatment Facilities” section should be a narrative.

In addition, there is little discussion of the O&M manual’s multiple purposes and audiences, or the tensions associated with trying to appease multiple audiences. In the “General” introduction section, two sentences are used to discuss the purpose and audience of the O&M manual. Lastly, the guidance document does not contain examples of good or poor passages from manuals. The following table summarizes the writing advice provided by MassDEP’s O&M Manual Guidelines, excluding discussion of what content should be included in each section.

Table 5: Writing Advice Provided in MassDEP's O&M Manual Guidelines

	Section	Writing Advice Beyond What Content Should be Included
a	Introduction	“general description”
b	Permits and Standards	“detailed description of responsibilities”
c	Description, Operation, and Control of Wastewater Treatment Facilities	“each component should be presented in a sequential order and discussed individually” “information can be incorporated into body...or appendices” “narrative” “provide detailed instructions”
d	Description, Operation, and Control of Sludge Handling Facilities	None
e	Description, Operation, Control and Testing of the Chemical Addition and Monitoring System	N/A
f	Personnel	None
g	Sampling and Laboratory Analysis	None
h	Records and Reporting	None
i	Maintenance	None
j	Emergency Operating and Response Program	None
k	Safety	None
l	Utilities and Energy Requirements	None
m	Infiltration and Inflow Removal	N/A
n	Emergency Notification Procedures for overflows or bypasses in accordance with 314 CMR 12.03(8)	N/A

The deficiencies in MassDEP’s O&M Manual Guidelines described above mean that no guidance pertaining specifically to O&M manuals for wastewater treatment facilities in Massachusetts adequately addresses the problems commonly found in O&M manuals, which include inaccuracy of content, over-generalization, poor organization, and use of technical jargon.

Unfortunately, I cannot be certain that MassDEP’s O&M Manual Guidelines would be consulted even if they provided more direction on how to satisfy the needs of operators through appropriate use of organization, level of detail, style, and diction. Though aware of the MassDEP’s O&M Manual Guidelines, Principal Engineer Wayne Bates does not use them when writing O&M manuals (personal communication, Nov. 21, 2016). Likewise, Georgine Grissop does not rely on guidance to write O&M manuals in Massachusetts; she is so familiar with the state’s regulations that she does not need to reference MassDEP’s guidance (personal communication, Feb. 15, 2017). Both Grissop and Bates suggested that the templates provided by their companies ensure that their O&M manuals meet MassDEP’s requirements (personal communication, Feb. 15, 2017; personal communication, Nov. 21, 2016).

However, Grissop stated that when she first learned how to write O&M manuals and the first time she writes an O&M manual in another state, she looks at the guidelines developed by the state (personal communication, Feb. 15, 2017). Much in the same way that O&M manuals are primarily used by new hires, the authors of O&M manuals only use guidance on writing O&M manuals when they are “new to the job.” Guidance on how to write O&M manuals is particularly important for engineering firms who do not frequently produce O&M manuals in Massachusetts.

It is my hope that if MassDEP’s O&M Manual Guidelines contained more advice concerning the problems discussed in the previous sections of this report (inaccuracy of content, over-generalization, poor organization, and use of technical jargon), they would better assist first-time authors of O&M manuals for facilities in Massachusetts. Before providing recommendations on how to revise MassDEP’s O&M Manual Guidelines, I will first analyze guidelines published by the US EPA, other states, and non-regulatory groups/persons, which will help inform my revisions.

4.2 Review of Other O&M Manual Guidance

Although there is only one guidance document that specifically addresses O&M manuals for wastewater treatment facilities in Massachusetts, there are a limited number of other guidance documents relating to O&M manuals for WWTFs. Many of these guidelines, which have been published by other states, the EPA, non-governmental organizations, and individuals, do a better job of addressing the common deficiencies of O&M manuals than MassDEP’s O&M Manual Guidelines. However, these documents still do not provide adequate guidance to help authors negotiate the challenges and constraints that interfere with O&M manuals meeting their audiences’ needs.

4.2.1 O&M Manual Guidance from Environmental Protection Agency

In 1973, the U.S. Environmental Protection Agency (EPA) published a document called “Considerations for Preparation of Operation and Maintenance Manuals” written by three Professional Engineers. The 236-page document provides an extremely detailed account of how to produce “complete and adequate municipal wastewater treatment plant operation and maintenance (O&M) manuals” (U.S. EPA, 1973, p. iii). The document was created as a substantial revision of existing EPA guidance. These revisions were

informed by survey of existing O&M manuals, questionnaire responses by municipal wastewater treatment facilities, and field trips, among other resources. For the remainder of the report, this document will be referred to as “EPA’s O&M Manual Guidance.”

Unlike MassDEP’s O&M Manual Guidelines, EPA’s O&M Manual Guidance is extremely comprehensive. In fact, the document is perhaps the most comprehensive document pertaining to the creation of O&M manuals specifically for wastewater treatment. However, the federal document still does not address the specific requirements of any state.

Interestingly, EPA’s O&M Manual Guidance begins with conclusions and recommendations gathered from a survey of O&M manuals, questionnaire responses from hundreds of municipal WWTFs, conferences, fieldtrips to facilities, review of relevant EPA programs, and input from sanitary design engineers. Providing these findings make the reader conscientious of the constraints that may be impacting the success of their O&M manual. Despite being over 40 years old, the EPA’s conclusions echo many of the findings I gathered through interviewing professionals who write, review, and use O&M manuals. The following list summarizes the EPA’s findings (U.S. EPA, 1973, pp. 1-2):

1. The content and preparation costs of O&M manuals for municipal WWTFs vary widely, primarily due to a lack of comprehensive guidance that is applicable to facilities of all types and sizes.
2. The purpose of an O&M manual is to provide operators with the “proper understanding, techniques, and references necessary to efficiently operate their facilities” (p. 1).
3. Many O&M manuals contain a few exceptional parts, but the majority of the document is inadequate.
4. Manuals that are written like engineering reports are insufficient.
5. There are few good O&M manuals; these manuals were produced through collaboration between operator and engineers.
6. A common problem with O&M manuals is their language because they are written by engineers.
7. To benefit a facility, O&M manuals must be targeted at operators, not design engineers.
8. Many facilities undergoing enlarging/upgrading have either inadequate O&M manuals or no manual.
9. With practice, a consulting firm will become more efficient at producing manuals.
10. The wishes of the client primarily dictate the O&M manual’s level of detail.
11. O&M manuals’ organization must be flexible in order to be continuously updated.
12. Treatment facilities without O&M manuals generally acquire sufficient equipment manufacturer’s data to make a makeshift manual, but this is still inadequate.

In light of these findings, the authors of EPA’s O&M Manual Guidance believe that engineers would benefit from a comprehensive guidance document to “help ensure consideration of all pertinent O&M topics during the development of the manual” (U.S. EPA, 1973, p. 3). Unlike MassDEP’s O&M Manual Guidelines, Section 2 of EPA’s O&M Manual Guidance provides recommendations that address problems associated with the author’s writing process. The document recommends that writers of O&M manuals consult an experienced operator, receive training on O&M manual preparation, strive for flexibility in their documents, and insure that information on all equipment items is accurate and timely (U.S. EPA, 1973, p. 3).

Section 4 titled, “Writing Skills Required in an O&M Manual Preparation,” clearly explains the purpose and identifies the primary audience of O&M manuals. This is important because engineers must be

cognizant of their primary purpose and audience during the writing process. Section 4 also states that “the key to a manual’s ultimate success is the language used and writing style” (U.S. EPA, 1973, p. 9). In my research, EPA’s O&M Manual Guidance is the only guidance specifically concerning the preparation of O&M manuals for wastewater treatment facilities that addresses style and diction. According to the document, there are two main problems that must be considered when writing an O&M manual:

1. translation of design engineers’ concepts into language that operators can understand, and
2. determination of operators’ comprehension level.

It is significant that EPA’s O&M Manual Guidance highlights the importance of style and diction; all too often, engineers are not predisposed to think about their audience or the language and sentence-structure that best suits them. EPA’s guidance goes beyond simply stating that language and style are important. The guidelines state that the language used in the document itself provides an example of the writing style that should be acceptable to operators.

The organization of the document is also intended to serve as a template for the organization of an O&M manual. Unfortunately, EPA’s O&M Manual Guidance provides only a few examples of text from a real/hypothetical O&M manual (one instance is shown below). However, several sample images and tables are incorporated into the guidance.

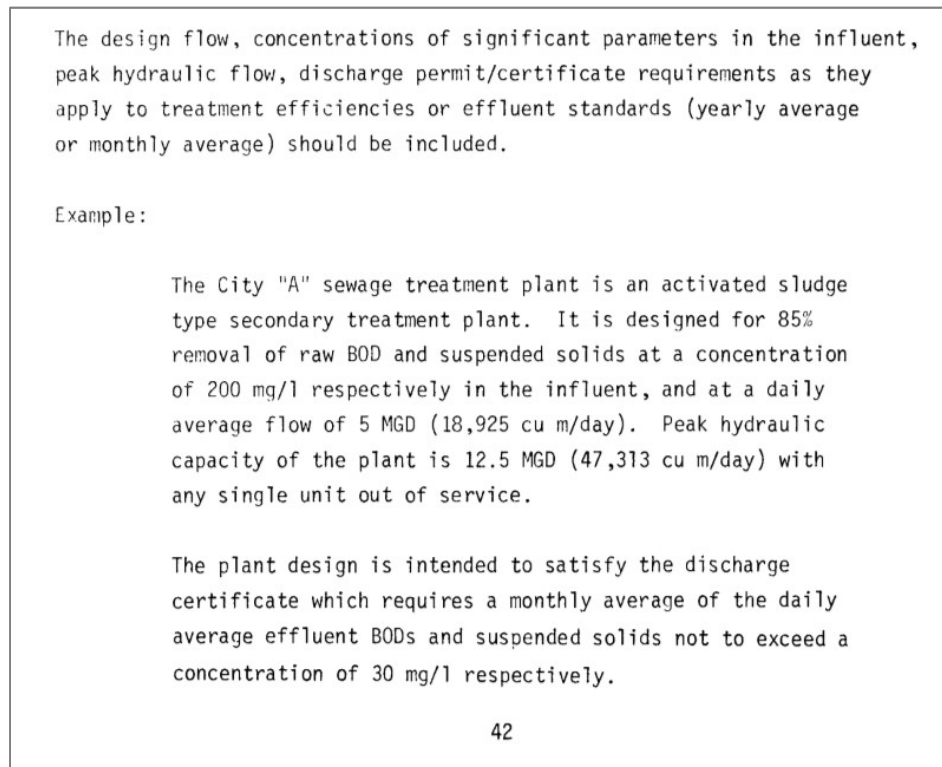


Figure 9: Example Provided in EPA's O&M Manual Guidance

Like MassDEP’s O&M Manual Guidelines, EPA’s guidance document first discusses O&M manuals generally and then discusses each section individually. However, the EPA document’s discussion of each section does not simply explain what content should be included in the section. Rather, it explains *why* that content should be included, how detailed the content should be, and how that content should be

organized, as shown in the excerpts from the section “Description of Plant Type and Flow Pattern” below (U.S. EPA, 1973, p. 43). Key phrases are underlined in red.

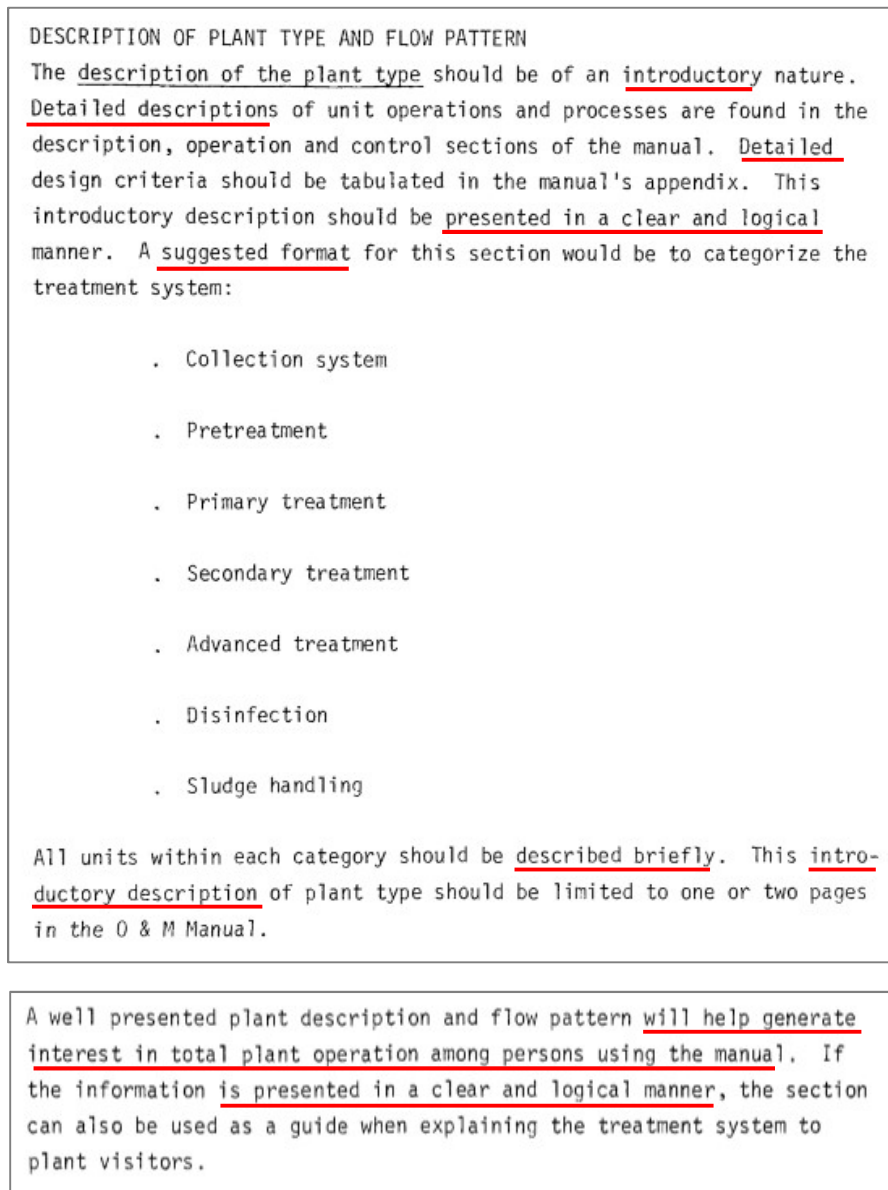


Figure 10: Discussion of Level of Detail and Purpose in EPA's O&M Manual Guidance

Discussion of level of detail, organization, and the purpose of each section for the audience is not exclusive to this passage, but carried throughout the guidance document.

Overall, EPA's text is extremely comprehensive. However, the intended goal of the document – to “help ensure consideration of all pertinent O&M topics during the development of the manual” – does not appear to be very successful (U.S. EPA, 1973, p. 3). Despite this document's publication, reviewers at the MassDEP still receive O&M manuals that vary greatly in content and quality. Perhaps EPA's O&M Manual Guidance document is too comprehensive; 236 pages is a lot of material to sift through. This document is also outdated and does not address electronic O&M manuals. If the document were in a navigable

document containing hyperlinks and athetically pleasing formatting, 236 pages might not seem so cumbersome. Lastly, this feredal document is not state-specific, which means that the document does not address some of the constraints that are imposed specifically by MassDEP’s regulations.

4.2.2 O&M Manual Guidance from Other State’s Environmental Regulatory Agencies

In addition to MassDEP, several other states’ environmental regulatory agencies have produced guidance on O&M manuals for wastewater treatment facilities including Minnesota, Tennessee, Oregon, New Jersey, and Virginia. In her interview, consultant Georgine Grissop of CDM Smith indicated that the states’ guidance documents are to varying extents based off of the EPA’s O&M Manual Guidance (personal communication, Feb. 15, 2017). Consequently, some of the states have similar documents.

Unlike MassDEP’s O&M Manual Guidelines, the guidance provided by other states contain much more in-depth discussion of the O&M manual’s audiences and purpose in their introduction. The first two paragraphs of Minnesota’s “Wastewater Treatment Facility Operation and Maintenance (OM) Guidelines” are dedicated to discussing the purpose and primary audience of the O&M manual. The guidelines state explicitly that O&M manuals have two main purposes: consultants use the O&M manual to train operators when the plant first begins operation and operating staff use the manual to maintain and operate the system once the plant is operational. Minnesota’s guidance identifies that O&M manuals often prove to be inadequate for the operators because authors have misguided strategies. The document states in bold that O&M manuals “**must be oriented toward the treatment plant operators**” (Minnesota Pollution Control Agency, 2000, p. 1).

Tennessee’s “Guidelines for the Preparation of Wastewater Treatment Facility Operation and Maintenance (O&M) Manuals” is structured and worded very similarly to Minnesota’s guidelines. The first two paragraphs of Tennessee’s guidelines also discuss the manual’s primary purpose and state that O&M manuals “must be written for use as a practical tool by the treatment plant operators” (Tennessee State Government, n.d., p. 1). Reinforcing these concepts is important because operators often confuse the primary audience of the O&M manual.

It was previously discussed that an author’s desire to satisfy a state’s regulations often obscures the fact that the manual should be useful to the operator. Both Tennessee’s and Minnesota’s guidance documents emphasize the critical idea that the O&M manual should not be written just to satisfy the agency’s review, but to provide adequate operation and maintenance instructions to plant operator(s). As a way of ensuring that the O&M manual satisfies operators’ needs, the two documents contend that operators must be consulted in the preparation of O&M manuals because “this will make the manual more usable to the operator and easier to upgrade” (Tennessee State Government, n.d., p. 2; Minnesota Pollution Control Agency, 2000, p. 2). Both states’ guidance documents discuss the manual’s level of detail, stating that the manual should be comprehensive enough to serve as a “textbook” for operator training. One common issue in Massachusetts is that the first draft of the O&M manual is often the only draft. Both Minnesota’s and Tennessee’s guidelines state that the manual must be revised to include information about actual plant operation obtained during the first year of operation. Lastly, both guidelines address the limitations of their guidance, stating that the guidelines are merely suggestions and not necessarily the best way to accommodate operators’ needs.

Oregon’s “Preparation of Operations and Maintenance Manuals for Domestic Wastewater Treatment Facilities” begins with a general description of O&M manuals that touches upon the manual’s purpose,

level of detail, and organization. In terms of level of detail, the guidance recommends that O&M manuals be “complete and thorough, but easy to use” and instructs the author to “avoid boilerplate language in favor of information that is specific to the treatment plant” (Oregon Department of Environmental Quality, 2012, p. 2). As stated in EPA’s O&M Manual Guidance, O&M manuals that are written like engineering reports are totally inadequate. Oregon’s document addresses this issue by instructing authors not to copy the Facilities Plan or Predesign Reports. The document also contends that information will be more accessible to the reader if the O&M manual contains more images and tables and less narrative. All of these recommendations are important tools that an author can employ to meet the needs of the primary audience.

It is imperative that an O&M manual acts as a living document. This is especially emphasized in the overview of O&M manuals found in New Jersey’s “Operation and Maintenance Assessment Guide for Wastewater Treatment Plants” shown in Figure 11 below (N.J. Department of Environmental Protection, 2016, p. 2). Each phrase related to the O&M manual functioning as a living document and its organization is underlined in red.

Overview

A WWTP O&M Manual should provide system operators with comprehensive guidance, procedures, and the necessary technical references to efficiently operate their facility. The O&M Manual should be a dynamic document that is written to be easily understood. It must be organized in a manner so that plant personnel can readily locate necessary information and so that it can be easily modified to reflect changes to the treatment system operation and maintenance. NJPDES regulations 7.14A-6.12(c) require that an O&M manual for the treatment works and related appurtenances and collection systems be completed. Additionally, NJPDES regulations require that “the operation and maintenance manual shall be amended whenever there is a change in the treatment works design, construction, operations or maintenance which substantially changes the treatment works operations and maintenance procedures” (7.14A-6.12 (c) 2). It is important that the O&M Manual is also routinely updated to reflect changes in personnel and contact information, particularly with regard to the Emergency Response Plan. When changes are made to the O&M Manual it is suggested that these changes be logged so that plant personnel can see the last date that different sections of the Manual have been updated.

Figure 11: Discussion of Timeliness and Organization in New Jersey’s O&M Manual Guidance

To make it easier to continuously update an O&M manual, Minnesota’s, Tennessee’s, and Oregon’s O&M manual guidelines all suggest that a hardcopy manual be bound in a 3-ring binder. Oregon’s and New Jersey’s documents identify the advantages of using electronic manuals, which makes it easier to reorganize the manual to accommodate changes to the facility and allows the operator to quickly and intuitively find information.

Virginia’s Department of Environmental Quality provides guidance on O&M manuals in the form of a template. While this guidance has only a brief mention of the manual’s audiences and purposes, it provides examples for most sections of the O&M manual. This is particularly useful to the authors of O&M manuals because it demonstrates the level of detail and style of language that should be used in an O&M manual. Seven readability tests rate excerpts of the examples provided in Virginia’s template at

an average grade level of 9, which corresponds to the 8th -10th grade level recommended by Georgine Grissop based on her experience working with operators (personal communication, Feb. 15, 2017).

Like MassDEP’s O&M Manual Guidelines, each state’s guidelines discuss each section of the manual in greater detail with an emphasis on the content that should be included in the section. However, these manuals integrate much more writing advice (other than what content should be included) throughout the document than MassDEP’s O&M Manual Guidelines. The following tables summarize the writing advice provided in O&M manual guidance published by Minnesota, Tennessee, Oregon, New Jersey, and Virginia, excluding discussion of what content should be included in each section.

Table 6: Writing Advice Provided in Minnesota’s O&M Manual Guidance

	Section	Writing Advice Beyond What Content Should be Included
1	Introduction	“general description of plant type” “design summary”
2	Permits	None
3	Operation and Control of Wastewater Treatment	“individually discuss each category of units and auxiliary systems” “Note: many of these sections need not be very detailed, if references can be made to other area of the O&M manual” “detailed step-by-step procedure for making adjustments and receiving feedback”
4	Operation and Control of Sludge Handling	“Individually discuss each category of units involved with handling sludge”
5	Personnel	None
6	Process Control and Laboratory Testing	“review each unit individually and discuss the laboratory tests and test results as they apply to that unit” “Give instruction for conducting tests or taking physical measurements, including interpretation of test results or measurements (i.e. expected range, what high or low ‘Discuss and provide examples of records values may indicate, etc.)...”
7	Records	“Discuss and provide examples of records”
8	Maintenance	“general discussion should be complete in the final manual” “revised final manual then should include a table” “Outline purpose of maintenance program”
9	Emergency Operating and Response Program	None
10	Safety	“General safety discussion”
11	Appendices	“The appendices should be a bound manual with Table of Contents, tabs or other indexing system, page numbers, etc., for easy reference”

Table 7: Writing Advice Provided in Tennessee’s O&M Manual Guidance

	Section	Writing Advice Beyond What Content Should be Included
1	Introduction	“tabular design summary”
2	Operation and Control of Wastewater Treatment	“it is not the intent of this manual to discuss detailed theory. Rather than this, other pertinent reference manuals should be purchased and referenced”
3	Operation and Control of Sludge Handling	None
4	Personnel	None
5	Process Control and Laboratory Testing	“in the past, O&M manuals have been quite inadequate in the area of applying laboratory testing to process control”
6	Records	None
7	Maintenance	Same as Minnesota
8	Safety	Same as Minnesota
10	Appendices	“the appendices should be listed in the TOC and tabbed for easy referencing”

Table 8: Writing Advice Provided in Oregon’s O&M Manual Guidance

Section	Writing Advice Beyond What Content Should be Included
Table of Contents/Homepage	“table of contents should correspond to the tabs”
Emergency Operations	“section should be separate and readily available”
General	<p>“Provide a narrative on the background and history”</p> <p>“The level of description in ODEQ’s approval letter for the project is a minimum. The engineer should be able to do better”</p> <p>“Briefly describe the type of treatment process employed”</p> <p>“Include simple schematics”</p> <p>“Describe the standby power system in detail”</p> <p>“Provide explicit procedures to be followed on loss of utility power”</p>
Operation and Control of Unit Processes	<p>“Each unit process should be under a separate tab”</p> <p>“Describe thoroughly the treatment process employed in each unit”</p> <p>“Thoroughly discuss all applicable process control parameters. equipment item in detail.” [and then gives an example]</p>
Operation and Control of Other Mechanisms	“Any of these may be sufficiently complex to warrant a separate section in the manual.”
Regulatory	None
Appendices and Attachments	<p>“General brochures and literature, if provided, should have irrelevant information marked out and/or relevant information highlighted”</p> <p>“At the writer’s discretion, any applicable charts, graphs, guidelines, or documents that may be significant and useful to plant operation and maintenance should be included in the appendix”</p>

Table 9: Writing Advice Contained in New Jersey's O&M Manual Guidance

	Section	Writing Advice Beyond What Content Should be Included
1.	Wastewater Treatment Plant Overview	None
2.	Permits and Standards	None
3.	Description, Operation, and Control of Wastewater Treatment Facilities	“Does the general description explain the entire treatment process?” “Are all treatment units and components described in detail?” “Are normal operations/procedures detailed or clarified?”
4.	Description, Operation, and Control of Sludge Handling Facilities	“Does the general description explain the sludge handling and process controls?”
5.	Personnel	“Does the O&M Manual include a current personnel organizational chart”
6.	Laboratory Testing	“Are types of required samples defined?”
7.	Records	None
8.	Preventative Maintenance	“Is preventative maintenance thoroughly discussed in the O&M Manual?” “Does the O&M Manual define the tasks required for preventative maintenance?”
9.	Emergency Operating and Response Program	None
10.	Safety	None
11.	Utilities	None
12.	Appendices	“Are all charts, tables, lists, forms, maps, schematics, manuals, warranties, etc. referenced in the O&M Manual included in an Appendices Section?”

Table 10: Writing Advice Provided in Virginia's O&M Manual Guidance

	Section	Writing Advice Beyond What Content Should be Included
A.	Title Page	None
B.	Table of Contents	None
C.	Emergency Phone Numbers	None
D.	Introduction	“Briefly describe the organization”
E.	Description of Wastes and Treatment Facility	“Describe the treatment units in detail.”
F.	Maintenance	None
G.	Spill Management Procedures	“Discuss step-by-step measures to be taken to contain and store liquid product”
H.	Effluent Monitoring Procedures	None
I.	Personnel	None
J.	Records	None
K.	SWCB Permits or Certificates	None
L.	References	None
	Appendices	None

One downfall of all of the state's O&M manual guidance is that discussion of level of detail, style, diction, accuracy, audience, and purpose is mostly confined to the brief introduction. Even though other states' guidance documents integrate more writing advice throughout the document, this advice is primarily about level of detail through use of terms such as "general," "thorough," "briefly," and "detailed." No document sufficiently describes the permittee's needs as different from the operator's.

In summary, although each state's guidance document has its merits, all could be improved. If the ideal aspects of each document were incorporated into MassDEP's O&M Manual Guidelines, the document would be vastly more helpful to the engineers who write O&M manuals.

4.2.3 O&M Manual Guidance from Other Sources

Beyond the guidelines published by environmental regulatory agencies, guidance concerning the production of O&M manuals for wastewater treatment facilities is scarce. In my research, I could find only two additional texts that were relevant to writing O&M manuals for wastewater treatment facilities. Mike Tidwell's book, "How to Produce Effective Operations and Maintenance Manuals," addresses the needs of O&M manuals' audiences, organization, level of detail, and style, among other topics. However, this text discusses the broader genre of operations and maintenance manuals for facilities in general; Tidwell's book does not address the specific challenges of writing O&M manuals for wastewater treatment facilities (let alone facilities in Massachusetts). Tidwell's book was written in 2000. Although Tidwell's book at least contains some discussion of online O&M manuals, much of the discussion is outdated.

During her first interview, Georgine Grissop indicated she has referenced "Operation of Water Resource Recovery Facilities: Manual of Practice No. 11" published by the Water Environment Federation when writing an O&M manual (personal communication, Feb. 15, 2017). Grissop identified MOP 11 as the "bible" of wastewater treatment. The text is intended to be used by the superintendent or chief operator of water resource recovery facilities across the U.S. Like Tidwell's book, MOP 11 is not specific to wastewater treatment facilities in Massachusetts.

MOP 11 contains only two paragraphs devoted specifically to O&M manuals on pages 29 and 30. This brief section provides a broad overview of the O&M manual, describing the O&M manual as "the core management tool for the facility manager to organize, administer, and respond to daily operational elements at the facility" (Water Environment Federation, 2016, p. 29). According to MOP 11, the O&M manual is a living document that defines the staff's responsibilities and establishes procedures for handling common and emergency situations. MOP 11 only mentions one audience: the facility manager.

According to MOP 11, all O&M manuals should be a compilation of the following five elements: staffing, personnel management, external relations and communication, reporting and recordkeeping, and emergency operations. These sections are not discussed as subsections of the larger section on operation and maintenance manuals. Instead, the five sections are discussed as individual entities, without much attention to how the topics should be written and incorporated into the larger O&M manual. Like MassDEP's O&M Guidelines, MOP 11 focuses almost exclusively on defining the section and what content should be included, rather than style, organization, or level of detail. Writing advice provided by MOP 11, excluding discussion of what content should be included in each section, is summarized in the following table.

Table 11: Writing Advice about O&M Manuals Provided in MOP 11

Section	Writing Advice Beyond What Content Should be Included
Staffing	<p>“an organizational chart should be used to convey this information”</p> <p>“should include a narrative describing elements of the organization’s structure”</p> <p>“brief description of the character of the work....”</p> <p>“although an organizational chart can provide a snapshot of an organizational structure, in reality the organization works in a much more fluid and dynamic way”</p>
Personnel Management	None
External Relations and Communication	None
Reporting and Recordkeeping	None
Emergency Operations	None

Neither of MOP 11 or Tidwell’s book would provide adequate guidance to an author writing an O&M manual for a wastewater treatment facility in Massachusetts for the first time. Although Tidwell’s book includes useful advice concerning technical writing, it does not address the specific information that must be included to satisfy MassDEP’s review. MOP 11 lacks any concrete guidance about how to organize and write an O&M manual for wastewater treatment facilities in Massachusetts.

4.3 Revision of MassDEP O&M Manual Guidelines

In the following section I share my revisions to MassDEP’s O&M Manual Guidelines, which address common weaknesses found in O&M manuals that are a product of the author’s writing process. These revisions provide recommendations on how to best tailor the O&M manual to the primary audience. In my revisions, I embrace the best aspects of the O&M manual guidelines that were analyzed in the above sections. However, my revisions go beyond these guidance documents to include information gathered through my interviews, tips from manuals on style, and examples of appropriate style and diction.

4.3.1 Acknowledging the Pressures of Multiple Audiences

As previously discussed, authors of O&M manuals rarely take the time to adequately consider the nature, needs, and comprehension-level of the operators who must read their work. Although the first sentence of MassDEP’s O&M Manual Guidelines indicates that the O&M manual is for “treatment system personnel,” the guidelines do not emphasize the importance of ensuring that the manual is written in a way that operators can use and understand it. MassDEP’s O&M Manual Guidelines also do not acknowledge the manual’s secondary audiences: MassDEP and the permittee. In light of the manual’s multiple audiences, a primary goal in revising MassDEP’s O&M Manual Guidelines was to establish the importance of orienting the O&M manual toward operators and provide tips on how the author can do so. For example, I revised the first line of the general overview of O&M manuals to clearly identify operators as the target audience as shown below. Text in blue has been added. Text in red has been deleted.

X. OPERATION AND MAINTENANCE PLAN

General: Overview of O&M Manuals

The purpose of the Operation and Maintenance (O&M) manual is to provide operators ~~treatment system personnel~~ with the proper understanding, techniques, and references needed ~~of recommended operating techniques and procedures, and the references necessary~~ to efficiently operate and maintain a particular wastewater treatment facility (WWTF) ~~their facilities~~. ~~The operations plan for the collection system is covered in Sections V and IX (K)~~. This includes a

Figure 12: An In-Depth Overview of O&M Manuals

After the “Overview of O&M Manuals,” I include an in-depth section on the O&M manual’s three audiences: operators, MassDEP, and the permittee. To encourage authors to recognize that operators are the primary audience, I first stress that, “**the O&M manual must be oriented toward treatment plant operators.**” After giving a brief definition of each of the three audiences, I acknowledge the challenge inherent in trying to accommodate three distinct audiences so that the author reflects on this difficulty. I then reiterate the importance of writing O&M manuals for operators despite these challenges. To help authors understand how each audience uses the manual, I describe each audience’s occupational duties and why they use the manual. I also remind authors that although most operators are high school graduates, they must pass an exam to become licensed. This is important because operators’ educational background impacts what type of language, detail, and information should be provided. Authors must not over or underestimate operators’ level of comprehension. These revisions are shown below.

The O&M Manual's Multiple Audiences:

The O&M manual must be oriented toward treatment plant operators. However, the O&M manual has three distinct audiences:

- **operator(s)** – the person(s) responsible for operation and/or maintenance of the treatment facility
- **MassDEP** – Massachusetts Department of Environmental Protection, which is the regulatory agency responsible for reviewing and approving the O&M manual
- **permittee/owner** – the organization that owns or manages the treatment facility

The engineers who write O&M manuals must contend with the challenge of communicating information to these three audiences. Due to differences in education level and expertise, each audience has different needs and expectations, some of which can be conflicting. As you write the O&M manual, do not lose sight of the fact that the O&M manual must be written for the operator(s). Each audience is described in further detail below.

Operators:

All wastewater treatment systems in Massachusetts are operated by licensed technicians. To acquire their license, operators must pass an exam. Although many operators take training courses provided by NEIWPCC, operators acquire most of their technical knowledge through on-the-job training and apprenticeships. Wastewater treatment plant operators typically have a high school diploma or equivalent. It is important not to over or underestimate the comprehension level of operators. Operators primarily use the O&M manual as a reference when they are a new hire or in the event of equipment malfunction. At large facilities, senior operators may develop training programs based on the O&M manual.

Permittee/Owner

The permittee, or owner, is legally responsible for the successful operation of the treatment facility. The owner may be a management association, a board of trustees, or a company. The

Figure 13: Discussion of Multiple Audiences

4.3.2 Establishing the Importance of O&M Manuals

Authors often perceive the O&M manual as just another “box to check off” when obtaining the system’s groundwater discharge permit. Therefore, many authors share the misguided strategy that the O&M manual should be written simply to satisfy MassDEP’s regulations. This results in hastily composed and disorganized documents that are useless. Consequently, I explain in the overview section that O&M manuals are critical to the successful operation of a treatment facility. I emphasize that the quality of the O&M manual impacts how well the facility operates. By highlighting the importance of O&M manuals for training new operators and remedying time-sensitive equipment malfunctions, I hope to make authors appreciate the need for an adequate and carefully composed manual.

O&M manuals are important to the safe and economical operation of a wastewater treatment facility. A thorough O&M manual can give WWTFs a measure of security during times of crisis and staff turnover by providing reliable guidance to responsible operators. *The adequacy of a wastewater treatment plant's O&M manual plays a significant role in determining how well the facility operates.* Before discussing the specific information that should be included in an O&M manual, this guidance document describes the multiple audiences who use O&M manuals and provides tips to help you ensure that the manual is adequate for the operator(s). This guidance is for authors writing O&M manuals for all wastewater treatment facilities that must adhere to 314 CMR 12, except Industrial Wastewater Pretreatment Systems (IWPS).

Figure 14: The Importance of O&M Manuals

4.3.3 Providing Writing Advice

After establishing that the O&M manuals are crucial documents that must be written for operators and not just to satisfy MassDEP's requirements, I provide tips on how to make the manual useful and readable to operators. As previously discussed, MassDEP's O&M Manual Guidelines do not provide any advice on writing style and language, include only three brief mentions about appropriate level of detail, and, in terms of organization, only recommend that each process be discussed in sequential order. My writing tips are not comprehensive, but are the most important recommendations that I distilled through interviews, other guidance on O&M manuals, and books on writing style. The advice is divided into sections on general writing advice, tips on accuracy and relevance of content, advice about level of detail, organizational recommendations, and advice about language and style.

4.3.3.1 General Writing Advice

The "General Tips" provide broad recommendations to help the author avoid creating an O&M manual that fails to meet operators' needs. Since engineers are inclined to use terminology and assumptions that are common among fellow engineers but are unfamiliar to operators, the first tip reiterates that the manual should be written for operators and not design engineers. The second tip directly addresses authors' tendency to produce an O&M manual that meets the bare minimum of what is required by MassDEP. The third strongly encourages authors to consult with the operator(s) who will use the manual because the best way to determine the end-users' needs is by asking them directly.

General Tips:

1. To benefit a facility, O&M manuals must be targeted at the operator(s), not design engineers. Manuals that are written like engineering reports are totally insufficient.
2. Do not write the O&M manual just to satisfy the MassDEP; write it to provide adequate operation and maintenance instructions to plant operator(s). The requirements of the MassDEP are a minimum. The engineer should be able to do better.
3. Good manuals are produced in collaboration with the operator(s) who will use the manual.

Figure 15: General Writing Advice

4.3.3.2 Advice on Accuracy of Content

The second set of tips, “Accuracy and Relevance of Content,” first explain that the manual is virtually worthless if not updated regularly. Due to the structure of MassDEP’s regulations, often the first draft of an O&M manual, which was written and submitted to the MassDEP before the facility began operation, is the only draft. As a result, the manual does not reflect how the plant actually operates. The first tip strongly advises the author to revise the manual after it is submitted to MassDEP so that it reflects how the plant operates once the facility goes online. The second tip reminds authors that the O&M manual should be updated to reflect any change at the facility, not just after operation begins. Lastly, authors are reminded that the O&M manual should not contain extraneous information because the operator should not have to wade through unnecessary or false details to find the information he or she needs.

Accuracy and Relevance of Content:

O&M manuals are essentially useless if not updated regularly to reflect how the plant actually operates. During a time-sensitive equipment malfunction or emergency, the operator must be able to reference accurate and up-to-date information. If the manual describes how the facility operated three years ago, and the equipment has been modified, the operator will not be able to quickly remedy an equipment failure. An accurate and up-to-date O&M manual also minimizes the learning curve for new hires.

1. The O&M manual must be updated once the facility begins operating to ensure that the manual reflects how the plant actually operates.
2. O&M manuals should be *living documents*, which means that they should be updated regularly to reflect any changes at the treatment facility.
3. The O&M manual should not contain any extraneous information that does not apply to that specific treatment facility.

Figure 16: Advice on Accuracy and Relevance of Content

4.3.3.3 Advice on Level of Detail

The next section of tips concerning level of detail further elaborate the point that the manual should contain only as much detail as the operator requires to run and maintain the treatment facility. The first three tips encourage the author to ensure that the manual is detailed enough for the operator to run that facility. The fourth tip recommends that level of detail increase throughout each section because high level of detail at the beginning of the section can overwhelm a reader. Authors are advised to be wary of the dangers of using templates; template-based manuals must be carefully revised to ensure that they do not include overly general process descriptions or inaccurate information belonging to another facility.

Level of Detail:

Determining the level of detail, or the “amount and type of information,” is a critical step in manual planning that should not be taken lightly. While an O&M manual that contains excessive detail is not an effective tool, a manual that is not sufficiently specific will be equally as useless to an operator. Determining the appropriate level of detail can be difficult, especially because it varies from section to section.

1. Ideally, an O&M manual is detailed enough to allow an operator who has never worked at a particular facility to run the facility.
2. More often than not, be more specific.
3. Manuals that are written from the engineer’s designs plans are not specific enough.
4. Level of detail should gradually increase within each section because too much detail at the beginning can confuse or intimate the reader.
5. When using a template, be sure to avoid general language and inclusion of inaccurate information.

Figure 17: Advice on Level of Detail

4.3.3.4 Advice on Organization

The advice on organization provides more concrete recommendations. I first explain that organization is key in enabling operators to quickly and intuitively find information, which is especially critical in emergency situations. I encourage authors to use a simple and consistent structure that discusses processes in the same order as the flow of wastewater through the system. This method of organization is easiest to follow and helps operators understand the relationship between processes. I also advise authors to use tables, lists, figures, bolding, highlighting, headings, table of contents with corresponding page numbers, and other visuals that improve the ease with which operators can locate information.

Organization:

An operator must be able to easily and intuitively find information within an O&M manual. Operators should not have to read an essay to find a specific piece of information. This is especially important when operators need to find information quickly to remedy a time-sensitive equipment malfunction. Therefore, an O&M manual must be well-organized. Well organized O&M manuals are also easier to frequently update.

1. O&M manuals should have a simple and consistent structure.
2. Discuss processes in the same order that wastewater flows.
3. When practical, use tables, lists, figures, and other visuals to convey information.
4. Emphasize especially important information through bolding, italicizing, underlining and/or highlighting.
5. Use multiple levels of headings to break up sections.
6. O&M manuals’ organization must be flexible in order to be regularly updated.
7. The table of contents should be specific and accurate; each entry should correspond to a page number.
8. Put design specifications and any infrequently used information that must be included per the regulations in the appendices.

Figure 18: Advice on Organization

4.3.3.5 Advice on Language & Style

Lastly, the tips on language and style are intended to help the authors write simply, clearly, and at a reading level appropriate for operators. These tips are based on Martin Cutts's *Oxford Guide to Plain English*. The international association of plain-language professionals have developed the following definition of plain English (Cutts, 2008, p. xii):

"A written communication is in plain language if its wording, structure, and design are so clear that that intended readers can easily find what they need, understand it, and use it."

To write in plain English, Cutts recommends that authors keep the average sentence length between 15 and 20 words, use technical terms only when necessary, use as few words as possible, use active and lively verbs, and break up complicated text into vertical lists (Cutts, 2008, p. xxxi). These recommendations are incorporated into my revisions with examples as shown below.

Language & Style:

Although the content that is included in an O&M manual is extremely important, the key to a manual's success is the language and style used. Unfortunately, engineers tend to write the O&M manual in overly-technical engineering lingo that is not suitable to operators, most of whom are high school graduates. The use of highly technical language can prevent operators from understanding equipment specifications and process descriptions and make reading the manual a laborious, unpleasant task.

1. O&M manuals should be written in "plain English" (8th -10th grade reading level).
 - a. **Engineering Jargon to Avoid:** "The inlet tee, located in the septic tank, serves to dissipate the flow's velocity and decrease the flow's hydraulic energy gradient."
 - b. **Plain English:** "The inlet tee in the septic tank slows down the wastewater."
2. Keep the average sentence length between 15 and 20 words, but be sure to vary the length of sentences.
3. Use common, everyday words, except for necessary technical terms that operators are likely to understand (which may require communicating with the operators to determine their comprehension level).
4. Use only as many words as you need.
5. Consider using active voice rather than passive voice.
 - a. **Active voice:** "The operator must turn the valve clockwise."
 - b. **Passive voice:** "The valve must be turned by the operator clockwise."
6. Use precise, lively verbs.
7. Use lists to break up complicated sentences.

Figure 19: Advice on Language & Style

4.3.4 Integrating of Writing Advice Throughout Guidelines

One significant downfall of MassDEP's O&M Manual Guidelines is that discussion of how the manual should be written in terms of style, diction, organization, and level of detail is not incorporated into the breakdown of each section. When discussing 11 of the 14 sections required by MassDEP's regulations, the guidelines almost exclusively discuss what content to include and not how the content should be presented and explained. Therefore, my revisions show how discussion of level of detail, organization,

and the purpose should be integrated into each section. As an example, I only revised Section C, “Description of Operating and Control of Wastewater Treatment Facilities,” because it is generally considered to be the most important section of the O&M manual. The following excerpt is the original description of Section C found in MassDEP’s O&M Manual Guidelines, which was deleted and re-written.

Description of Operation and Control of Wastewater Treatment Facilities

The substance of how to operate the treatment facility lies within this section. This section is intended to provide a description of the various treatment plant components and their function. Each component should be presented in a sequential order and discussed individually. The narrative should discuss the treatment system from the point of generation (including the conveyance system) through the treatment processes to final disposal.

The method for operating each unit of the treatment system shall be discussed in this section. For example, if pretreatment tanks are proposed then how often they require sludge removal should be mentioned.

The O&M manual shall include the manufacturer’s operating, maintenance and repair instructions for all process units and appurtenances associated with the WWTF such as: motors, pumps, valves, blowers, bearings, drive assemblies, control panels, electrical systems, alarms, piping, tankage, and equipment. This information can be incorporated into the body of the Operation and Control of Wastewater Treatment Facilities section or included as appendices. This section shall go on to provide detailed instructions on treatment plant operation including chemical storage and handling, process testing, standard operational mode, optional modes available (such as seasonal operations), process controls and safeguards.

If the WWTF includes storage of chemicals that are required as part of the treatment process (e.g. methanol) the O&M must provide information such as name, address, and telephone number for each chemical supplier.

Figure 20: Original Description of Operation and Control of WWTFs

In my revisions to this section, I first explain the purpose of “Description of Operation and Control of Wastewater Treatment Facilities” so that authors understand how the information in that chapter is used by operators and why it is critical for the successful operation of a wastewater treatment facility. For convenience, the content that should be included in this section is listed in a table. The table also contains what level of detail is adequate for each piece of content listed. This discussion of sufficient level of detail is far more comprehensive than the original MassDEP’s O&M Manual Guidelines. The table is then followed by specific suggestions regarding the section’s organization. Lastly, I included an example to help authors understand what level of detail, style, and diction is appropriate for operators. This sample passages implements the writing advice provided throughout the revised guidelines; the excerpt is at a 10th grade reading level, has an average sentence length of 16 words, has multiple levels of headings, and includes a captioned image. The entire re-written “Description of Operation and Control of Wastewater Treatment Facilities” is shown below.

C) Description of Operation and Control of Wastewater Treatment Facilities

Purpose: The purpose of this section is to describe how to operate and control the treatment plant. This section provides a detailed description of each unit in the treatment process and explains how that unit works. The treatment facility’s flexible modes of operation are discussed, which may be invaluable when correcting problems. This section also describes controls, maintenance procedures, troubleshooting guidance, and safety information. This chapter is VERY important and should be consulted when an emergency exists.

Content and Level of Detail: First, provide an overview of the entire treatment process in the introduction to “Description of Operation and Control of Wastewater Treatment Facilities.” Within this section and subsections, level of detail should gradually increase. For each unit/process, first provide a general description of the process. Then, provide very detailed and thorough descriptions of unit operations and processes. Some parts of this need not be very detailed if references can be made to other areas of the O&M manual. For example, the controls and maintenance sections may reference other sections within the manual or the appendices.

For each unit/process, this section should include:

Content	Appropriate Level of Detail
The purpose of the equipment or unit(s)	General
How the equipment accomplishes its purpose	General
Equipment or unit description <ul style="list-style-type: none"> • Include dimensions and a description of how materials (wastewater, sludge, etc.) flow through the unit • Include a description of all auxiliary equipment (motors, pumps, valves, blowers, drive assemblies, control panels, electrical systems, piping, tankage, etc.) 	Specific, include schematics, diagrams, and/or photos.
Theory behind how the process works and/or a reference to this information	Brief and general
Relationship to adjacent units and how this unit will affect/be affected by adjacent units	Specific
Operational procedures for: <ul style="list-style-type: none"> • Normal, alternate, and seasonal modes of operation • Startup, shutdown, and draining • Bypass and emergency operation 	Very specific, step-by-step. Include schematics, valve positions for each mode of operation, when to use the unit or alternative mode of operation, flow rates, sludge concentrations, expected results or efficiencies, etc.
Controls (flow controls, electrical controls, manual controls, alarms, etc.) and control parameters (dissolved oxygen, pH, sludge age, volatile solids, etc.)	Very specific and exhaustive
Relevant chemical dosing, handling, and storage procedures <ul style="list-style-type: none"> • Include the name, address, and telephone number for each chemical supplier 	Specific
Potential operational problems and solutions such as foaming, frothing, sludge bulking, rising sludge, etc.	Specificity depends on the level of detail in manufacturer manuals, which should be referenced as needed.
Specific maintenance and repair procedures, including a spare parts list	Specificity depends on the level of detail in manufacturer manuals, which should be referenced as needed.
Safety measures and failsafe features of the unit(s)	Specific

Organization: The following section provides recommendations on the organization of “Description of Operation and Control of Wastewater Treatment Facilities.”

- Begin with a general description of the entire treatment process. A schematic of the overall system will be helpful here.
- Discuss each unit/treatment process individually, following flow of wastewater through the plant. Discuss all units/processes from the point of generation (including the conveyance system) through the treatment processes to final disposal.
 - Recommended unit/process categories include: Influent Pump Station(s), Pre-Treatment, Primary Treatment, Secondary Treatment, Tertiary Treatment, Disinfection, Recycled Water, Solids Treatment/Storage/Disposal, and Miscellaneous Equipment.
- Multiple processes may be grouped under one category (i.e. include grit collection, pre-aeration, and screening under pre-treatment processes).
- Manufacturer manuals for specific equipment pieces should be in the appendices, but include references to these manuals in this section.
- The following order of subsections can be used for each unit/process category. Not all subsections will be appropriate for all units/processes.
 - Overview of unit/process
 - Detailed description of unit/process
 - Controls
 - Chemical dosing, handling, and storage
 - Modes of operation
 - Troubleshooting
 - Maintenance
 - Safety and failsafe features

Examples: The following passage is an example of the general description that should be provided for each unit/process. This passage is considered to be at a 10th grade reading level.

3.2. Pre-treatment

3.2.1 Bar Rack: General

Screening is a preliminary treatment process that removes debris from wastewater entering the (insert name) wastewater treatment facility. The purpose of preliminary treatment is to remove plastics, rags, trash, leaves, and rocks from the raw wastewater. These materials would interfere with downstream treatment by clogging or damaging tanks, piping, pumps, or valves.

Large, harmful solids are removed from the wastewater by bar racks. The bar racks have parallel steel bars that are spaced 5/8-inches apart. As wastewater flows through the bar racks, the racks will trap any solid that is larger than 5/8". The materials that are trapped by the bar racks are known as *screenings*. Screenings are cleaned from the bar racks by a mechanical rake. The removed solids are washed, automatically carried to containers, and land-filled.

One bar rack is located in each of the two influent channels within the Screenings and Grit Building. The flow of wastewater entering the building is continuous and can be directed to either of the influent channels by opening the corresponding inlet slide gate. Likewise, flow into a channel can be stopped by closing its inlet slide gate.



Figure 1: Bar Screen

Figure 21: Revised Description of Operation and Control of WWTFs

4.3.5 Discussion the Advantages of Electronic O&M Manuals

Finally, my revisions discuss the advantages of using electronic operations and maintenance manuals. According to Georgine Grissop of CDM Smith, having a hardcopy version of the O&M manual is the “worst-case scenario” (personal communication, Feb. 15, 2017). Tidwell (2000) contends that the versatility of electronic O&M manuals “greatly increases the accuracy and usefulness of the O&M manuals and eliminates reliance on outside organizations for help” (p. 75). Use of an electronic manual could help resolve many of the weaknesses commonly found in O&M manuals. Searchable PDFs and hyperlinks allow operators to quickly navigate through the manual and locate information. In contrast to bulky 1000-page paper O&M manuals, digital copies can be easily carried around a treatment facility, which would increase the likelihood that the manual will be used by operators.

Advantages of Electronic O&M Manuals:

The emergence of electronic O&M manuals has improved the ease with which operators can locate specific information. Searchable PDF versions of O&M manuals allow operators to use key words to find specific information. The table of contents can be hyperlinked so that operators can quickly reach sections of interest. Hyperlinks can also be used to link to definitions, images, more detailed standard operating procedures, reference materials, or other related sections. Electronic O&M manuals can be updated more easily than hard copies. One significant advantage of digital O&M manuals is that they can be accessed via tablets, which operators can easily carry around the treatment facility.

Figure 22: Discussion of the Advantages of Electronic O&M Manuals

5 Conclusion

I am confident that these revisions to MassDEP's O&M Manual Guidelines are a vast improvement to the original. My revisions help authors avoid the common deficiencies of O&M manuals by encouraging them to orient the O&M manual toward operators, stressing the importance of regularly updating the manual, advising authors to consult with operators, providing numerous tips on style, language, and organization, and supplying examples that implement my advice. But a problem remains: I am not certain that the engineers who write O&M manuals would consult the improved guidelines even if MassDEP were to implement similar revisions. For engineers to feel compelled to consult MassDEP's guidelines, they would first need to recognize that their manuals are not meeting operators' needs. Since few engineers collaborate with operators, authors might not realize that O&M manuals are often inadequate. Second, these engineers would also need to perceive O&M manuals as critical tools for the successful operation of a WWTF and not just an inconvenient part of the groundwater discharge permit application process. Third, they would need to realize that the adequacy of the O&M manual depends on the manual's accuracy, organization, level of detail, style, and diction in order to seek guidance on these aspects of the manual. However, as Georgine Grissop of CDM Smith suggested, first-time authors of O&M manuals for WWTFs in Massachusetts do reference guidance on writing O&M manuals (personal communication, Feb. 15, 2017). It is my hope that these authors would benefit from my revised O&M manual guidelines.

Perhaps the most important function of this report is not to provide revisions to MassDEP's guidance, but to illuminate the scope of the problem. There is a discrepancy between the O&M manuals that engineers produce and the manuals that operators need. There are fundamental flaws in the way that O&M manuals are regulated and produced. Engineers are required by law to produce extensive O&M manuals, but these manuals can satisfy the regulations and still be of little use to operators. As a result, many O&M manuals are essentially a waste of time and resources. There is also an automatic disconnect between the designers who write the manual and the operators who use it because many engineers have never worked at a treatment facility. As a result, many O&M manuals are written like engineering design reports, which are totally insufficient for wastewater treatment operators.

According to Andrew Osei from MassDEP, the nationwide community of wastewater treatment plant operators consists primarily of highly-experienced operators who have worked in the field for decades (personal communication, Nov. 18, 2016). Because of their extensive experience, few licensed operators must rely on a facility's O&M manual to learn the system and remedy equipment malfunctions. However, a substantial proportion of operators are quickly reaching retirement age, leading to a shortage of experienced operators (G. Grissop, personal communication, Feb. 15, 2017). This will soon lead to an influx of new, young, and inexperienced operators who will rely much more heavily on the O&M manual to learn and repair a treatment system. As the shortage of wastewater treatment operators becomes more critical, the O&M manual will become increasingly important in the capture and transfer of knowledge to young, inexperienced operators (G. Grissop, personal communication, Feb. 15, 2017). Consequently, the inadequacy of O&M manuals will become a much more pressing problem. If O&M manuals do not provide inexperienced operators with the tools required to properly run a wastewater treatment facility, the health of the public and environment may be put at risk.

By shedding light on the weaknesses commonly found in O&M manuals and providing improved guidance to help engineers who write O&M manuals negotiate these problems, I hope to contribute to the prevention of potential disasters like the hypothetical scenario described at the beginning of this paper. Think back to that scenario, only this time, the design engineer consulted MassDEP's newly revised *Operation and Maintenance Manual Guidelines* and implemented many of the guidelines' recommendations as he produced the O&M manual. This time, the new operator spends an entire day reading through the treatment facility's electronic operation and maintenance manual. Since the operator is not able to see the innerworkings of the underground bioreactor, he uses the hyperlinked table of contents to jump to section "3.2.1 Bioreactor." The section begins with an overview of how the bioreactor works and includes a schematic. On the diagram, the young operator notices the label "filter" and an arrow pointing to the pipe leaving the bioreactor. The operator then uses the "find" function to direct him to the passage about the filter. There, he discovers this bolded sentence written in plain English: **"The filter must be cleaned each month so that the pipe leaving the bioreactor does not clog."** Soon afterwards, the operator checks the filter and discovers that it is partially clogged with debris. He cleans it, allowing wastewater to flow through the system unimpeded. The operator continues to clean the filter monthly and the wastewater treatment facility continues to operate successfully. As a result, the public drinking water supply is never jeopardized and the permittee is never fined, all because the operator used an adequate O&M manual.

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