MICHIGAN DEPARTMENT OF
ENVIRONMENT, GREAT LAKES, AND ENERGY

DISTRIBUTION AND LIMITED TREATMENT STUDY GUIDE

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PREFACE

This manual is intended to be used by individuals involved in the operation of small water systems employing limited chemical treatment and/or operators of water distribution systems. The fifth edition of this manual is a compilation of much of the information presented in these courses. This manual is not an attempt to replace the courses but as it is presented here, it contains a good overview of the information important for operators involved with D and S system operations.

This manual is divided into three parts. Water operators involved with the operation of small water systems are encouraged to study the entire manual. Individuals studying to write certification examinations in the D classification will find Parts I and III most helpful. Students working with limited treatment systems may also want to consult Small Water System Operation and Maintenance, 2018, by CSUS Foundation, Inc., California State University, Sacramento, California. Students working with water distribution systems might also refer to Recommended Standards for Waterworks, Ten States Standards, the AWWA Standards for Distribution Systems, and Water Distribution System Operation and Maintenance, 2018, by CSUS Foundation, Inc., California State University, Sacramento, California.

NOTE: The information contained in this manual is correct to the best of our knowledge and current to the best of our ability; however, changes in rules and practices may supersede the information provided in this manual.

5th Edition – 2024
4th Edition – 2020
3rd Edition – 2004
2nd Edition – 1992

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PART I

CHAPTER 1 – Legislation and Rules

Late in 1974, the federal government passed the "Safe Drinking Water Act," Public Law No. 93-523 (Act). This Act gave the federal government regulatory control of all public water systems. Each state, if they are granted primary enforcement responsibility (primacy), by the United States Environmental Protection Agency (USEPA), will enforce the Act within their state. For Michigan, this required the state to pass a law to conform with the requirements of the federal law. In 1976, the State of Michigan passed the Michigan Safe Drinking Water Act, 1976 PA 399, as amended (Act 399). Rules for enforcing Act 399 were promulgated following its passage. Copies of the Act 399 Rules can be downloaded from the Internet; links are also available on the Michigan Department of Environment, Great Lakes, and Energy (EGLE) Community Water Supply page. Go to Michigan.gov/EGLE, click on "Water," then "Drinking Water," then on "Community Water Supply home page". The links are listed under "Laws and Rules." The 28 parts of the Act 399 Administrative Rules are as follows:

Table 1.1 Act 399 Administrative Rules – Supplying Water to the Public

Part 1	**General Provisions:** Describes the purpose of the Act 399 Rules and provides definitions. Note that "the department" refers to EGLE.
Part 2	**Hearings and Contested Cases:** Sets guidelines for holding public hearings and resolving contested cases.
Part 3	**Variances, Exemptions, and Treatment Technologies:** Prescribes procedures by which EGLE may grant or deny a variance or exemption from a state drinking water standard. Variances or exemptions with respect to the following are not allowed: • *E. coli* maximum contaminant level (MCL) violations. • Filtration requirements. • Disinfection requirements. This part also identifies the best technology, treatment technique, or other means generally available for achieving compliance with the various MCLs. In addition, Part 3 contains criteria for use of point-of-use (POU) and point-of-entry (POE) treatment devices.
Part 4	**Public Notification and Public Education:** The owner of a public water supply (PWS) is required to notify its customers or users of violations of drinking water standards (MCLs), violations of monitoring requirements, requirements of a compliance schedule, and so on. The notifications are "tiered," that is, there are three different levels of urgency for distribution to customers. This notification

	must be accomplished in accordance with the time limits and by the means spelled out in the Act 399 Rules for the type of violation encountered. Naturally, if an emergency exists, the supply should notify its customers immediately. EGLE can also order a PWS to make notification to the public.
Part 5	**Types of Public Water Supplies:** A PWS provides water for drinking or household purposes to persons other than the supplier of water. PWSs are classified as Type I, Type II, or Type III. Regulatory requirements vary depending on the “type” of the water supply.
Part 6	**State Drinking Water Standards and Analytical Techniques:** Establishes drinking water standards for specific contaminants that shall be met by a supplier of water to assure the protection of the public health. This part also specifies methods to be used in the analyses of water samples from PWSs to determine compliance with the state drinking water standards. Applicability will depend on the size of the supply and the need for treatment.
Part 7	**Surveillance, Inspection, and Monitoring:** Specifies inspection activities by EGLE to assure compliance by a PWS with Act 399 and Act 399 Rules, prescribes monitoring requirements and procedures for suppliers of water, and establishes a schedule of fees for the collection and analysis of water samples by EGLE. This part sets the sanitary survey schedule, describes total coliform monitoring procedures, the collection and analysis of samples for inorganic chemicals, volatile organic chemicals, synthetic organic chemicals, per- and polyfluoroalkyl substances (PFAS), disinfectant residuals and disinfectant byproducts, lead and copper in tap water and source water, water quality parameters, and filtration and disinfection requirements.
Part 8	**Groundwater Sources:** Establishes certain requirements and objectives for the isolation and construction of wells used by PWSs to provide a continuous, accurate quantity of water meeting Act 399 standards.
Part 9	**Surface Water Sources:** Establishes certain requirements for the location and use of raw water intakes in surface water sources to assure a continuously adequate quantity of the best quality raw water available for treatment and distribution to the public.
Part 10	**Treatment Systems and Pumping Facilities:** Establishes requirements for the treatment of surface water sources or other sources of water that must be treated. Establishes requirements for water pumping facilities to provide a continuously adequate quantity of water meeting Act 399 standards.
Part 11	**Distribution Systems and Storage Tanks:** Sets certain construction standards for distribution systems and water storage tanks and discusses system capacity requirements.

	Distribution systems are required to have sufficient capacity to meet peak demands, including fire flow, while maintaining adequate pressure throughout the distribution system. Requires sufficient valves to minimize sanitary hazards and interruptions in service. Requires that new water mains, prior to being put into service: • Be pressure tested. • Be flushed before disinfection. • Be disinfected. • Obtain at least two consecutive non-detect total coliform samples taken at least 24 hours apart. Requires accurate records on: • Operation of water distribution system. • Location and type of maintenance performed. • Type of materials and appurtenances used. • Requires gravity storage tanks have high- and low-level alarms. • Requires pressure testing of all new storage tanks prior to being placed into service.
Part 12	**Reliability:** Requires water suppliers to develop water demand projections and propose a method to reliably meet these demands, based on five- and 20-year water demand projections. The Reliability Study must: • Analyze the ability of a water system to adequately treat and deliver water in order to meet these future demands. • Include recommendations for improvements, as necessary, that will allow the water system to comply with these future demands. • Be updated every five years.
Part 13	**Construction Plans and Specifications and Permits:** Water systems must obtain a construction permit from EGLE before making any changes or additions in the water system. Plans must be approved before a construction permit is issued.
Part 14	**Cross Connections:** Prohibits cross connections and requires water suppliers to develop a cross connection control program.
Part 15	**Operation Reports and Recordkeeping:** Sets requirements for periodic submission of reports and the retention of certain records. Reports may include Monthly Operation Reports, Annual Cross Connection Reports, Annual Pumpage Reports, etc. Record

	Retention applies to turbidity records, bacteriological results, correspondence, etc.
Part 16	**General Plans:** Establishes the requirement that community water suppliers submit and periodically update a water system general plan. The general plan must contain a layout that includes, at a minimum, all of the following: • Treatment systems (with capacity). • Watermains (and their size). • Valves. • Hydrants. • Storage tanks (with capacity).
Part 17	**Ownership of Public Water Supplies:** Prescribes certain requirements and procedures for private ownership of a PWS system when public ownership cannot be achieved.
Part 19	**Examination and Certification of Operators:** Part 19 classifies public water systems and the certification levels required to operate public water systems. Requirements for obtaining and maintaining operator certification are also provided. Every Community Water Supply (CWS) must be under the supervision of a full-time operator-in-charge (OIC) certified at or above the CWS classification.
Part 21	**Approval of Chemicals and Other Materials:** This part prescribes certain requirements for the approval of chemicals, materials, coatings, additives, or other substances proposed to be used in the treatment of or during the distribution of drinking water, or which are proposed to be used in contact with drinking water prior to, or during, distribution to the customer or user of a PWS. Part 21 prohibits a person from using unapproved chemicals or materials which may come into contact with, or serve as an additive to, drinking water.
Part 23	**Emergency Response Plans:** All Type I systems are required to develop Emergency Response Plans to reduce the effects of certain emergency situations. These plans must outline a program for rapid correction or mitigation of emergencies and be placed in all waterworks facilities to assure use of the plan by all necessary personnel.
Part 24	**Water Hauling Equipment Standards:** Prescribes standards for tanks and equipment used by water haulers to transport drinking water.
Part 25	**Licensing of Water Haulers:** Specifies certain criteria and requirements for licensing of water haulers.
Part 26	**Bottled Water:** Approval and monitoring of sources and recordkeeping requirements for all persons providing bottled drinking water for drinking or household purposes.

Part 27	**Laboratory Certification:** Details requirements set forth by federal act for laboratory certification.
Part 28	**Source Water Protection Grant Assistance:** Details requirements and procedures for applying for grant assistance.

This has been a very brief outline of the parts of the Act 399 Rules. It is recommended that each operator obtain a complete set of the Act 399 Rules for study and reference.

CHAPTER 2 – Mathematics

A water plant operator must have a working knowledge of ratios, proportions, and solving for an unknown. Some basic concepts are covered in this chapter, but it is highly recommended that operators attend the Water Operator Math courses offered by EGLE to gain a better understanding of “operator math.”

COMMON FRACTIONS

Decimals are numbers to the right of the decimal point. Decimals may be expressed as tenths (0.1), hundredths (0.01), thousands (0.001), etc. The decimal portion of a number is referred to as the "decimal fraction." Water operators also encounter numbers expressed as "common fractions."

A common fraction is a numerical expression for division. The fraction $1/2$ means the same as $1 \div 2$. Think of a common fraction as an incomplete division problem.

Fractions have a numerator and a denominator. For the fraction $1/2$, 1 is the numerator and 2 is the denominator. The line drawn between them is called the fraction bar.

$$\frac{1 = \text{numerator}}{2 = \text{denominator}}$$

When the numerator and the denominator of a fraction are equal, the fraction reduces to 1.

Examples: $5 \,/\, 5 = 1$
$2 \,/\, 2 = 1$

Likewise, a whole number can be expressed as a fraction by putting 1 in the denominator.

Examples: $7 \,/\, 1 = 7$
$3 \,/\, 1 = 3$

To convert a common fraction to a decimal fraction, simply divide the numerator by the denominator.

Examples: $1 \,/\, 4 = 1 \div 4 = 0.25$
$2 \,/\, 3 = 2 \div 3 = 0.67$

Knowing this allows us to work problems involving common fractions on a calculator if we convert the common fraction to a decimal fraction first.

Example: $12 / 16 + 4 / 32 + 1 / 2 + 3 / 4 = ?$

Solution: First, convert each fraction to its decimal equivalent.

$$12 / 16 = 0.75$$
$$4 / 32 = 0.125$$
$$1 / 2 = 0.5$$
$$3 / 4 = 0.75$$

Then you can add the decimal numbers on your calculator.

$$0.75 + 0.125 + 0.5 + 0.75 = 2.125$$

Water works operators often work with fractions in the conventional way, adding and subtracting them together after first finding the common denominator; for multiplication, multiplying numerators together and multiplying denominators together; for division, inverting then multiplying, etc. Some people prefer to work with common fractions in the conventional way; others convert them to decimals first. Either way is acceptable. Because the use of calculators is routine, this book will take the approach of converting the fractions to decimals, then performing the computations.

PERCENTAGES

Percentage computations are frequently made by utility personnel when calculating chlorine dosages and other chemical feed rates, and, in other instances, pump and motor efficiencies. Percent means parts per 100 parts. Percent expresses a fraction which has a denominator equal to 100. Percentages are related to common fractions and decimal fractions.

Percentage	*Common Fraction*	*Decimal Fraction*
11.00%	11/100	0.11
60.00%	60/100	0.60
0.50%	5/1,000	0.005
0.07%	7/10,000	0.0007
0.003%	3/100,000	0.00003

By comparing the percentage column to the decimal fraction column, we see the relationship between them. If we move the decimal point in a percentage two places to the left, we have a decimal; if we move the decimal point in a decimal fraction two places to the right, we have a percentage. This is the same as dividing by or multiplying by 100.

We are often required to determine what percent one number is of another number. To do this, we convert the percentage to a decimal and multiply as appropriate.

Example: What is $25\% \text{ of } 90$?

Solution: First, convert 25% to its decimal equivalent, which is 0.25. Since we want "percent of" we multiply the decimal equivalent by the number we want to take the percentage of.

$$25\% \text{ of } 90 = ?$$
$$0.25 \times 90 = 22.5$$

Rounding off, we get $23 = 25\% \text{ of } 90$.
Think of "percent of" as meaning the same as "multiply by."

Example: What is $32\% \text{ of } 612$?

Solution: Since $32\% = 0.32$, we get $0.32 \times 612 = 195.84$
Rounding off, we get $196 = 32\% \text{ of } 612$.

Example: A 500-gallon (gal) tank contains 320 gal.
What percent of the tank is full?

Solution: Remember that a percent means parts per 100 parts. In this example, we need to express the problem as a fractional or decimal relationship and then convert the fraction or decimal to a percentage. First, think of the problem as a "parts per parts" problem. Relate the number of gallons in the tank to the total number of gallons available in the tank.

320 gal in a 500-gal tank is the same as:

$$320 \text{ gal} \,/\, 500 \text{ gal or } 320 \text{ gal} \div 500 \text{ gal}$$
$$320 \text{ gal} \div 500 \text{ gal} = 0.64$$

Converting the decimal 0.64 to a percent gives us 64%, so a 500-gallon tank holding 320 gallons is 64% full.

Example: City Hall conducted a survey of the water customers. 2,275 out of 3,500 people want a new iron removal plant. What percent of those surveyed want a new iron removal plant?

Solution: 2,275 out of 3,500 means $2{,}275 \div 3{,}500$, which equals 0.65, converting the decimal fraction to a percent (by multiplying by 100) yields 65%. This means 65% of the customers surveyed were in favor of the new plant.

SAMPLE PROBLEMS

(Solutions to Sample Problems can be found at the end of the Chapter.)

(1) Write the decimal equivalent of the following percentages.

(a) 49% Answer __________
(b) 1/2 of 1% Answer __________
(c) 3% Answer __________
(d) 151% Answer __________

(2) Express the following decimals in percentages.

(a) 0.1 Answer __________
(b) 7.52 Answer __________
(c) 0.006 Answer __________
(d) 0.19 Answer __________

(3) An elevated tank is half full. What percent is this?

(4) A chemical solution tank with a 50-gal capacity is to be filled to the 90% mark. How many gallons are required to do this?

(5) A water treatment plant with a capacity of 550,000 gal/day is operating at 75% capacity. How much water is this plant processing?

(6) Water flows from two basins. Total flow is 90 million gallons per day (MGD). 65% flows from basin #1, the rest from basin #2. How many MGD flow from each basin?

(7) The population of a community is expected to grow by 5% each year for the next three years. If the present population is 7,700, what will the population be at each yearly interval over this time period?

BASIC ALGEBRA

A common practice used in algebra is the use of letters to represent unknown numerical quantities. Frequently, the letter "X" is used to represent the unknown. We will use an upper case "X" to denote an "unknown" (a lower case "x" or × denotes the multiplication symbol). To solve for the unknown "X", two basic objectives are considered:

1. Get X to the numerator.
2. Clear all other numbers from the “X”-side of the equation to get "X" alone.

Accomplishing these objectives will require shifting numbers from one side of an equation to the other. This can be done, provided equal quantities are added or subtracted to each side of the equation, or that both sides of the equation are multiplied or divided by the same quantity.

Example: $15 = \mathrm{X} + 9$

In this example, "X" is already in the numerator (basic objective #1). To clear all other numbers from the "X”-side" of the equation, we subtract 9 from both sides.

$$15 - 9 = \mathrm{X} + 9 - 9$$

Because 15 minus 9 is 6, we have 6 on the left side of the equation. Because 9 minus 9 is zero, we have nothing but "X" on the right side of the equation, or:

$$6 = \mathrm{X}$$

Now we have solved for the unknown "X", and our answer is 6. At this point we should check our answer. We do this by going back to the original equation and substituting a 6 anywhere we had an "X".

$$15 = \mathrm{X} + 9$$

Substituting $6 = \mathrm{X}$ gives

$$15 = 6 + 9$$
$$15 = 15$$

Since 15 does equal 15, we have the correct answer.

Let us review a couple of important points with the above example. First, we said we needed to clear all numbers from the "X"-side. This will get “X” alone. If we can get "X" alone on one side of the equation, then "X" will be equal to whatever is on the other side of the equation, and we will have our answer. To get "X" alone, we need to shift numbers around. We can do this, and still have a mathematical situation where the left side of the equation is equal to the right side of the equation, *so long as whatever we do to one side of the equation we also do to the other side of the equation*.

To help visualize this, think of the equation as a scale, with the equal sign (=) being the pivot point. With a scale, if we subtract 9 of something from one side, we also have to subtract 9 of the same thing from the other side or else the scale will no longer be in balance. For this example, because we must subtract 9 from the right side of the equation (in order to get "X" by itself), we must also subtract 9 from the left side of the equation (in order to keep the equation in balance).

Example: $85 - \mathrm{X} = 40$

Solution: Here, as in the previous example, "X" is already in the numerator, so basic objective #1 is complete. Since "X" is a negative number (because we are subtracting "X" from a number), we should add "X" to both sides of the equation.

$$85 - \mathrm{X} + \mathrm{X} = 40 + \mathrm{X}$$
$$85 = 40 + \mathrm{X}$$

Now we have a "new" problem, but this problem is similar to the previous example. In this new problem, we have some number (85 in this case) on one side of the equation, equal to some other number (40) plus "X". To solve for the unknown "X,” we must next clear all other numbers from the "X”-side of the equation. Since 40 is being added to

"X," we need to "do the opposite" to get "X" by itself. Because the opposite of adding is subtracting, we subtract 40. We must also subtract 40 from the left side of the equation (to balance the scale). Because we are doing the same thing to both sides of the equation, the problem will still be an equality after we "shift" numbers from side to side.

$$85 - 40 = 40 - 40 + \mathrm{X}$$

Because 85 minus 40 is 45, we have 45 on the left side of the equation and because 40 minus 40 is zero, we have nothing but "X" on the right side of the equation, or

$$\begin{aligned} 85 - 40 &= 40 - 40 + \mathrm{X} \\ 45 &= \mathrm{X} \end{aligned}$$

Now we have solved for the unknown "X," and our answer is 45. Again, we should check our answer. Go back to the original equation and substitute 45 anywhere we previously had "X".

$$85 - \mathrm{X} = 40$$

Substituting $45 = \mathrm{X}$ gives

$85 - 45 = 40 \qquad\qquad 40 = 40$

Since 40 does equal 40, we have the correct answer.

Example: $520 = \frac{\mathrm{X}}{6{,}750}$

Solution: Since "X" is in the numerator already, we only need to clear all other numbers from the "X"-side. The "X"-side of the equation has "X" divided by 6,750. To clear everything from the "X"-side and get "X" by itself, we do the opposite. Since the opposite of dividing is multiplying, we multiply the right side of the equation by 6,750. Since we are dealing with an equality (scales), whatever is done to one side of the equation, must also be done to the other side (to keep it in balance). Multiplying both sides of the equation by 6,750 gives us:

$$520 \times 6{,}750 = \frac{X}{\cancel{6{,}750}} \times \cancel{6{,}750}$$

Because the two 6,750s on the right side of the equation cancel each other $(6{,}750 \div 6{,}750 = 1)$ we have:

$$520 \times 6{,}750 = 1\text{X}$$

since 1X is the same as X, we have

$$520 \times 6{,}750 = 1\text{X}$$

$$3{,}510{,}000 = \text{X}$$

Again, check the solution by substituting it back into the original problem. (This is an important step, but for this and for other examples in the rest of this book, this step will be left to the reader).

Example: $12{,}000 = \frac{18{,}000}{\text{X}}$

Solution: To get “X” in the numerator, move it from one side of the equation to the other by multiplying through by “X” and cancelling “X” over “X” on the right.

$$12{,}000 \times \text{X} = \frac{18{,}000 \times \cancel{\text{X}}}{\cancel{\text{X}}}$$

Now clear the “X”-side by cancelling “X” divided by “X” to get 1.

$12{,}000 \times \text{X} = 18{,}000 \times 1$, or
$12{,}000 \times \text{X} = 18{,}000$

Now divide both sides by 12,000 to get “X” by itself.

$$\frac{\cancel{12{,}000} \times \text{X}}{\cancel{12{,}000}} = \frac{18{,}000}{12{,}000}$$

$$\text{X} = 1.5$$

The above examples typify “solving for the unknown X” situations. We will use these principles later in this course and will build on them to develop other ideas and concepts. Understanding them is very important. For more practice, work through the following sample problems.

SAMPLE PROBLEMS

Solve for "X".

(8) $3X = 15$ X = __________

(9) $4X \div 5 = 21$ X = __________

(10) $21 + 7X = 112$ X = _________

(11) $X - 15 = 22$ X = __________

(12) $4X + 25 = 125$ X = __________

PROPORTIONS

A ratio is the quotient of two numbers. The ratio of 1 to 2 can be written several ways: $1 \div 2$ or $1 / 2$ or $1{:}\,2$. A proportion is a relationship where two or more ratios are said to be equal. For example:

$$1 / 2 = 4 / 8 = 3 / 6$$

Proportions are written in the form

$$\frac{a}{b} = \frac{c}{d} \quad \text{or} \quad a{:}\,b = c{:}\,d$$

Verbally, this says that "a" is to "b" as "c" is to "d." To solve problems involving proportions, we "cross-multiply." This means we multiply "a" and "d" to get (a x d) and we multiply "b" and "c" to get (c x b). Cross-multiplication says that the product of "a" and "d" must equal the product of the "b" and "c".

$$\frac{a}{b} = \frac{c}{d}$$

When we cross-multiply (multiplying in the direction of the arrows) we get:

$$a \times d = c \times b$$

To find one unknown value in this equation when the other three values are known, we must use the "solving for the unknown" techniques discussed earlier in this section. For example, say the value of "a" is unknown but the values of "b," "c," and "d" are known. To solve for the unknown "a," put "a" in the numerator and clear all other numbers from the "X"-side (or in this case the "a"-side as we are using the letter "a" for our unknown).

$$\frac{a \times d}{d} = \frac{c \times b}{d} \qquad \frac{c \times b}{d} = a$$

If we knew what the values of "c," "b," and "d" were, we could easily determine the unknown "a."

The following examples use cross-multiplication to solve for the unknown quantity "X."

Example: $\frac{X}{5} = \frac{8}{2}$

Solution: First, cross-multiply.

$$\frac{X}{5} = \frac{8}{2}$$

$$2X = 5 \times 8$$
$$2X = 40$$

Now divide both sides of the equation by 2 to get the unknown quantity "X" by itself.

$$\frac{2X}{2} = \frac{40}{2}$$

From this we find that $X = 20$.

Example: Solve for the unknown quantity "X."

$$\frac{15}{9} = \frac{X}{3}$$

Solution: Again, we start by cross multiplying.

$$\frac{15}{9} = \frac{X}{3}$$

$$15 \times 3 = 9X$$
$$45 = 9X$$

Now divide both sides of the equation by 9 to isolate the unknown quantity “X.”

$$\frac{45}{9} = \frac{9X}{9}$$

From this we find:

$$45 \div 9 = X$$
$$X = 5$$

SAMPLE PROBLEMS

Solve for the unknown quantity "X."

(13) $\frac{16}{4} = \frac{X}{2}$ $X =$ ________

(14) $\frac{9}{X} = \frac{3}{3}$ $X =$ ________

(15) $\frac{15}{5} = \frac{9}{\mathrm{X}}$ $\qquad$ $\mathrm{X} =$ ________

UNITS AND CONVERSIONS

To attach any meaning to numbers used to indicate lengths, widths, volumes, areas, and the like, we must assign units to these numbers. The number 12 has a considerably different meaning if it is assigned different units, such as acres, gallons, grams, or inches. Quite often, measurements must be converted from one set of units to another. (For a review of the abbreviations for the various units, refer to the next page where the conversions are located.)

1 foot = 12 inches
1 yard = 3 feet = 36 inches

When adding, subtracting, multiplying or dividing quantities, the quantities must be in the same units. If they are not, they must be converted to a common unit. Values for conversion factors are considered to be exact values.

Example: 8 miles + 4 feet + 50 yards = ?

Solution: If all these are converted to feet, then:

$$8 \text{ miles } = \frac{8\ \cancel{\text{miles}}}{1} \times \frac{5{,}280 \text{ feet}}{1\ \cancel{\text{mile}}} = 42{,}240 \text{ feet}$$

$$4 \text{ feet} = (\text{already in feet}) = 4 \text{ feet}$$

$$50 \text{ yards} = \frac{50\ \cancel{\text{yards}}}{1} \times \frac{3 \text{ feet}}{1\ \cancel{\text{yard}}} = 150 \text{ feet}$$

So $42{,}240 \text{ feet} + 4 \text{ feet} + 150 \text{ feet} = 42{,}394 \text{ feet}$

Example: $5 \text{ yards} + 2 \text{ feet} + 10 \text{ inches} = ?$

Solution: Convert all units to feet.

$$5 \text{ yards} = \frac{5\ \cancel{\text{yards}}}{1} \times \frac{3 \text{ feet}}{1\ \cancel{\text{yard}}} = 15 \text{ feet}$$

$$2 \text{ feet} = (\text{already in feet}) = 2 \text{ feet}$$

$$10\text{ inches} = \frac{10\ \cancel{\text{inches}}}{1} \times \frac{1\text{ foot}}{12\ \cancel{\text{inches}}} = 0.83\text{ feet}$$

$$\text{So } 15\text{ feet} + 2\text{ feet} + 0.83\text{ feet} = 17.83\text{ feet}$$

To convert figures from one unit to another, use of a conversion factor is necessary. Table 2.1 lists some commonly used conversion factors.

Table 2.1 Conversion Factors

Multiply	**By**	**To Obtain**
Acres (ac)	43,560	Square Feet (ft^2 or sq. ft.)
Cubic Feet (ft^3 or cu.ft.)	7.48	Gallons (gal)
Cubic Feet (ft^3 or cu.ft.)	62.4	Pounds (lbs) of Water
Cubic Feet/Second (cfs)	0.646	Million Gal/Day (M gal/day)
Feet of Water (ft)	0.433	Pounds/Square Inch (psi)
Gallons (gal)	0.1337	Cubic Feet (ft^3 or cu.ft.)
Gallons (gal) of Water	8.34	Pounds (lbs) of Water
Grains/U.S. Gallon (gr/gal)	17.118	Parts per Million (ppm)
Grams/Liter (g/l)	1,000	Parts per Million (ppm)
Inches (in or ")	0.0833	Feet (ft or ')
Inches of Water	0.03513	Pounds/Square Inch (psi)
Parts per Million (ppm)	0.0584	Grains/U.S. Gallon (gr/gal)
Pounds (lbs) of Water	0.01602	Cubic Feet (ft^3 or cu.ft.)
Pounds (lbs) of Water	0.1198	Gallons (gal)
Pounds/Square Inch (psi)	2.31	Feet of Water (ft)
Million Gal/Day (M gal/day)	1.55	Cubic Feet/Second (cfs)

To use Table 2.1, take a value in a unit from the left column and multiply it by the "conversion factor" in the middle column to obtain a value in the corresponding unit in the right column. The following example demonstrates this.

Example: A storage tank holds 2,000 cubic feet of water.

a. How many gallons of water will it hold?
b. How much does this amount of water weigh?

Solution: To work this problem, you should refer to Table 2.1.

a. Multiply 2,000 ft^3 by 7.48 to obtain the number of gallons of water in 2,000 ft^3.

$2{,}000\ \mathrm{ft}^3 \times 7.48 = 14{,}960\ \text{gallons};$
rounding off, we get 15,000 gallons.

This works because 7.48 is the "conversion factor" used to convert from cubic feet (ft^3) to gallons. This conversion factor has units, and it should be used with the units, so mistakes are not made.

$$7.48\ \text{gallons per cubic foot} = 7.48\ \text{gallons}/\mathrm{ft}^3$$

When working with conversion factors and units, remember that units above the fraction bar cancel out similar units below the fraction bar. For our example:

$$\frac{2000\ \cancel{\mathrm{ft}^3}}{1} \times \frac{7.48\ \mathrm{gal}}{1\ \cancel{\mathrm{ft}^3}} = 14{,}960\ \mathrm{gal}$$

The unit "ft^3" is in both the numerator and denominator (above and below the fraction bar) so they cancel each other out; the unit "gallons" appears only above the fraction bar, so the answer is in gallons.

b. Convert from gallons to pounds. The conversion factor used to convert water measurements from gallons to pounds is 8.34 pounds per gallon (lbs/gal), therefore:

$$\frac{15{,}000\ \cancel{\mathrm{gal}}}{1} \times \frac{8.34\ \mathrm{lbs}}{1\ \cancel{gal}} = 125{,}100\ \text{lbs of water}$$

125,100 lbs can be rounded to 125,000 lbs.

In this case, the unit "gallons" is in both the numerator and the denominator and can, therefore, be cancelled.

The two conversion factors discussed above are so important to mathematical computations involving water and wastewater treatment that they simply must be memorized.

Memorize: 1 ft^3 of water equals 7.48 gallons (7.48 gal/ft^3)

and

1 gallon of water equals 8.34 lbs (8.34 lbs/gal)

From these two conversion factors we can develop another important factor:

$$\frac{7.48\ \cancel{\text{gal}}}{1\ \text{ft}^3} \times \frac{8.34\ \text{lbs}}{1\ \cancel{\text{gal}}} = \frac{62.4\ \text{lbs}}{\text{ft}^3}$$

This value, 62.4 lbs/ft^3, is the density of water. Density is a weight (lbs) per unit volume (ft^3).

In this chapter, we have presented two approaches to converting units. The first approach is the simplest. It involves consulting a chart (Table 2.1), looking down the chart for the units you have, and multiplying by the indicated number to obtain the desired units. This is simple and easy. The only problem is that you need to have the chart. Without the chart, it is easy to get confused. You might know that the number 7.48 is important when converting between cubic feet and gallons, but do you know when to multiply or when to divide? You can be certain to do the right thing if you make a habit of always writing a conversion factor with its accompanying units. You may need to consult a chart or table to determine the value of the conversion factor (or you may have committed some of the more basic and important ones to memory) but if you get in the habit of writing down the conversion factors with the units and apply the "cancelling units" techniques discussed below, you will know when to multiply by a conversion factor and when to divide by one.

CANCELLING UNITS

Sometimes, simply knowing what units you have and what units you need determines which conversion factor(s) you should use. For example, if we have "days" and want to go to "seconds," it is best to write out the unit conversions first, then supply the numerical conversion factors later.

$$\frac{days}{1} \times \frac{hrs}{day} \times \frac{min}{hr} \times \frac{sec}{min} = seconds$$

This gives seconds, now put in the numerical conversion factor values.

$$\frac{\cancel{1\ days}}{1} \times \frac{24\ \cancel{hrs}}{1\ \cancel{day}} \times \frac{60\ \cancel{min}}{1\ \cancel{hr}} \times \frac{60\ sec}{1\ \cancel{min}} = 86{,}400\ seconds$$

When working with units, it is important to remember that converting from one unit to another does not change the quantity or value that we are dealing with, it simply changes the form in which we are expressing the quantity or value. For example, 1 foot is the same as 12 inches. When we express this in the form of a ratio, 1 foot/12 inches, the value of the ratio is 1; therefore, we can multiply through by this ratio without changing the value or quantity. Likewise, a volume of water equal to 7.48 gallons is equal to a volume of 1 cubic foot (7.48 gallons/ft^3). We can use this relationship to convert from cubic feet to gallons or from gallons to cubic feet.

$$\frac{7.48\ gallons}{1\ cubic\ foot} \quad or \quad \frac{1\ cubic\ foot}{7.48\ gallons}$$

This ratio is the same written either way. How we use it depends on what units we are converting from.

Example: A basin has a volume of 1,500 cubic feet. How many gallons of water could this basin hold?

Solution: We want to convert from cubic feet to gallons. We need a couple of things to do this: (1) the conversion factor that takes us from cubic feet to gallons, and (2) we need to write the conversion factor in the right form so we can properly cancel units. The correct conversion factor is:

$$\frac{7.48\ gallons}{1\ cubic\ foot} \quad or \quad \frac{1\ cubic\ foot}{7.48\ gallons}$$

We now need to choose what form of the conversion factor to use so we can cancel ft^3 units to give us our answer in gallons. If we remember that units above the fraction bar cancel out the same units below the fraction bar, we know we must set up our conversion as follows:

$$\frac{1{,}500\ \cancel{cubic\ feet}}{1} \times \frac{7.48\ gal}{1\ \cancel{ft^3}} = 11{,}220\ gallons$$

Example: We have 16,456 gallons of water that need to be transferred to a basin. What is the minimum number of cubic feet that the basin must be in order to be adequately to hold this amount of water?

Solution: For this example, we proceed like we did in the previous one, except in this case we want to convert from gallons to cubic feet. We need (1) the conversion factor that takes us from gallons to cubic feet and (2) we need to write the conversion factor in the right from so we can properly cancel units. The correct conversion factor is:

$$\frac{7.48\,gal}{1\,ft^3} \;or\; \frac{1\,ft^3}{7.48\,gal}$$

Now choose the form of the conversion factor to give us our answer in cubic feet. Because units above the fraction bar cancel out similar units below the fraction bar, we set up our conversion as follows:

$$\frac{16{,}456\,\cancel{gallons}}{1} \times \frac{1\,ft^3}{7.48\,\cancel{gal}} = 2{,}200\,ft^3$$

Example: We determine an area to be 87,120 ft^2. How many acres is this?

Solution: We need the conversion factor that relates square feet to acres. Write the factor with the accompanying units.

$$\frac{43{,}560\,ft^2}{1\,acre} \;or\; \frac{1\,acre}{43{,}560\,ft^2}$$

Use the conversion factor to write out an equation that allows us to cancel the units of square feet to obtain acres.

$$\frac{87{,}120\,\cancel{ft^2}}{1} \times \frac{1\,acre}{43{,}560\,\cancel{ft^2}} = 2\,acres$$

SAMPLE PROBLEMS

(16) What is the sum of $12\ feet + 18\ inches + 3\ yards$?

(17) Three cubic feet of water weigh how many pounds?

(18) Sixteen gallons of water occupy how many cubic feet?

(19) How many acres are there in 536,000 square feet?

(20) A tank has a capacity of 50,000 cubic feet. What is the gallon capacity of the tank?

CALCULATION OF AREAS

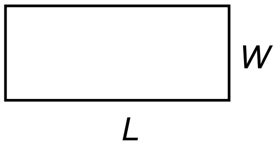
Area can be thought of as a measurement of the surface of a figure, having only two dimensions; length (L) and width (w). Units of length and width commonly used in the English system are the inch, foot, yard, and mile; the common units in the metric system are the centimeter, meter, and kilometer. Units of surface or area are expressed as square inches (in^2), square feet (sq. ft. or ft^2), and so forth, depending on the unit of length used.

Some of the simpler shapes commonly encountered and their area formulas are given as follows:

The RECTANGLE, a four-sided figure having four right (90°) angles.

Area = length (L) times width (W).

$Area = L \times W$



Example: Calculate the area of a room given the following dimensions: length = 34 feet and width = 22 feet.

Solution: Write down the formula for determining the area of a rectangle. Substitute in the values given for length and width. Perform calculations.

$Area = A = L \times W$

$A = 34\,ft \times 22\,ft = 748\ square\ feet$

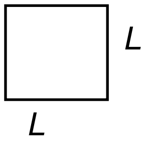
The units are square feet because ft x ft = ft^2.

A SQUARE is a special case of the rectangle in which all sides are of equal length, L = w.

Area = length (L) times width (W).

$Area = L \times W$

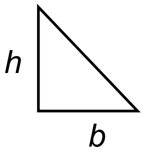
Since $L = W$



$Area = L^2$

A TRIANGLE is a figure enclosed by three straight lines. Its area is half the product of the base times its height.

Area = 1/2 times length of base (b) times height (h).



$Area = \frac{1}{2}(b \times h)$

An easy way to remember the area of a triangle is to think of it as half of a rectangle. We know the area of a rectangle is L x W, so half of that is:

$\mathrm{A} = \frac{1}{2}(\mathrm{L} \times \mathrm{W}) = \frac{1}{2}(\mathrm{b} \times \mathrm{h})$

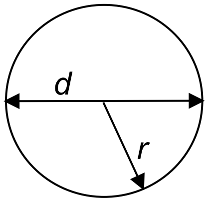
Since we are working with multiplication, it does not matter if we multiply length times width first before multiplying by1/2 or multiply the length by 1/2 first and then multiply by width.

A CIRCLE is a closed curve in which all points on the curve are equally distant from a fixed point called the center. The length of measurement from the circle's center to the circle itself is called the radius (r). The diameter (d) is the length from one side of the circle to the other side, passing through the center point. The diameter is equal to 2 times the radius.

The area of a circle is given as pi (π) times the radius squared.
π is a constant value equal to approximately 3.14.

Area = pi times radius times radius.

$$Area = \pi \times r \times r$$
$$A = \pi r^2 = 3.14 \times r^2$$



Example: What is the area of a circle that has a radius of 10 inches?

Solution: Because we are given a "radius," we know the shape of the area we are asked to determine is a circle. Therefore, we use the area of a circle formula, substitute in the given value and perform the calculation.

$$Area\ is\!:\ A = \pi r^2 \quad so \quad A = 3.14 \times 10\ in^2 = 314\ in^2$$

The area of a circle can be expressed using other formulas as well. These other formulas are simply modifications to the basic $A = \pi r^2$ formula. Two of these, which substitute diameter for radius, are shown here.

Since the diameter is equal to 2 times the radius, we have:

$$d = 2r \quad or \quad \frac{d}{2} = r$$

We can substitute: $\frac{d}{2}\ for\ r$

$$A = \pi\left(\frac{d^2}{2^2}\right) = \pi\left(\frac{d^2}{4}\right)$$

$$\mathrm{A} = \pi\left(\frac{d^2}{4}\right) = 3.14\left(\frac{d^2}{4}\right) = 0.785\ d^2$$

In summary, we typically see the formula for calculation the area of a circle in three ways:

$$A = \pi r^2$$
$$\mathrm{A} = \pi d^2/4$$
$$\mathrm{A} = 0.785 d^2$$

Operators need to decide which formula they prefer to use. The formula using radius (r) is the most common. Waterworks operators, however, may want to consider using an area formula that uses diameter (d) as the dimensions of a water main are typically given in terms of diameter. It is also recommended that diameters given in inches be converted to feet prior to making the calculation. The reason for this is because, as we shall see in the section on "calculation of volumes," most water and wastewater operations deal in square and cubic feet rather than in square or cubic inches.

Example: A water main has a diameter of 8 inches. Calculate, in square feet, the cross-sectional area of the main.

Solution: Convert the diameter from inches to feet. Substitute the value for the diameter into the area of a circle formula. Make calculation.

$$\frac{8\ \cancel{inches}}{1} \times \frac{1\ foot}{12\ \cancel{inches}} = 0.67\ ft = d$$

$$A = 0.785 \times (0.67\ ft)^2 = 0.35\ square\ feet\ or\ 0.35 ft^2$$

Our units are in terms of square feet because when we square the diameter, which is in feet, we get $ft \times ft\ = ft^2$

The CIRCUMFERENCE (C), or length of the line forming the closed curve of the circle, is 2 times *pi* times the radius, or *pi* times the diameter, shown by:

$$C = 2(\pi)r \quad or \quad C = (\pi)d$$

When calculating areas, be sure that the units used are the same. For example, if you are calculating the area of a room, the dimensions might be given in terms of feet and inches. You will need to convert to a common unit (most likely feet) before multiplying length times width.

SAMPLE PROBLEMS

(21) What is the area of a rectangular room measuring 28 feet in length and 18 feet wide?

(22) The standard isolation area of a municipal well is 200 feet in all directions from the well. How many acres is this?

(23) What is the circumference of the well isolation area circle noted in Problem 22?

CALCULATION OF VOLUMES

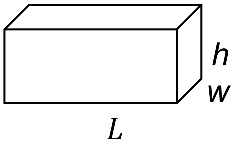
A figure in three dimensions is termed a solid figure and its size or occupied space is expressed in terms of its volume. The volumes of several common shapes are shown below. Units of volume for the most common shapes, rectangular prisms and cylinders, are expressed as the cube of the linear dimensions. For example, if we are measuring the contents of a box with dimensions given in feet, the unit of volume of the box will be cubic feet (ft^3). If the dimensions are given in inches, the unit of volume will be cubic inches (in^3). Another important unit of volume is the gallon. From the "units" discussion, we know that the various units of volume can be converted from one to another, provided we know the proper relationships between the units (conversion factors).

The volume (V) for some of the more common shapes are given below. Combining the information discussed in this chapter with the "converting units" information allows us to calculate the volumes of tanks, basins, cylinders, pipelines, etc. and convert from "cubic" units of volume to gallons. On the other hand, if we are given a volume in gallons, we can determine how many "cubic" units we need to hold this amount of water.

The RECTANGULAR PRISM

Volume = area of base (L × w) times height (h)

$$V = L \times w \times h$$



Example: Calculate the volume of a tank that has the following dimensions:

length = 34 feet
width = 14 feet
height = 11 feet

Solution: Since we are given length, width, and height, we know the shape of the basin must be a rectangular prism. We first write down the formula for the volume of a prism and then substitute in the appropriate dimensions.

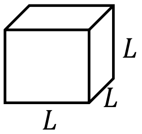
$$V = L \times w \times h$$

$$V = 34\,ft \times 14\,ft \times 11\,ft \quad V = 5{,}236\,ft^3$$

The units are "cubic feet" because we are multiplying ft x ft x ft = ft^3

The CUBE is a special version of the rectangular prism where the length, the width, and the height are the same. We can use the formula for the rectangular prism to determine the volume of a cube.

$$V = L \times w \times h$$



For a cube, $L \times w \times h$, so we can represent these values by one letter, L.

Therefore: $V = L \times L \times L \quad or \quad V = L^3$

Example: Calculate the volume of a cubic basin. The length, width, and heights of the basin are equal to 6 feet.

Solution: Since we are told this basin is a cube (all dimensions are the same), we can write down the formula for the volume of a cube and then substitute in the appropriate dimensions.

$$V = L^3 = (6\,ft)^3 = 216\,ft^3$$

Again, our units are "cubic feet" because we are multiplying:
ft x ft x ft = ft^3

We could also have done this example by simply using the formula for the volume of a rectangular prism, as we were given the basin's dimensions as length, width, and height so we know the shape.

$$V = L \times w \times h$$
$$V = 6\,ft \times 6\,ft \times 6\,ft$$
$$V = 216\,ft^3$$

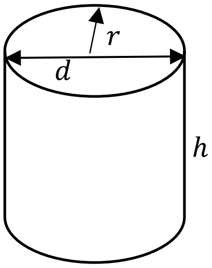
If you know or are given that the shape of the container (tank, box, basin, etc.) is a cube, you can simply take the cube of the dimension to determine the volume. In most cases, however, you may not realize the shape is that of a cube, so it is probably best to simply use the $V = L \times w \times h$ formula.

The CYLINDER

Volume = area of base (πr^2) × height (h)

$$V = (\pi r^2)h \quad or \quad V = (\pi r^2)\frac{d^2h}{4}$$

$$\mathrm{V = 0.785d^2h}$$



Example: A chemical solution barrel is 4 feet high and has a diameter of 3 feet. How many gallons of solution can this barrel hold?

Solution: Write down the formula for determining the volume of a cylinder (barrel). Substitute the appropriate dimensions, being consistent with the units, and calculate. Convert from cubic feet to gallons.

$V = 0.785 \times d^2 \times 4 = 0.785 \times \ (3\ ft)^2 \times 4\ ft = 28.26\ ft^3$
Or rounded off, $V\ = 28\ ft^3$

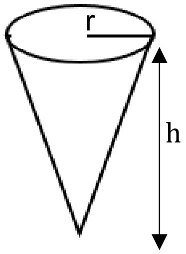
Using the conversion factor for changing cubic feet to gallons

$$\frac{28\cancel{ft^3}}{1} \times \frac{7.48\ gal}{1\ \cancel{ft^3}} = 209\ gallons$$

The CONE

Volume = 1/3 area of base (πr^2) x height (h)

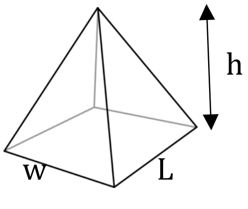
$$\mathrm{V} = \frac{1}{3}(\pi \mathrm{r}^2)\mathrm{h}$$



The PYRAMID

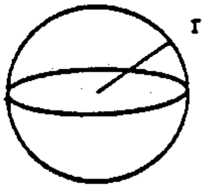
Volume = area of base (L x w) times 1/3 height (h)

$$\mathrm{V} = \mathrm{L\ x\ w\ x}\left(\frac{1}{3}\mathrm{h}\right)$$



The SPHERE

$$\mathrm{V} = \frac{4}{3}(\pi \mathrm{r}^3)$$



Of these shapes, the rectangular prism and the cylinder are the most important and their formulas should be memorized. The formulas for the cone, pyramid, and sphere shapes may have application in water works, but probably do not need to be memorized.

Special note: When determining the volume of a cylinder, you need the diameter (or radius) and another dimension. The other dimension is either the height or the length. We can think of cylinders in terms of their vertical height (like the height of a barrel or standpipe) or horizontally (like a length of water main). The volume formula is the same except we use "height" (h) in one case and "length" (L) in the other.

For example, the volume of a barrel is

$$V = 0.785 \text{ x } d^2 \text{ x } h$$

whereas the volume of a length of main is

$$V = 0.785 \text{ x } d^2 \text{ x } L$$

Whenever you are asked to determine the volume of a shape and you are given a diameter, then you know immediately that the shape is that of a cylinder. You then determine the volume by multiplying the cross-sectional area of the circle by the height or length. If you are to determine the volume of a shape that has dimensions of length, width, and height, then the shape is a rectangular prism.

The following Sample Problems will test your understanding of volume concepts.

SAMPLE PROBLEMS

(24) What is the volume of a tank exactly 30 feet long and 15 feet wide with a depth of 8 feet? Express your answer in cubic feet and gallons.

(25) What is the volume of a cylinder 10 feet high having a diameter of 6 feet?

(26) What is the volume of a pyramid having a 3 foot by 5-foot base and a height of 7 feet?

(27) What is the volume of a spherical tank having a radius of 10 feet?

VELOCITY AND RATES

Velocity is the rate of change of position, having both speed and direction. A train traveling 30 miles per hour (mph) has a velocity of 30 mph. This means that for each hour the train moves at this velocity, it will travel 30 miles. Water velocity is similar except for the units. Feet per minute (fpm) or feet per second (fps) are commonly used units for expressing water velocity. The average velocity of flow is determined by dividing the traveling time into the distance traveled. The example below shows this and converts from one unit to another.

$$60\text{ fpm } = 60\ \text{ ft}/1\text{ min} = 60\text{ ft}/60\text{ sec} = 1\text{ ft}/1\text{ sec} = 1\text{ fps}$$

The velocity of flow of water indicates how fast a "point" within the water is traveling past a reference spot.

The RATE OF FLOW is an indication of how much water (a volume) is moving past a spot in a unit of time. Flow rates are typically referred to as discharge (Q) and expressed in volumes per units of time, such as gallons per minute (gpm), millions of gallons per day (mgd), and cubic feet per second (cfs).

There are conversion charts available that show the relationship between various water flow units. These charts show the pathways, and necessary conversion factor values, to convert the water flow units: cfs to gpm; gpm to lbs/day; gpd to gps; and several others as well. The problem with relying upon a conversion chart of this type is, "What do you do when you don't have the chart?" Charts of this type have intentionally been left out of this book. Instead, it is recommended that you use the conversion factors you already know to work problems of this sort. Some examples should help.

Example: Convert 700 gpm to cfs.

Solution: Write down what you are given (700 gpm) and determine what "unit" conversions are needed to go from where we are to where we need to be (from gpm to cfs). It usually helps to write out the abbreviated units to see the "picture" more clearly.

$$\frac{700\ \cancel{gal}}{1\ \cancel{min}} \times \frac{1\ ft^3}{7.48\ \cancel{gal}} \times \frac{1\ \cancel{min}}{60\ sec} = \frac{1.56\ ft^3}{sec}$$

Therefore, $700\ gpm = 1.56\ cfs$

Example: Convert $2.25\ cfs\ to\ \frac{gal}{hr}$

Solution: Get appropriate units and conversion factors in order and calculate.

$$\frac{2.25\ \cancel{ft^3}}{\cancel{1\ sec}} \times \frac{7.48\ gal}{1\ \cancel{ft^3}} \times \frac{60\ \cancel{sec}}{\cancel{1\ min}} \times \frac{60\ \cancel{min}}{1\ hr} = \frac{60{,}588\ gal}{hr}$$

Example: Convert 0.1 million lbs/day to gpm.

Solution: Write down what we have and look for a conversion unit "pathway" to get us where we want to go.

$$0.1 \quad M\ lbs/day \times 1{,}000{,}000\ lbs/1\ M = 100{,}000\ lbs/day$$

so

$$\frac{100{,}000\ \cancel{lbs}}{\cancel{1\ day}} \times \frac{1\ gal}{8.34\ \cancel{lbs}} \times \frac{1\ \cancel{day}}{24\ \cancel{hrs}} \times \frac{1\ \cancel{hr}}{60\ min} = \frac{8.3\ gal}{min}$$

The above examples are typical of "rate of flow" (Q) conversions. They all involve converting between units of volume per unit of time. Since pounds, gallons, and cubic feet are common units of volume, we frequently need to use 7.48 gal/ft^3 or 8.34 lbs/gal to convert between the various units of "Q." The second unit of "Q" is time. Since we already know the conversion factors for the units of time, we simply need to write it down, cancel similar units that appear both above and below the fraction bar, and perform the necessary calculations.

SAMPLE PROBLEMS

(28) Convert 150 fpm to fps Answer ________

(29) Convert 5 cfs to gpm Answer ________

(30) Convert 300 gpm to gpd Answer ________

(31) Convert 750 gpm to cfs Answer ________

AVERAGES AND MEANS

A method for relating or representing a group of numbers is to average them. In this sense, we take the arithmetic mean, which is the average of a set of numerical values, calculated by adding them together and dividing by the number of terms in the set.

Arithmetic mean formula: $A = S/N$

A = average (or arithmetic mean).
N = the number of terms (e.g., the number of items or numbers being averaged).
S = the sum of the numbers in the set of interest (e.g., the sum of the numbers being averaged)

Example: Find the mean (average) of the following list of numbers:
5, 3, 4, 5, 6, 4, 7, 5, 5, 6, 5, 5

Solution:

a) Add up all the numerical values to get 60
(5+3+4+5+6+4+7+5+5+6+5+5 = 60)
b) Divide 60 by the number of terms (60 ÷ 12 = 5)
c) The mean (average) is 5

ANSWERS TO CHAPTER 2 SAMPLE PROBLEMS

(1) (a) 0.49 (b) 0.005 (c) 0.03 (d) 1.51

(2) (a) 10% (b) 752% (c) 0.6% (d) 19%

(3) 1/2 = 0.5 = 50%

(4) 90% of 50 = ? 0.9 x 50 = 45 gallons

(5) 75% of 550,000 gpd = ? 0.75 x 550,000 gpd = 412,500 gpd

(6) Basin #1: 65% of 90 MGD = ? 0.65 x 90 MGD = 58.5 MGD
Basin #2: 35% of 90 MGD = ? 0.35 x 90 MGD = 31.5 MGD

(7) Find 5% of 7,700: 0.05 x 7,700 = 385;
Add increase to starting population, so first year is 7,700 + 385 = 8,085
Find 5% of 8,085: 0.05 x 8,085 = 404;
Add increase to starting population, so second year is 8,085 + 404 = 8,489
Find 5% of 8,489: 0.05 x 8,489 = 424;
Add increase to starting population, so third year is 8,489 + 424 = 8,913

(8) $\frac{3X}{3} = \frac{15}{3} = 5 \qquad \mathrm{X} = 5$

(9) 4X + 5 = 21 is the same as 21 – 5 = 4X, so 16 = 4X. 16 ÷ 4 = 4. X = 4.

(10) 21 + 7X = 112 is the same as 112 – 21 = 7X, so 91 ÷ 7 = X. X = 13.

(11) X – 15 = 22 is the same as 22 + 15 = X, so X = 37.

(12) 4X + 25 = 125 is the same as 125 – 25 = 4X, so 100 = 4X. 100 ÷ 4 = 25. X = 25.

(13) $\frac{16}{4} = \frac{X}{2} \qquad 4X = 32;\ 32 \div 4 = 8,\ so\ X = 8$

(14) $\frac{9}{X} = \frac{3}{3} \qquad 3X = 27;\ 27 \div 3 = 9,\ so\ X = 9$

(15) $\frac{15}{5} = \frac{9}{X} \qquad 15X = 45;\ 45 \div 15 = 3,\ so\ X = 3$

(16) 12 ft + 1.5 ft + 9 ft = 22.5 ft

(17) $\frac{3\ \cancel{ft^3}}{1} \times \frac{62.4\ lbs}{\cancel{ft^3}} = 187.2\ lbs$

(18) $\frac{16\ \cancel{gal}}{1} \times \frac{1\ ft^3}{7.48\ \cancel{gal}} = 2.1\ ft^3$

(19) $\frac{536{,}000\cancel{ft^2}}{1} \times \frac{1\ acre}{43{,}560\ \cancel{ft}^2} = 12.3\ acres$

(20) $\frac{50{,}000\ \cancel{ft^3}}{1} \times \frac{7.48\ gal}{1\ \cancel{ft^3}} = 374{,}000\ gal$

(21) $Area\ = L\ \times W\ = 28\ feet\ \times 18\ feet\ = 504\ ft^2$

(22) Radius = 200 feet Diameter = 400 feet

$$Area\ =\ 0.785D^2 = 0.785(400\ ft)^2\ = 125{,}600\ ft^2$$

$$\frac{125{,}600\ \cancel{ft^2}}{1} \times \frac{1\ acre}{43{,}560\ \cancel{ft^2}} = 2.9\ acres$$

(23) $Circumference\ = C\ = (\pi)d$
$3.14\ \times 400\ ft\ = 1.256\ ft$

(24) $Volume\ = L\ \times W\ \times H\ = 30\ feet\ \times 15\ feet\ \times 8\ feet\ = 3{,}600\ ft^3$

$$\frac{3{,}600\ \cancel{ft^3}}{1} \times \frac{7.48\ gal}{1\cancel{ft}^3} = 26{,}928\ gallons\ \ (Rounded\ is\ 27{,}000\ gallons)$$

(25) $Volume\ = 0.785d^2h\ = 0.785 \times 6\ ft^2\ \times 10\ ft\ = 282.6\ ft^3$

(26) $V\ = L\ \times w\ \times \frac{1}{3}h\ = 5\ ft\ \times 3\ ft\ \times 0.33\ \times 7\ ft\ = 35\ ft^3$

(27) $V\ = \frac{4}{3}(\pi r^3) = \frac{4}{3}(3.14)(10\ ft)^3 = 4{,}187\ ft^3$

(28) $\frac{150\ ft}{1\ \cancel{min}} \times \frac{1\ \cancel{min}}{60\ sec} = 2.5\ fps$

(29) $\frac{5\ \cancel{ft}^3}{1\ \cancel{sec}} \times \frac{7.48\ gal}{1\ \cancel{ft}^3} \times \frac{60\ \cancel{sec}}{1\ min} = 2.244\ gpm$

(30) $\frac{300\ gal}{1\ \cancel{min}} \times \frac{60\ \cancel{min}}{1\ \cancel{hr}} \times \frac{24\ \cancel{hrs}}{1\ day} = 232{,}000\ gpd$

(31) $\frac{750\ \cancel{gal}}{1\ \cancel{min}} \times \frac{1\ ft^3}{7.48\ \cancel{gal}} \times \frac{1\ \cancel{min}}{60\ sec} = 1.7\ cfs$

CHAPTER 3 – Bacteriological Sampling and Analysis

BACTERIOLOGY

Improperly treated or unprotected water may contain microorganisms that are disease causing or "pathogenic." Coliform bacteria, while usually not causing disease themselves, are often associated with pathogenic organisms and are a good index of the bacteriological safety of a water source. Coliform bacteria normally occur in the intestines of humans and other warm-blooded animals and are discharged in great numbers in human and animal waste. The coliform group includes all aerobic (live in air) and facultatively anaerobic (live with or without air), gram-negative, nonspore-forming, rod-shaped bacteria which ferment lactose with gas production in prescribed culture media within 48 hours at 35°C. Coliform bacteria are more hardy than disease-causing bacteria; therefore, their absence from water is usually an indication that the water is bacteriologically safe for human consumption. The presence of coliform bacteria, on the other hand, is an indication that disease-causing bacteria also may be present and that the water may be unsafe to drink.

Part 6 of the Rules establishes drinking water standards and the methods to be used in the analyses of water samples from PWSs and stipulates that the coliform group be used as the official indicator of the bacteriological quality of water. It also states that the procedures used for the detection and enumeration of coliform bacteria must be in accordance with USEPA requirements. Part 7 of the Rules includes the *"Total Coliform Rule,"* which was updated in 2016, and is now commonly referred to as the *"Revised Total Coliform Rule,"* or "RTCR," and specifies how many bacteriological samples must be taken each month.

ANALYSIS

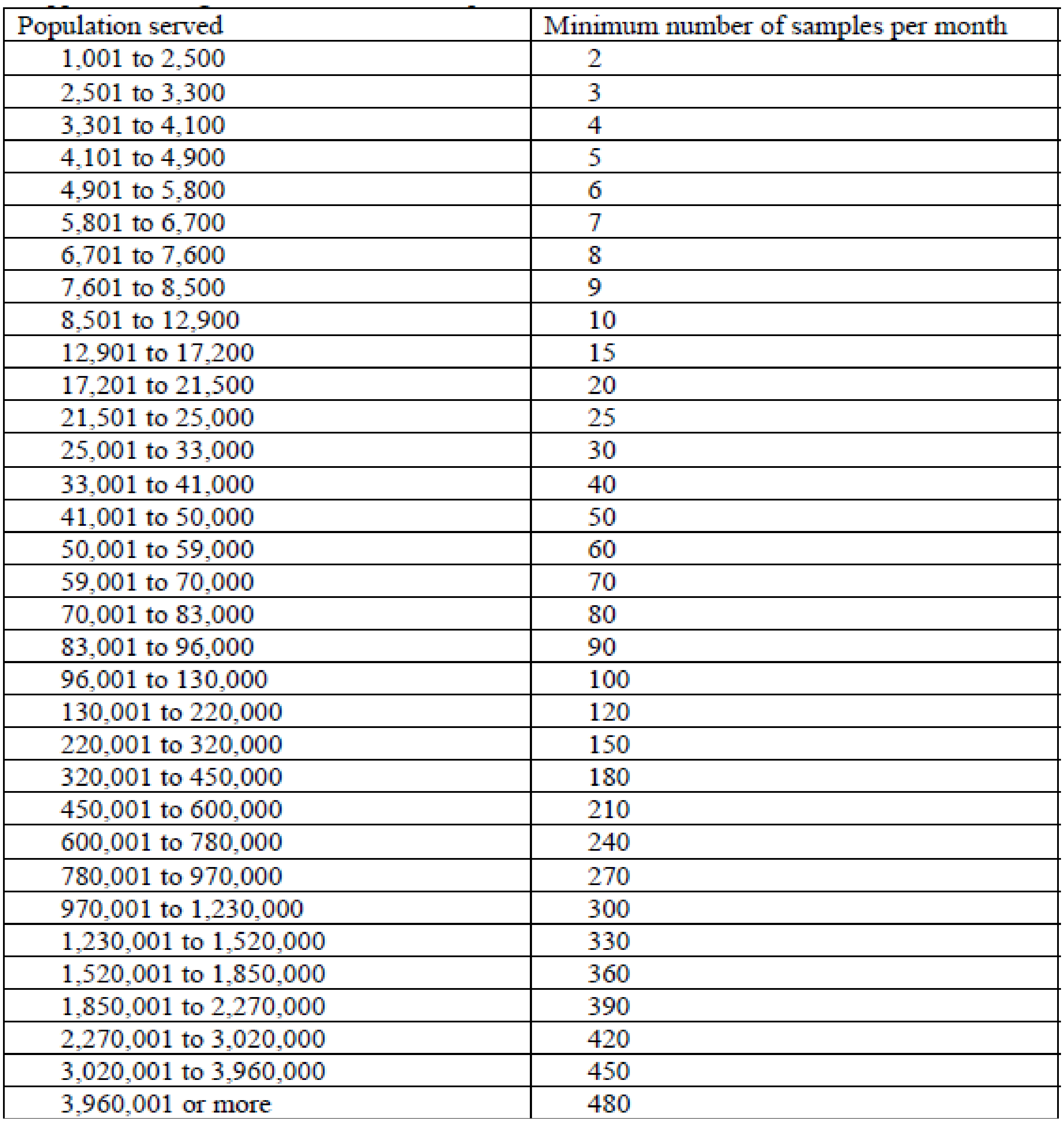
There are several analytical procedures currently approved by the USEPA for the testing of drinking water for total coliform bacteria. The laboratory may perform an analysis for total coliform bacteria using the membrane filter (MF) technique, the multiple tube format (MTF) technique, the presence-absence (P-A) technique, or the minimal medium (ONPG-MUG) test technique. Depending on the procedures used, the results may be reported in a variety of different ways. If the P-A technique or the ONPG-MUG technique utilizing the presence-absence format are used, the results will simply report either the absence or presence of total coliform bacteria. If the MTF technique or the ONPG-MUG technique with the MTF are used, the results are reported as an estimated total coliform density or a most probable number (MPN). Laboratory results produced through the MF technique will report an actual number of total coliforms detected. Also, for the MF, P-A, and the MTF techniques, the laboratory may report that the growth of non-coliform bacteria interfered with the test for total coliform. Any of these methods may be used, but the most common method in use for routine drinking water compliance samples is the ONPG-MUG technique, which gives an "Absent or Present" result.

The MTF and the ONPG-MUG techniques may be run in either a MTF with a series of five or ten tubes or in the presence-absence format (not to be confused with the presence-absence test) with a single vial. The MTF technique is also known as the most MPN technique. MMO-MUG, Colilert^{TM}, and Modified Colitag™ are some other names for the ONPG-MUG technique.

Analytical results from the MF or the ONPG-MUG techniques are available within twenty-four (24) hours if no coliform bacteria are detected. The negative results for total coliform from the MTF or P-A techniques are available after forty-eight (48) hours. If suspicious growth is detected in any of these techniques, additional time will be required to confirm the growth as total coliform bacteria and to determine if the growth is either fecal coliform or *E. coli* in origin. Confirmation for total coliform in the MF, MTF, and P-A techniques requires up to an additional forty-eight (48) hours. The ONPG-MUG test does not require an additional confirmatory test for total coliform. Testing for *E. coli* requires twenty-four (24) hours for each of the techniques. The fecal and *E. coli* portion of the procedure may be done concurrently or sequentially with the total coliform confirmatory test. The RTCR requires that any sample testing positive for total coliform also be tested for *E. coli*.

The format of the results reported by a laboratory depends on the techniques used and the confirmatory tests required to complete an analysis. Typical analytical results as expected from a laboratory for total coliform bacteria are shown in Figure 3.2. If the *E. coli* tests are performed, the results are simply reported as either positive or negative.

Table 3.1 Coliform Monitoring Frequency

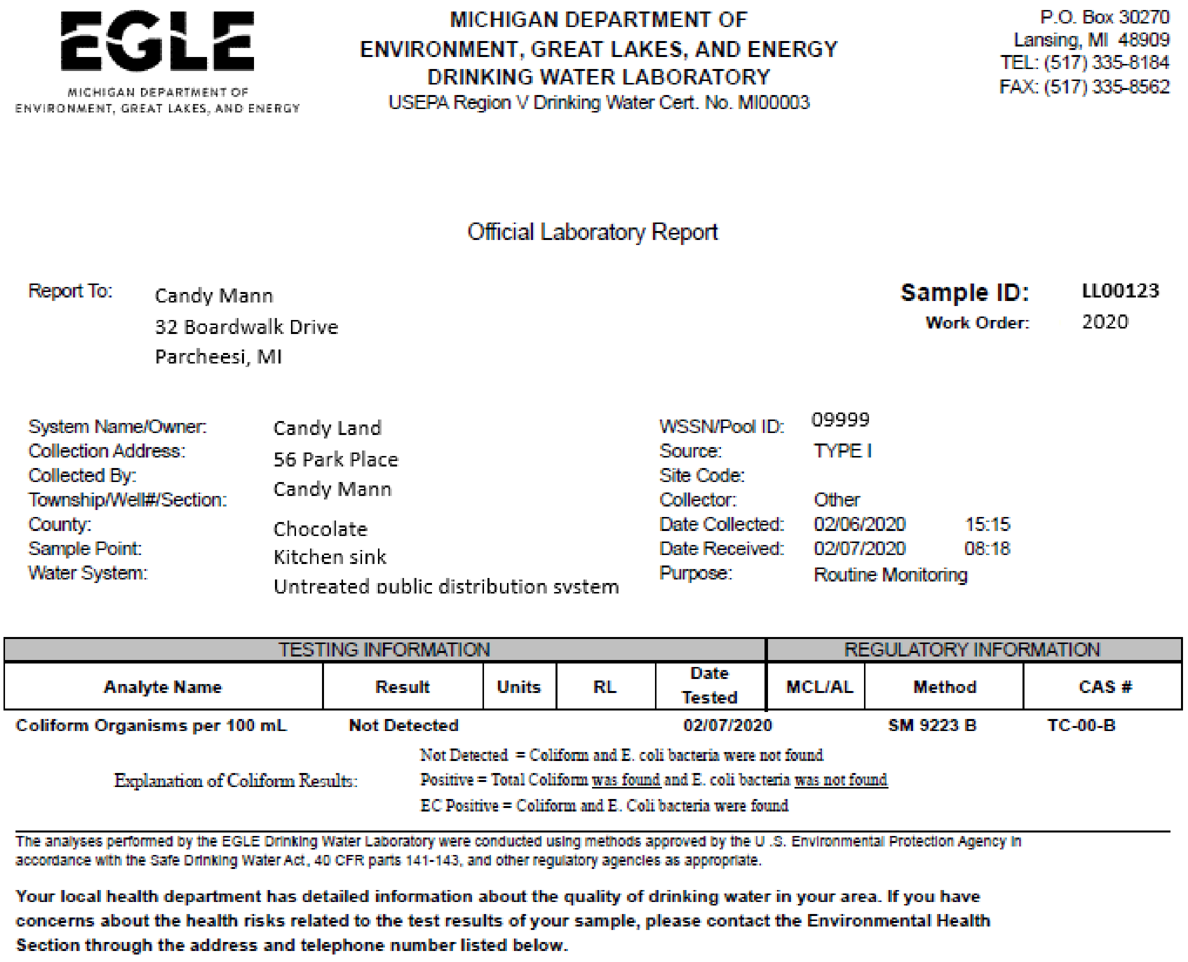


Population served	Minimum number of samples per month
1,001 to 2,500	2
2,501 to 3,300	3
3,301 to 4,100	4
4,101 to 4,900	5
4,901 to 5,800	6
5,801 to 6,700	7
6,701 to 7,600	8
7,601 to 8,500	9
8,501 to 12,900	10
12,901 to 17,200	15
17,201 to 21,500	20
21,501 to 25,000	25
25,001 to 33,000	30
33,001 to 41,000	40
41,001 to 50,000	50
50,001 to 59,000	60
59,001 to 70,000	70
70,001 to 83,000	80
83,001 to 96,000	90
96,001 to 130,000	100
130,001 to 220,000	120
220,001 to 320,000	150
320,001 to 450,000	180
450,001 to 600,000	210
600,001 to 780,000	240
780,001 to 970,000	270
970,001 to 1,230,000	300
1,230,001 to 1,520,000	330
1,520,001 to 1,850,000	360
1,850,001 to 2,270,000	390
2,270,001 to 3,020,000	420
3,020,001 to 3,960,000	450
3,960,001 or more	480

Table 3.2 Coliform Reporting

Test Technique	Reported Result	Explanation of Result
MF	0 or < 1	No coliform bacteria found
	Any number from 1-200	The number indicates the number of total coliform detected.
	o-INT or OG	No coliform bacteria found, but an overgrowth of non-coliform bacteria possibly interfered with the test.
	> 1	There was an overgrowth of interfering bacteria, but at least 1 coliform bacteria confirmed to be present.
P-A, MTF, or NPG-MUG (MTF format)	0 or < 1.1	No coliform bacteria found.
	Any number from 1.1 to > 23.0	The number indicates the MPN of total coliform present.
	Int or OG	There was a sufficient number of non-coliform bacteria present to cause a cloudy tube and may have interfered with the detection of coliform (not applicable to the ONPG-MUG test).
P-A, Colisure Test, or ONPG-MUG (P-A format)	Negative or Absent or Not Detected	No coliform bacteria detected.
	Positive or Present	Coliform bacteria detected.

Figure 3.3 Example Bacteriological Result



MICHIGAN DEPARTMENT OF
ENVIRONMENT, GREAT LAKES, AND ENERGY
DRINKING WATER LABORATORY
USEPA Region V Drinking Water Cert. No. MI00003

P.O. Box 30270
Lansing, MI 48909
TEL: (517) 335-8184
FAX: (517) 335-8562

Official Laboratory Report

Report To: Candy Mann
32 Boardwalk Drive
Parcheesi, MI

Sample ID: LL00123
Work Order: 2020

System Name/Owner: Candy Land
Collection Address: 56 Park Place
Collected By: Candy Mann
Township/Well#/Section:
County: Chocolate
Sample Point: Kitchen sink
Water System: Untreated public distribution system

WSSN/Pool ID: 09999
Source: TYPE I
Site Code:
Collector: Other
Date Collected: 02/06/2020 15:15
Date Received: 02/07/2020 08:18
Purpose: Routine Monitoring

TESTING INFORMATION					REGULATORY INFORMATION		
Analyte Name	**Result**	**Units**	**RL**	**Date Tested**	**MCL/AL**	**Method**	**CAS #**
Coliform Organisms per 100 mL	**Not Detected**			**02/07/2020**		**SM 9223 B**	**TC-00-B**

Explanation of Coliform Results:
Not Detected = Coliform and E. coli bacteria were not found
Positive = Total Coliform was found and E. coli bacteria was not found
EC Positive = Coliform and E. Coli bacteria were found

The analyses performed by the EGLE Drinking Water Laboratory were conducted using methods approved by the U.S. Environmental Protection Agency in accordance with the Safe Drinking Water Act, 40 CFR parts 141-143, and other regulatory agencies as appropriate.

Your local health department has detailed information about the quality of drinking water in your area. If you have concerns about the health risks related to the test results of your sample, please contact the Environmental Health Section through the address and telephone number listed below.

SAMPLING

The RTCR requires sampling sites be representative of the water throughout the distribution system. A water supply complies with this portion of the regulation by submitting a Sample Siting Plan (SSP). This plan documents the addresses of the locations where the routine compliance samples are collected, the upstream and downstream repeat sample locations for each compliance site (located within five service connections), and the locations of source samples. It is suggested that these locations be public buildings, commercial establishments, or permanent sampling stations, where access may be more readily assured in the event repeat samples are needed. Routine locations should be chosen with upstream and downstream sample locations in mind. It is recommended that the water system include the addresses of one or two alternate locations on the SSP to be used in the event the regular site is unavailable. SSPs are subject to EGLE review and revision.

For water supplies collecting more than five (5) routine distribution system samples each month, all the samples must be collected at regularly spaced intervals throughout the month. Pinpointing the routine and repeat sample sites on a copy of the general plan will assist water supplies in assuring that the entire system is covered by the bacteriological SSP. The minimum number of samples required to be collected during a month is based on the population served by the water supply. This number may be increased by the department as needed to assess water quality problems within the system, maintenance or operation practices, or a geographically large system with diverse usage areas.

Sampling Technique

Using proper sampling techniques is the first step toward obtaining accurate water quality information. Improperly collected samples can cause a “false positive,” where the sample shows contamination, but it was a result of the sampling procedure, not the water quality.

In this case, the water supply is not contaminated but since the sample was positive for coliform, all of the repeat samples must still be taken. This unnecessary additional sampling and analysis cost can be avoided if proper sampling procedures are learned and followed.

A good sampling technique includes the following:

1. Select a representative sampling point. The faucet or tap should be as clean as possible without attachments such as aerators, dishwasher connectors, etc.

2. Thoroughly wash hands and avoid introducing any outside contaminants.

3. Flame the tap with a propane torch or disinfect with a bleach solution.

4. Allow cold water to run at least five minutes to flush the line to draw a fresh sample through the sampling tap. After flushing, reduce the flow to a steady, pencil-sized stream.

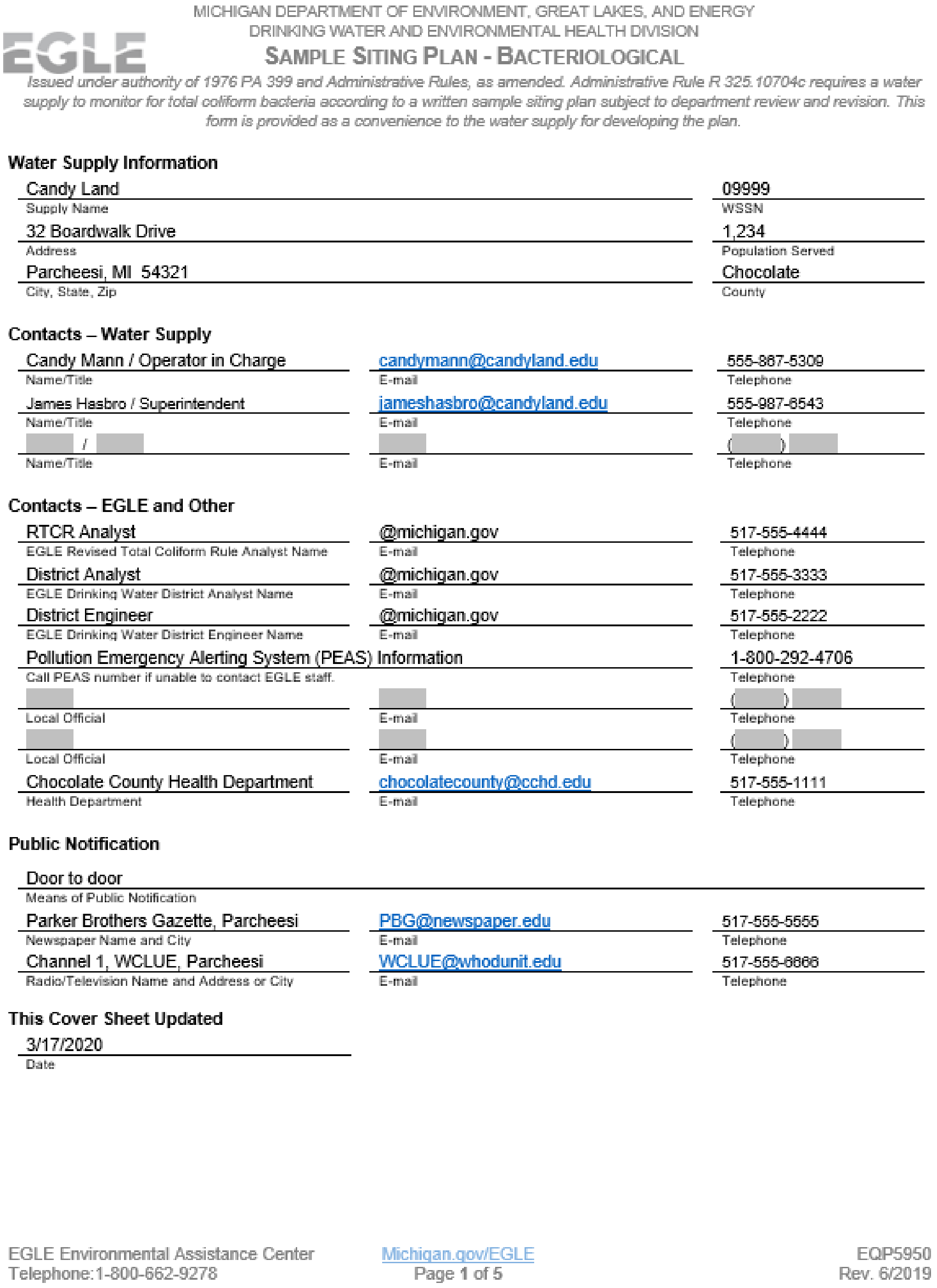
5. Remove cap from sample bottle, without touching the lip of the bottle or the inside of the cap; hold cap so that water will not splash on it, and fill bottle to 100 ml line.

6. Quickly recap the bottle, being sure to not touch the lip of the bottle or the inside of the cap.

7. Turn off the water tap and double check that the bottle cap is secure.

8. Complete the form provided with the sample bottle and deliver it to the laboratory as soon as possible, preferably the same day. Sample analysis should be initiated within 30 hours of collection. Ensure that the form is properly completed with all the required information, including the Public Water Supply Identification (PWSID), formally known as Water Supply Serial Number (WSSN). The sample will not be credited to the water system without it.

Figure 3.4 Sample Site Plan Example



MICHIGAN DEPARTMENT OF ENVIRONMENT, GREAT LAKES, AND ENERGY
DRINKING WATER AND ENVIRONMENTAL HEALTH DIVISION

SAMPLE SITING PLAN - BACTERIOLOGICAL

Issued under authority of 1976 PA 399 and Administrative Rules, as amended. Administrative Rule R 325.10704c requires a water supply to monitor for total coliform bacteria according to a written sample siting plan subject to department review and revision. This form is provided as a convenience to the water supply for developing the plan.

Water Supply Information

Candy Land	09999
Supply Name	WSSN
32 Boardwalk Drive	1,234
Address	Population Served
Parcheesi, MI 54321	Chocolate
City, State, Zip	County

Contacts – Water Supply

Candy Mann / Operator in Charge	candymann@candyland.edu	555-867-5309
Name/Title	E-mail	Telephone
James Hasbro / Superintendent	jameshasbro@candyland.edu	555-987-6543
Name/Title	E-mail	Telephone
/		( )
Name/Title	E-mail	Telephone

Contacts – EGLE and Other

RTCR Analyst	@michigan.gov	517-555-4444
EGLE Revised Total Coliform Rule Analyst Name	E-mail	Telephone
District Analyst	@michigan.gov	517-555-3333
EGLE Drinking Water District Analyst Name	E-mail	Telephone
District Engineer	@michigan.gov	517-555-2222
EGLE Drinking Water District Engineer Name	E-mail	Telephone
Pollution Emergency Alerting System (PEAS) Information		1-800-292-4706
Call PEAS number if unable to contact EGLE staff.		Telephone
		( )
Local Official	E-mail	Telephone
		( )
Local Official	E-mail	Telephone
Chocolate County Health Department	chocolatecounty@cchd.edu	517-555-1111
Health Department	E-mail	Telephone

Public Notification

Door to door
Means of Public Notification

Parker Brothers Gazette, Parcheesi	PBG@newspaper.edu	517-555-5555
Newspaper Name and City	E-mail	Telephone
Channel 1, WCLUE, Parcheesi	WCLUE@whodunit.edu	517-555-6666
Radio/Television Name and Address or City	E-mail	Telephone

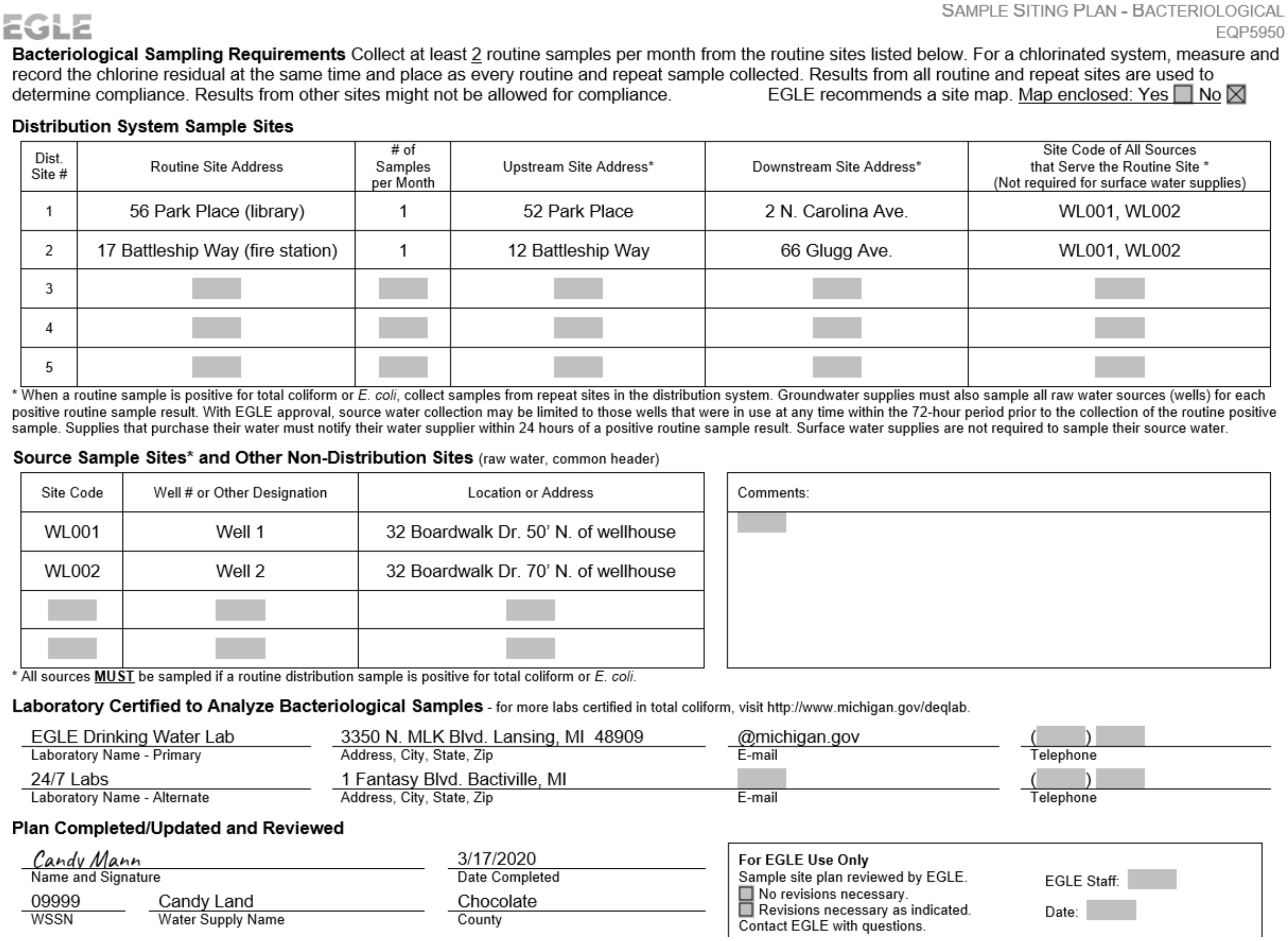
This Cover Sheet Updated

3/17/2020
Date

EGLE Environmental Assistance Center
Telephone:1-800-662-9278

Michigan.gov/EGLE
Page 1 of 5

EQP5950
Rev. 6/2019



EGLE

SAMPLE SITING PLAN - BACTERIOLOGICAL
EQP5950

Bacteriological Sampling Requirements Collect at least 2 routine samples per month from the routine sites listed below. For a chlorinated system, measure and record the chlorine residual at the same time and place as every routine and repeat sample collected. Results from all routine and repeat sites are used to determine compliance. Results from other sites might not be allowed for compliance. EGLE recommends a site map. Map enclosed: Yes ☐ No ☒

Distribution System Sample Sites

Dist. Site #	Routine Site Address	# of Samples per Month	Upstream Site Address*	Downstream Site Address*	Site Code of All Sources that Serve the Routine Site * (Not required for surface water supplies)
1	56 Park Place (library)	1	52 Park Place	2 N. Carolina Ave.	WL001, WL002
2	17 Battleship Way (fire station)	1	12 Battleship Way	66 Glugg Ave.	WL001, WL002
3					
4					
5					

* When a routine sample is positive for total coliform or *E. coli*, collect samples from repeat sites in the distribution system. Groundwater supplies must also sample all raw water sources (wells) for each positive routine sample result. With EGLE approval, source water collection may be limited to those wells that were in use at any time within the 72-hour period prior to the collection of the routine positive sample. Supplies that purchase their water must notify their water supplier within 24 hours of a positive routine sample result. Surface water supplies are not required to sample their source water.

Source Sample Sites* and Other Non-Distribution Sites (raw water, common header)

Site Code	Well # or Other Designation	Location or Address
WL001	Well 1	32 Boardwalk Dr. 50' N. of wellhouse
WL002	Well 2	32 Boardwalk Dr. 70' N. of wellhouse

Comments:

* All sources **MUST** be sampled if a routine distribution sample is positive for total coliform or *E. coli*.

Laboratory Certified to Analyze Bacteriological Samples - for more labs certified in total coliform, visit http://www.michigan.gov/deqlab.

Laboratory Name - Primary: EGLE Drinking Water Lab
Address, City, State, Zip: 3350 N. MLK Blvd. Lansing, MI 48909
E-mail: @michigan.gov
Telephone: ( )

Laboratory Name - Alternate: 24/7 Labs
Address, City, State, Zip: 1 Fantasy Blvd. Bactiville, MI
E-mail:
Telephone: ( )

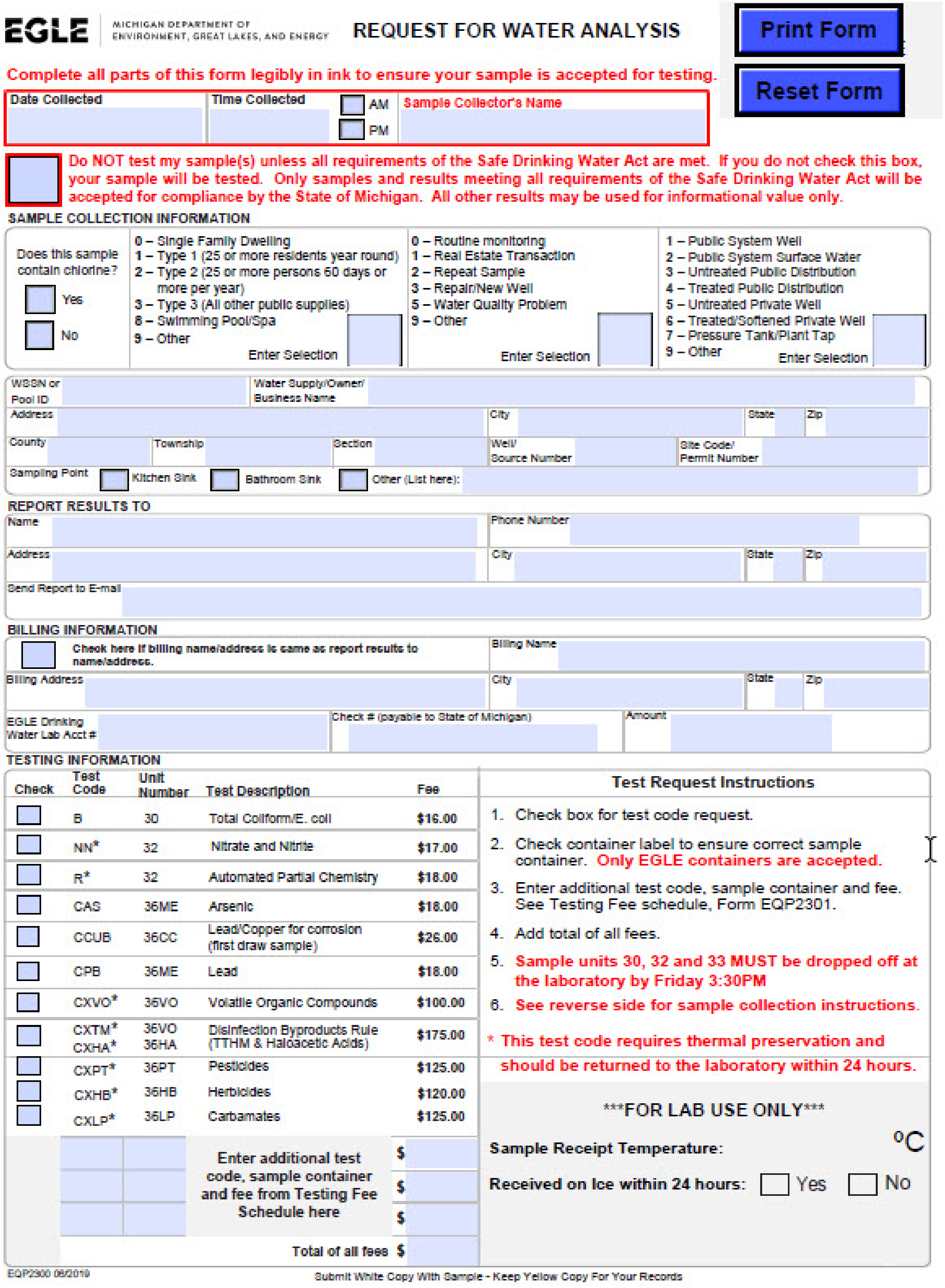
Plan Completed/Updated and Reviewed

Name and Signature: Candy Mann
Date Completed: 3/17/2020
WSSN: 09999
Water Supply Name: Candy Land
County: Chocolate

For EGLE Use Only
Sample site plan reviewed by EGLE.
☐ No revisions necessary.
☐ Revisions necessary as indicated.
Contact EGLE with questions.
EGLE Staff:
Date:

Note that the request for water analysis form has multiple choices for the sample collection sites. Ensure that the correct numbers are chosen so the sample is acceptable for compliance. For instance, a routine bacteriological sample for a Type I system with chlorination would be “1,” “0,” and “4.” A common mistake is to re-use that set of numbers for all other samples. Chemistry samples must be taken at the plant tap and cannot be accepted for compliance if marked as taken in distribution. Make sure the numbers used for plant tap chemistry are “1,” “0,” and “7.” Other labs will have similar methods for recording the sample site.

Figure 3.5 Request for Water Analysis



EGLE MICHIGAN DEPARTMENT OF ENVIRONMENT, GREAT LAKES, AND ENERGY

REQUEST FOR WATER ANALYSIS

Print Form

Reset Form

Complete all parts of this form legibly in ink to ensure your sample is accepted for testing.

Date Collected

Time Collected ☐ AM ☐ PM

Sample Collector's Name

☐ Do NOT test my sample(s) unless all requirements of the Safe Drinking Water Act are met. If you do not check this box, your sample will be tested. Only samples and results meeting all requirements of the Safe Drinking Water Act will be accepted for compliance by the State of Michigan. All other results may be used for informational value only.

SAMPLE COLLECTION INFORMATION

Does this sample contain chlorine?

☐ Yes

☐ No

0 – Single Family Dwelling
1 – Type 1 (25 or more residents year round)
2 – Type 2 (25 or more persons 60 days or more per year)
3 – Type 3 (All other public supplies)
8 – Swimming Pool/Spa
9 – Other

Enter Selection ☐

0 – Routine monitoring
1 – Real Estate Transaction
2 – Repeat Sample
3 – Repair/New Well
5 – Water Quality Problem
9 – Other

Enter Selection ☐

1 – Public System Well
2 – Public System Surface Water
3 – Untreated Public Distribution
4 – Treated Public Distribution
5 – Untreated Private Well
6 – Treated/Softened Private Well
7 – Pressure Tank/Plant Tap
9 – Other

Enter Selection ☐

WSSN or Pool ID

Water Supply/Owner/ Business Name

Address

City

State

Zip

County

Township

Section

Well/ Source Number

Site Code/ Permit Number

Sampling Point ☐ Kitchen Sink ☐ Bathroom Sink ☐ Other (List here):

REPORT RESULTS TO

Name

Phone Number

Address

City

State

Zip

Send Report to E-mail

BILLING INFORMATION

☐ **Check here if billing name/address is same as report results to name/address.**

Billing Name

Billing Address

City

State

Zip

EGLE Drinking Water Lab Acct #

Check # (payable to State of Michigan)

Amount

TESTING INFORMATION

Check	Test Code	Unit Number	Test Description	Fee
☐	B	30	Total Coliform/E. coli	$16.00
☐	NN*	32	Nitrate and Nitrite	$17.00
☐	R*	32	Automated Partial Chemistry	$18.00
☐	CAS	36ME	Arsenic	$18.00
☐	CCUB	36CC	Lead/Copper for corrosion (first draw sample)	$26.00
☐	CPB	36ME	Lead	$18.00
☐	CXVO*	36VO	Volatile Organic Compounds	$100.00
☐	CXTM* CXHA*	36VO 36HA	Disinfection Byproducts Rule (TTHM & Haloacetic Acids)	$175.00
☐	CXPT*	36PT	Pesticides	$125.00
☐	CXHB*	36HB	Herbicides	$120.00
☐	CXLP*	36LP	Carbamates	$125.00
			Enter additional test code, sample container and fee from Testing Fee Schedule here	$
				$
				$
			Total of all fees	$

Test Request Instructions

1. Check box for test code request.
2. Check container label to ensure correct sample container. Only EGLE containers are accepted.
3. Enter additional test code, sample container and fee. See Testing Fee schedule, Form EQP2301.
4. Add total of all fees.
5. **Sample units 30, 32 and 33 MUST be dropped off at the laboratory by Friday 3:30PM**
6. **See reverse side for sample collection instructions.**

* This test code requires thermal preservation and should be returned to the laboratory within 24 hours.

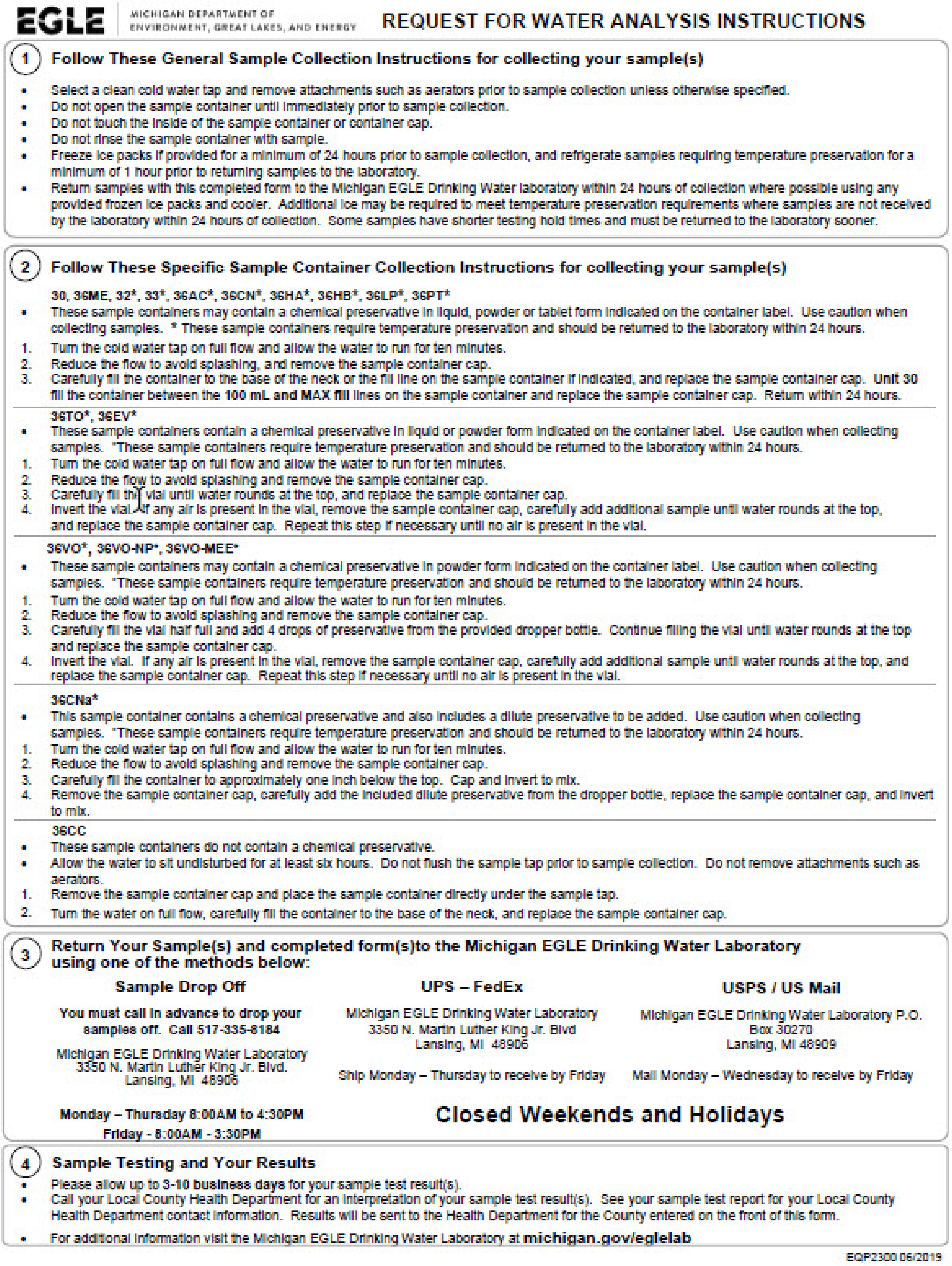
FOR LAB USE ONLY

Sample Receipt Temperature: °C

Received on Ice within 24 hours: ☐ Yes ☐ No

EQP2300 06/2019

Submit White Copy With Sample - Keep Yellow Copy For Your Records



EGLE | MICHIGAN DEPARTMENT OF ENVIRONMENT, GREAT LAKES, AND ENERGY

REQUEST FOR WATER ANALYSIS INSTRUCTIONS

① Follow These General Sample Collection Instructions for collecting your sample(s)

- Select a clean cold water tap and remove attachments such as aerators prior to sample collection unless otherwise specified.
- Do not open the sample container until immediately prior to sample collection.
- Do not touch the inside of the sample container or container cap.
- Do not rinse the sample container with sample.
- Freeze ice packs if provided for a minimum of 24 hours prior to sample collection, and refrigerate samples requiring temperature preservation for a minimum of 1 hour prior to returning samples to the laboratory.
- Return samples with this completed form to the Michigan EGLE Drinking Water laboratory within 24 hours of collection where possible using any provided frozen ice packs and cooler. Additional ice may be required to meet temperature preservation requirements where samples are not received by the laboratory within 24 hours of collection. Some samples have shorter testing hold times and must be returned to the laboratory sooner.

② Follow These Specific Sample Container Collection Instructions for collecting your sample(s)

30, 36ME, 32*, 33*, 36AC*, 36CN*, 36HA*, 36HB*, 36LP*, 36PT*

- These sample containers may contain a chemical preservative in liquid, powder or tablet form indicated on the container label. Use caution when collecting samples. * These sample containers require temperature preservation and should be returned to the laboratory within 24 hours.

1. Turn the cold water tap on full flow and allow the water to run for ten minutes.
2. Reduce the flow to avoid splashing, and remove the sample container cap.
3. Carefully fill the container to the base of the neck or the fill line on the sample container if indicated, and replace the sample container cap. **Unit 30** fill the container between the **100 mL and MAX fill** lines on the sample container and replace the sample container cap. Return within 24 hours.

36TO*, 36EV*

- These sample containers contain a chemical preservative in liquid or powder form indicated on the container label. Use caution when collecting samples. *These sample containers require temperature preservation and should be returned to the laboratory within 24 hours.

1. Turn the cold water tap on full flow and allow the water to run for ten minutes.
2. Reduce the flow to avoid splashing and remove the sample container cap.
3. Carefully fill the vial until water rounds at the top, and replace the sample container cap.
4. Invert the vial. If any air is present in the vial, remove the sample container cap, carefully add additional sample until water rounds at the top, and replace the sample container cap. Repeat this step if necessary until no air is present in the vial.

36VO*, 36VO-NP*, 36VO-MEE*

- These sample containers may contain a chemical preservative in powder form indicated on the container label. Use caution when collecting samples. *These sample containers require temperature preservation and should be returned to the laboratory within 24 hours.

1. Turn the cold water tap on full flow and allow the water to run for ten minutes.
2. Reduce the flow to avoid splashing and remove the sample container cap.
3. Carefully fill the vial half full and add 4 drops of preservative from the provided dropper bottle. Continue filling the vial until water rounds at the top and replace the sample container cap.
4. Invert the vial. If any air is present in the vial, remove the sample container cap, carefully add additional sample until water rounds at the top, and replace the sample container cap. Repeat this step if necessary until no air is present in the vial.

36CNa*

- This sample container contains a chemical preservative and also includes a dilute preservative to be added. Use caution when collecting samples. *These sample containers require temperature preservation and should be returned to the laboratory within 24 hours.

1. Turn the cold water tap on full flow and allow the water to run for ten minutes.
2. Reduce the flow to avoid splashing and remove the sample container cap.
3. Carefully fill the container to approximately one inch below the top. Cap and invert to mix.
4. Remove the sample container cap, carefully add the included dilute preservative from the dropper bottle, replace the sample container cap, and invert to mix.

36CC

- These sample containers do not contain a chemical preservative.
- Allow the water to sit undisturbed for at least six hours. Do not flush the sample tap prior to sample collection. Do not remove attachments such as aerators.

1. Remove the sample container cap and place the sample container directly under the sample tap.
2. Turn the water on full flow, carefully fill the container to the base of the neck, and replace the sample container cap.

③ Return Your Sample(s) and completed form(s)to the Michigan EGLE Drinking Water Laboratory using one of the methods below:

Sample Drop Off

You must call in advance to drop your samples off. Call 517-335-8184

Michigan EGLE Drinking Water Laboratory
3350 N. Martin Luther King Jr. Blvd.
Lansing, MI 48906

Monday – Thursday 8:00AM to 4:30PM
Friday - 8:00AM - 3:30PM

UPS – FedEx

Michigan EGLE Drinking Water Laboratory
3350 N. Martin Luther King Jr. Blvd
Lansing, MI 48906

Ship Monday – Thursday to receive by Friday

USPS / US Mail

Michigan EGLE Drinking Water Laboratory P.O. Box 30270
Lansing, MI 48909

Mail Monday – Wednesday to receive by Friday

Closed Weekends and Holidays

④ Sample Testing and Your Results

- Please allow up to **3-10 business days** for your sample test result(s).
- Call your Local County Health Department for an interpretation of your sample test result(s). See your sample test report for your Local County Health Department contact information. Results will be sent to the Health Department for the County entered on the front of this form.
- For additional information visit the Michigan EGLE Drinking Water Laboratory at **michigan.gov/eglelab**

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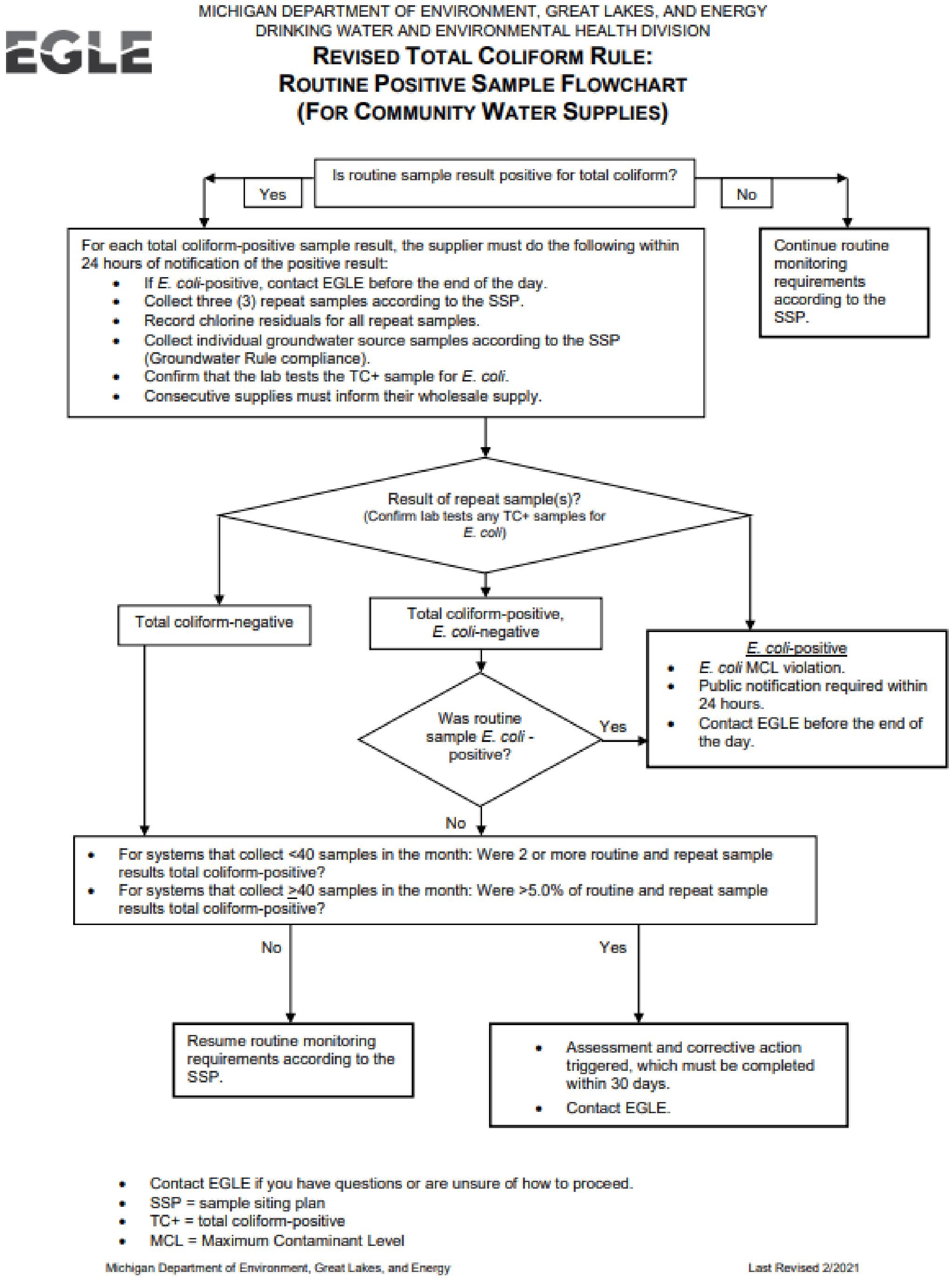
Water samples for bacteriological analysis are to be collected in the sample bottles provided by the laboratory for this purpose. The bottles are sterile and are chemically treated with sodium thiosulfate as a dechlorinating agent, so the bottle must not be rinsed out prior to sampling. All water systems have the option of submitting the routine samples to either a private laboratory, which must have state certification, or to the EGLE Drinking Water Laboratory. A list of certified laboratories is available on the EGLE Drinking Water website. Results from samples analyzed at the EGLE Drinking Water Laboratory are automatically forwarded to EGLE Drinking Water and Environmental Health (DWEHD) staff. If a private laboratory is used, a copy of the results must be forwarded to EGLE DWEHD as soon as practical, but no later than ten (10) days following the end of the sampling period. Also, if the private laboratory is used, it is the water system's responsibility to notify EGLE staff of any coliform positive sample results. It is required to notify EGLE of an *E. coli*-positive result by the end of the day. It is recommended to contact EGLE for any total coliform-positive result. All water sample results are to be submitted to the appropriate EGLE District Office.

Figure 3.6 Positive Sample Response



MICHIGAN DEPARTMENT OF ENVIRONMENT, GREAT LAKES, AND ENERGY
DRINKING WATER AND ENVIRONMENTAL HEALTH DIVISION

REVISED TOTAL COLIFORM RULE:
ROUTINE POSITIVE SAMPLE FLOWCHART
(FOR COMMUNITY WATER SUPPLIES)

Is routine sample result positive for total coliform?

Yes

For each total coliform-positive sample result, the supplier must do the following within 24 hours of notification of the positive result:

- If *E. coli*-positive, contact EGLE before the end of the day.
- Collect three (3) repeat samples according to the SSP.
- Record chlorine residuals for all repeat samples.
- Collect individual groundwater source samples according to the SSP (Groundwater Rule compliance).
- Confirm that the lab tests the TC+ sample for *E. coli*.
- Consecutive supplies must inform their wholesale supply.

No

Continue routine monitoring requirements according to the SSP.

Result of repeat sample(s)? (Confirm lab tests any TC+ samples for *E. coli*)

Total coliform-negative

Total coliform-positive, *E. coli*-negative

Was routine sample *E. coli* -positive?

Yes

E. coli-positive

- *E. coli* MCL violation.
- Public notification required within 24 hours.
- Contact EGLE before the end of the day.

No

- For systems that collect <40 samples in the month: Were 2 or more routine and repeat sample results total coliform-positive?
- For systems that collect >40 samples in the month: Were >5.0% of routine and repeat sample results total coliform-positive?

No

Resume routine monitoring requirements according to the SSP.

Yes

- Assessment and corrective action triggered, which must be completed within 30 days.
- Contact EGLE.

- Contact EGLE if you have questions or are unsure of how to proceed.
- SSP = sample siting plan
- TC+ = total coliform-positive
- MCL = Maximum Contaminant Level

Michigan Department of Environment, Great Lakes, and Energy Last Revised 2/2021

Under the RTCR, if a sample is total coliform positive, the water supply must collect a set of three (3) repeat samples in the distribution system within twenty-four (24) hours of being notified of the positive result. The supply must collect three (3) repeat samples for each routine positive sample result. All the repeat samples must be done on the same day. If one or more of the repeat samples are also positive, the supply must collect an additional set of repeat samples within 24 hours of notification of the laboratory results. The supply shall continue to collect additional sets of repeat samples until either total coliform is not detected in one complete set of repeat samples, or the supply determines that a coliform treatment technique trigger has been exceeded and notifies EGLE. Results of all routine and repeat samples taken shall be used to determine whether a coliform treatment technique trigger has been exceeded. Any sample that is found to be total coliform positive must also be tested for *E. coli*. If *E. coli* is present, the supply must notify EGLE by the end of the day when notified of the test result.

For groundwater supplies, for each routine positive, a raw water sample from each well must be collected within 24 hours following notification of a routine positive sample result.

PUBLIC NOTIFICATION

The owner of a PWS is required to notify its customers or users of violations with drinking water standards (MCLs), violations of monitoring requirements, requirements of a compliance schedule, and so on. The notifications are “tiered,” that is there are three different levels of urgency for distribution to customers. This notification must be accomplished in accordance with the time limits and by the means spelled out in the Rules for the type of violation encountered. Naturally, if an emergency exists, the utility should notify its customers immediately. EGLE can also order a PWS to make notification to the public. Public notices must be distributed in a form and manner that is reasonably calculated to reach persons served in the required time period. Examples for large supplies – radio broadcast or televised announcements. Examples for small supplies – door to door, posting at mailboxes or offices.

- Tier 1 Notices
  Must be provided within 24 hours, used for acute health risks and emergencies.

- Tier 2 Notices
  Must be provided within 30 days, used for violations of MCL, maximum residual disinfectant level (MRDL), and TT for situations with chronic health risks, etc.

- Tier 3 Notices
  Must be provided within one (1) year, used for monitoring violations, etc.

Certain language is required.

- Must be certified and a copy provided to EGLE within ten days of issuing.

- Each public notice shall include all of the following elements:

  (a) A description of the violation or situation, including the contaminant or contaminants of concern and, as applicable, the contaminant level or levels.

(b) When the violation or situation occurred.

(c) The potential adverse health effects from the violation or situation, including the standard language given in the Rule.

(d) The population at risk, including subpopulations particularly vulnerable if exposed to the contaminant in their drinking water.

(e) If alternative water supplies should be used.

(f) What actions consumers should take, including when they should seek medical help, if known.

(g) What the supply is doing to correct the violation or situation.

(h) When the supply expects to return to compliance or resolve the situation.

(i) The name, business address, and phone number of the contact who can provide additional information.

(j) A statement to encourage the notice recipient to distribute the public notice to other persons served by the water supply.

Figure 3.7 Example Public Notice

Important Information About Your Drinking Water

Tests showed coliform bacteria in the Candy Land Water Supply

Our water supply recently violated a drinking water standard. Although this incident was not an emergency, as our customers, you have a right to know what happened and what we did to correct the situation.

We routinely monitor for drinking water contaminants. We took six samples to test for the presence of coliform bacteria during the month of March 2020. Four of those samples showed the presence of coliform bacteria. The standard is that no more than 1 sample per month may do so.

What should I do?

You do not need to boil your water or take other corrective actions. However, if you have specific health concerns, consult your doctor. People with severely compromised immune systems, infants, and some elderly may be at increased risk. These people should seek advice about drinking water from their healthcare providers. General guidelines on ways to lessen the risk of infection by microbes are available from EPA's Safe Drinking Water Hotline at 1-800-426-4791.

What does this mean?

This is not an emergency. If it had been, you would have been notified immediately. Coliform bacteria are generally not harmful themselves.

Coliforms are bacteria which are naturally present in the environment and are used as an indicator that other, potentially harmful, bacteria may be present. Coliforms were found in more samples than were allowed and this was a warning of potential problems.

Usually, coliforms are a sign that there could be a problem with the system's treatment or distribution system (pipes). Whenever we detect coliform bacteria in any sample, we do follow-up testing to see if other bacteria of greater concern, such as fecal coliform or *E. coli*, are present. We did not find any of these bacteria in our subsequent testing, and further testing shows that this problem has been resolved.

What happened? What was done?

We have isolated the problem to one of the wells. The well was taken offline for maintenance to fix the issue. Distribution samples will be taken during the month of February to test for coliform bacteria.

For more information, please contact Mr. John Hasbro at 555-555-5555.
Please share this information with all the other people who drink this water, especially those who may not have received this notice directly (for example, people in apartments, nursing homes, schools, and businesses). You can do this by posting this notice in a public place or distributing copies by hand or mail. This notice is being sent to you by Candy Land.

CERTIFICATION: PWSID: 09999

I certify that this water supply has fully complied with the public notification requirements in the Michigan Safe Drinking Water Act, 1976 PA 399, as amended, and the administrative rules.

Signature	Title	Date Distributed

TREATMENT TECHNIQUE TRIGGERS AND ASSESSMENTS

Under the RTCR, water supplies shall conduct assessments of their systems after exceeding treatment technique triggers. There are both Level 1 assessments and Level 2 assessments. The Level 1 assessment is done by the water supply personnel and Level 2 assessments are completed by EGLE personnel. The proper assessment form and all corrective actions must be completed and submitted to EGLE within thirty (30) days after the supply learns that it has exceeded a trigger.

Exceeding the following treatment techniques triggers a Level 1 assessment:

- For supplies taking 40 or more samples per month, exceeding 5.0 percent total coliform positive samples for the month.
- For supplies taking fewer than 40 samples per month, the supply has two (2) or more total coliform positive samples in the same month.
- The supply fails to take every required repeat sample after a single total coliform positive sample.

Exceeding the following treatment techniques triggers a Level 2 assessment:

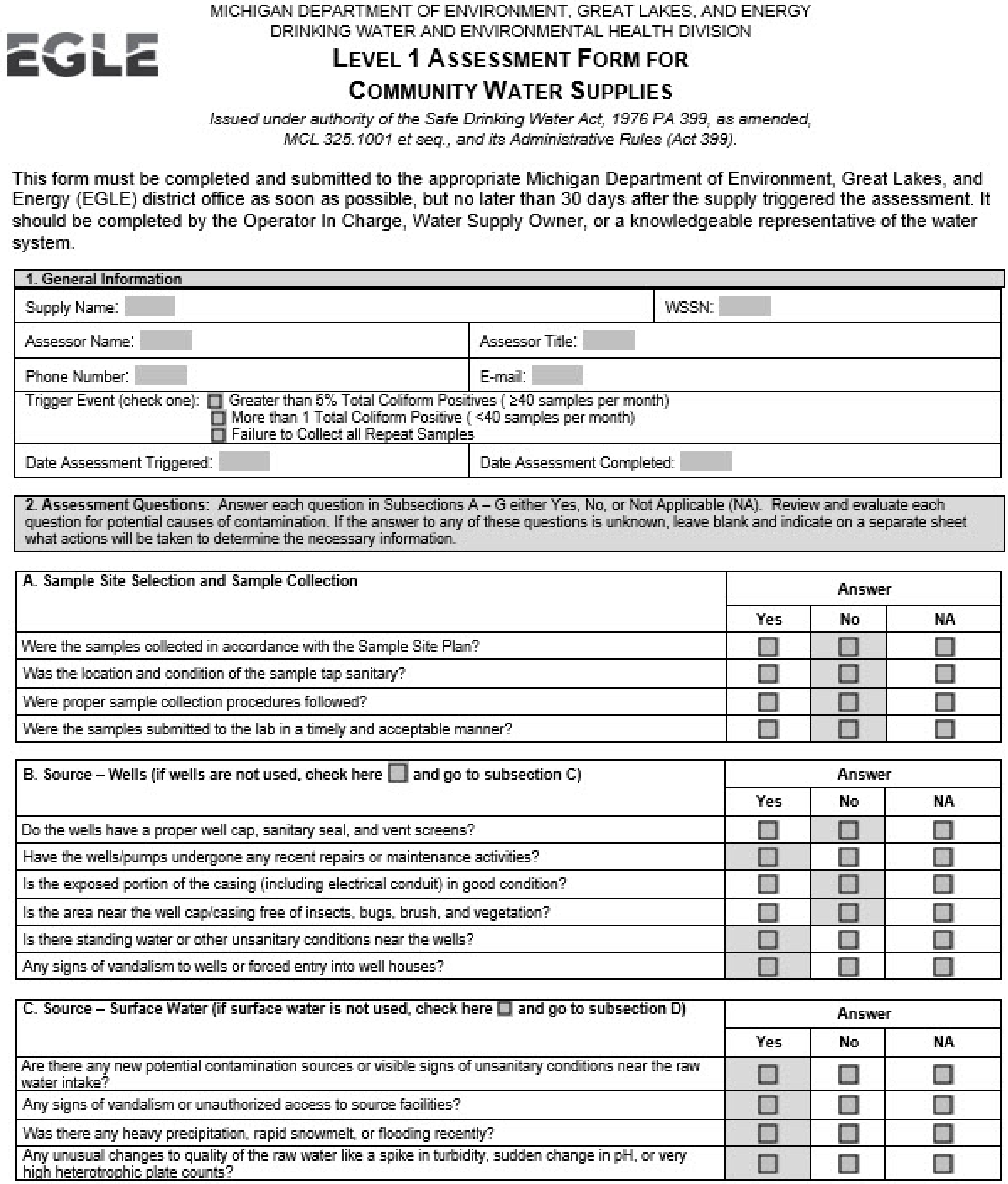
- An *E. coli* MCL violation.
- A second Level 1 trigger within a rolling 12-month period.

An assessment is an inspection and evaluation of the water supply components, operation, and maintenance in an effort to determine the source of the total coliform found in the water sample. Specific areas to cover are:

- Review and identification of inadequacies of the sample site.
- Sampling protocol.
- Sample processing.
- Atypical events (flooding, power loss, damage, etc.).
- Changes in distribution system maintenance and operation that could affect distributed water quality, including storage.
- Source and treatment considerations that affect distributed water quality.
- Existing water quality monitoring data.

When completing the Level 1 assessment form, the supply shall describe any sanitary defects found, the corrective actions completed, and a proposed timetable for each corrective action not already completed. EGLE staff will review the assessment and consult with the supply on the findings. If a Level 2 assessment is triggered, EGLE staff will complete the assessment in the same manner, describing findings, and the corrective actions taken or scheduled to be taken by the supply. In some cases, the cause of the coliform positive result may not be apparent; this will also be noted in the assessment form.

Figure 3.7 Level 1 Assessment Form



MICHIGAN DEPARTMENT OF ENVIRONMENT, GREAT LAKES, AND ENERGY
DRINKING WATER AND ENVIRONMENTAL HEALTH DIVISION

EGLE

LEVEL 1 ASSESSMENT FORM FOR COMMUNITY WATER SUPPLIES

Issued under authority of the Safe Drinking Water Act, 1976 PA 399, as amended, MCL 325.1001 et seq., and its Administrative Rules (Act 399).

This form must be completed and submitted to the appropriate Michigan Department of Environment, Great Lakes, and Energy (EGLE) district office as soon as possible, but no later than 30 days after the supply triggered the assessment. It should be completed by the Operator In Charge, Water Supply Owner, or a knowledgeable representative of the water system.

1. General Information

Supply Name:

WSSN:

Assessor Name:

Assessor Title:

Phone Number:

E-mail:

Trigger Event (check one):
☐ Greater than 5% Total Coliform Positives (≥40 samples per month)
☐ More than 1 Total Coliform Positive (<40 samples per month)
☐ Failure to Collect all Repeat Samples

Date Assessment Triggered:

Date Assessment Completed:

2. Assessment Questions: Answer each question in Subsections A – G either Yes, No, or Not Applicable (NA). Review and evaluate each question for potential causes of contamination. If the answer to any of these questions is unknown, leave blank and indicate on a separate sheet what actions will be taken to determine the necessary information.

A. Sample Site Selection and Sample Collection	Answer		
	Yes	No	NA
Were the samples collected in accordance with the Sample Site Plan?	☐	☐	☐
Was the location and condition of the sample tap sanitary?	☐	☐	☐
Were proper sample collection procedures followed?	☐	☐	☐
Were the samples submitted to the lab in a timely and acceptable manner?	☐	☐	☐

B. Source – Wells (if wells are not used, check here ☐ and go to subsection C)	Answer		
	Yes	No	NA
Do the wells have a proper well cap, sanitary seal, and vent screens?	☐	☐	☐
Have the wells/pumps undergone any recent repairs or maintenance activities?	☐	☐	☐
Is the exposed portion of the casing (including electrical conduit) in good condition?	☐	☐	☐
Is the area near the well cap/casing free of insects, bugs, brush, and vegetation?	☐	☐	☐
Is there standing water or other unsanitary conditions near the wells?	☐	☐	☐
Any signs of vandalism to wells or forced entry into well houses?	☐	☐	☐

C. Source – Surface Water (if surface water is not used, check here ☐ and go to subsection D)	Answer		
	Yes	No	NA
Are there any new potential contamination sources or visible signs of unsanitary conditions near the raw water intake?	☐	☐	☐
Any signs of vandalism or unauthorized access to source facilities?	☐	☐	☐
Was there any heavy precipitation, rapid snowmelt, or flooding recently?	☐	☐	☐
Any unusual changes to quality of the raw water like a spike in turbidity, sudden change in pH, or very high heterotrophic plate counts?	☐	☐	☐

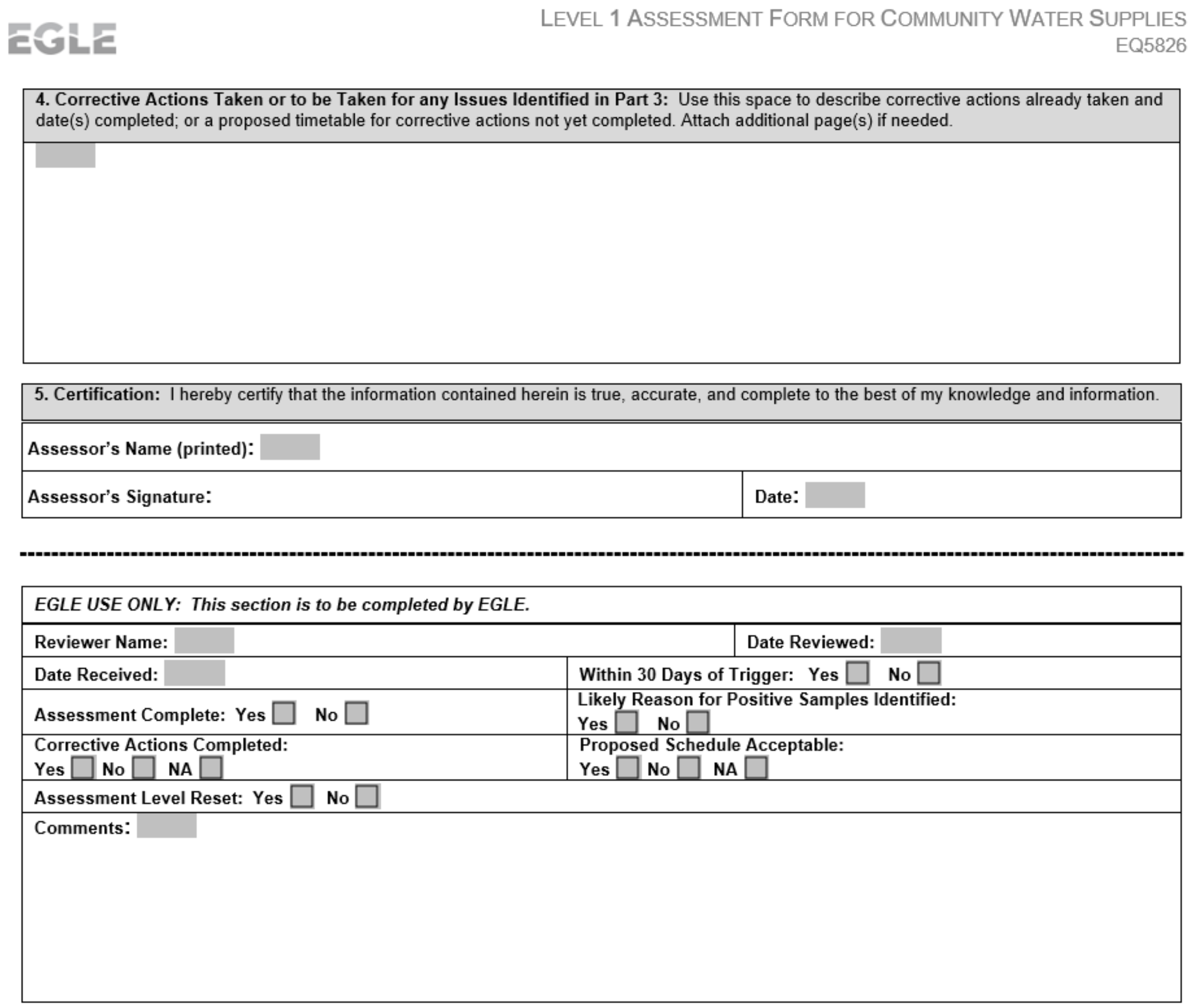
D. Treatment (if no treatment, check here ☐ and go to subsection E)	**Answer**		
	Yes	**No**	**NA**
Have there been additions or modifications to any treatment process?	☐	☐	☐
Have there been interruptions in any treatment process?	☐	☐	☐
Any signs of vandalism or unauthorized access to treatment equipment or facilities?	☐	☐	☐
Are there any issues with operation or maintenance of treatment equipment, units, or processes?	☐	☐	☐
Is there any water quality data that indicates treatment is ineffective?	☐	☐	☐

E. Storage (if no water storage tank, check here ☐ and go to subsection F)	**Answer**		
	Yes	**No**	**NA**
Are there any holes, leaks, or other structural problems?	☐	☐	☐
Are access hatches and manhole openings tightly covered and secured?	☐	☐	☐
Are all vents and overflow pipes screened?	☐	☐	☐
For hydropneumatic tanks, is the tank waterlogged?	☐	☐	☐
Any signs of vandalism or unauthorized access to storage facilities?	☐	☐	☐
Have the tank(s) been recently drained, cleaned, or inspected?	☐	☐	☐

F. Distribution System	**Answer**		
	Yes	**No**	**NA**
Have there been any low pressure events (≤ 20 psi)?	☐	☐	☐
Have there been any water main breaks, repairs, or new main installations?	☐	☐	☐
Have there been any recent fires or hydrant flushing?	☐	☐	☐
Have there been any booster pump issues, repairs, or new installations?	☐	☐	☐
Is the supply actively performing cross connection control inspections, including frequent testing of all testable backflow preventers?	☐	☐	☐
Have there been other construction activities like hydrant or valve replacement that could have introduced contamination into the system?	☐	☐	☐
If samples were collected from inside a building, has there been any recent plumbing work performed within the building?	☐	☐	☐

G. Operation and Maintenance (O&M)	**Answer**		
	Yes	**No**	**NA**
Any changes in procedures or staff effecting O&M activities?	☐	☐	☐
Any water quality data collected from the treated water tap or distribution system show results are indicative of an issue?	☐	☐	☐
Any complaints from customers related to water quality or low pressure?	☐	☐	☐
Any other issues or items that may have caused bacteriological contamination?	☐	☐	☐

3. Issue Description: For any answer in Part 2, Subsections A – G that are in a shaded box, use this space to describe the event and provide additional information on potential causes of contamination identified during the assessment. Include corresponding dates with your findings. Attach additional page(s) if needed. Include date(s) of low pressure events, water main breaks, maintenance activities, etc. with your findings.



LEVEL 1 ASSESSMENT FORM FOR COMMUNITY WATER SUPPLIES
EQ5826

4. Corrective Actions Taken or to be Taken for any Issues Identified in Part 3: Use this space to describe corrective actions already taken and date(s) completed; or a proposed timetable for corrective actions not yet completed. Attach additional page(s) if needed.

5. Certification: I hereby certify that the information contained herein is true, accurate, and complete to the best of my knowledge and information.	
Assessor's Name (printed):	
Assessor's Signature:	**Date:**

EGLE USE ONLY: This section is to be completed by EGLE.	
Reviewer Name:	**Date Reviewed:**
Date Received:	**Within 30 Days of Trigger: Yes** ☐ **No** ☐
Assessment Complete: Yes ☐ **No** ☐	**Likely Reason for Positive Samples Identified:** **Yes** ☐ **No** ☐
Corrective Actions Completed: **Yes** ☐ **No** ☐ **NA** ☐	**Proposed Schedule Acceptable:** **Yes** ☐ **No** ☐ **NA** ☐
Assessment Level Reset: Yes ☐ **No** ☐	
Comments:	

VIOLATIONS

Part 7 of Act 399 also defines violations under the RTCR.

A supply is in violation of the MCL for *E. coli* when one or more of these conditions occur:

- The supply has an *E. coli*-positive repeat sample following a total coliform-positive routine sample.
- The supply has a total coliform-positive repeat sample following an *E. coli*-positive routine sample.
- The supply fails to take all required repeat samples following an *E. coli*-positive routine sample.
- The supply fails to test for *E. coli* when a repeat sample tests positive for total coliform.

A treatment technique violation occurs when:

- A supply exceeds a treatment technique trigger and then fails to conduct the required assessment or corrective actions within the specified time frame.

Monitoring violations are both of the following:

- Failure to take every required routine or additional routine sample in a compliance period.
- Failure to analyze for *E. coli* following a total coliform-positive routine sample.

Reporting violations are all the following:

- Failure to submit a monitoring report or completed assessment form after a supply properly conducts monitoring or assessment in a timely manner.
- Failure to notify the department following an *E. coli*-positive sample in a timely manner.
- Failure to submit certification of completion of department-approved start-up procedure by a seasonal supply.

CHAPTER 4 - Disinfection

The disinfection of water may be defined as the destruction of disease causing, or "pathogenic" organisms. The term disinfection is not interchangeable with the term sterilization, which implies that all living organisms have been destroyed. Disinfection is considered the single most important treatment in the production of safe, potable water. Due to its effectiveness and lower cost, chlorination is the most widely used process for disinfecting water.

CHLORINATION

Chlorination, which is the application of chlorine to water, is used both for disinfection and for chemical oxidation. When chlorine is used as an oxidizing agent, the chemical will react with various impurities in the water, such as hydrogen sulfide or organic matter (which may cause tastes and odors). Used as a disinfecting agent, chlorine is effective, reliable, economical, and relatively easy to handle.

The element chlorine can exist in solid, liquid, or gaseous states, depending upon temperature and pressure. Chlorine will react with almost all elements and with many organics. In its gaseous state, chlorine is greenish yellow in color and has a penetrating odor. It is a respiratory irritant; exposure to high concentrations will cause death by suffocation. The gas is not explosive or flammable but is 2.5 times heavier than air. As a liquid, chlorine is amber colored and about 1.5 times as heavy as water. It is only slightly soluble in water with a maximum solubility of about 1 percent at 49.2° F. At temperatures below this point, it combines with water to form chlorine "ice," a crystalline substance which may cause operations difficulties in gas chlorinators. Liquid chlorine is a skin irritant and can cause damage to body tissues resembling a burn. Chlorine is not explosive or flammable. In its dry form, it is not corrosive, but at high temperatures or in the presence of moisture, chlorine is very corrosive. Due to these factors, care must be used when handling any form of chlorine. Proper ventilation must be provided and appropriate protective equipment, such as gloves and goggles, must be worn. In addition, air masks should be readily available when working with chlorine gas.

Chlorine Compounds Used in Disinfection

Calcium Hypochlorite - $Ca(OCl)_2$: Calcium hypochlorite is a dry powder with 65 percent available chlorine. It is sold under various trade names such as "HTH" and "Pittchlor." The dry powder must either be mixed with water to form a solution and pumped into the system or added as a powder to a non-pressurized system. Calcium hypochlorite is also available in tablet form. The tablets are sometimes used to disinfect new mains after construction or to disinfect old mains after repairs.

Chlorine Gas - Cl_2: 99.99 percent of the weight of chlorine gas is available chlorine. It can be purchased as a combination of gas and liquid in pressurized cylinders. Due to heat exchange problems encountered when changing from the liquid to gas state, chlorine gas may only be withdrawn at a rate equal to 20 percent of the cylinder contents per 24 hours. However, chlorine gas can be withdrawn at higher rates if a special gas evaporating unit is used. Only reliable and trained personnel should handle chlorine gas.

Sodium Hypochlorite – NaOCl: Sodium hypochlorite is a liquid solution containing 3 to 19 percent available chlorine. It is sold under numerous trade names and at a large variety of locations.

Table 4.1 Chlorination Terms

Available chlorine	Refers to the oxidizing power of a chlorine compound.
Free available chlorine	The concentration of hypochlorous acid and hypochlorite ions existing in chlorinated water.
Chlorine applied	The amount of available chlorine applied to the water.
Total chlorine residual	The amount of chlorine in the free and/or combined form after a certain contact time.
Free chlorine residual	The amount of chlorine that has not reacted with other compounds found in the water.
Combined chlorine residual	The amount of chlorine that has reacted with the natural ammonia or organic nitrogen compounds in the water to form chloramines.
Chlorine demand	The difference between the chlorine applied and the chlorine residual. Usually, the amount of chlorine that has reacted with or is lost to other substances in the water and is not found as a free or combined chlorine residual. Chlorine applied - chlorine demand = chlorine residual.
Breakpoint chlorination	The point at which the disinfection demand has been met, or all undesirable contaminants in the water have been oxidized, leaving free available chlorine.

Chlorine Reactions

When chlorine is added to water, a mixture of hypochlorous acid (HOCl) and hydrochloric acid (HCl) is formed, as indicated in the following equation:

$$Cl_2 + H_2O \leftrightarrow HOCl + HCl$$

Depending on pH, the hypochlorous acid will further dissociate to hydrogen (H^+) and hypochlorite (OCl^-) ions:

$$HOCl \leftrightarrow H^+ + OCl^-$$

Chlorine (Cl_2), hypochlorous acid (HOCl), and hypochlorite ion (OCl^-) are all termed free available chlorine. The relative amounts of each are dependent on the pH of the water.

As the pH decreases, more hypochlorous acid (HOCl) will be formed. At the ranges of pH values encountered in water treatment, all of the free chlorine will be in the form of hypochlorous acid (HOCl) and hypochlorite ion (OCl^-). At a pH of about 7.5, the amount of these two compounds is equal. In terms of oxidation potential though, hypochlorous acid is a much stronger disinfectant that hypochlorite ion; about 100 times as powerful. As such, hypochlorous acid is the major disinfectant in most water treatment practices.

If nitrogen compounds exist in the water, the hypochlorous acid will react further to form combined chlorine compounds. These include monochloramine, dichloramine, and trichloramine, and are formed in accordance with the following reactions:

$NH_3 + HOCl \rightarrow NH_2Cl + H_2O$ (monochloramine)

$NH_2Cl + HOCl \rightarrow NHCl_2 + H_2O$ (dichloramine)

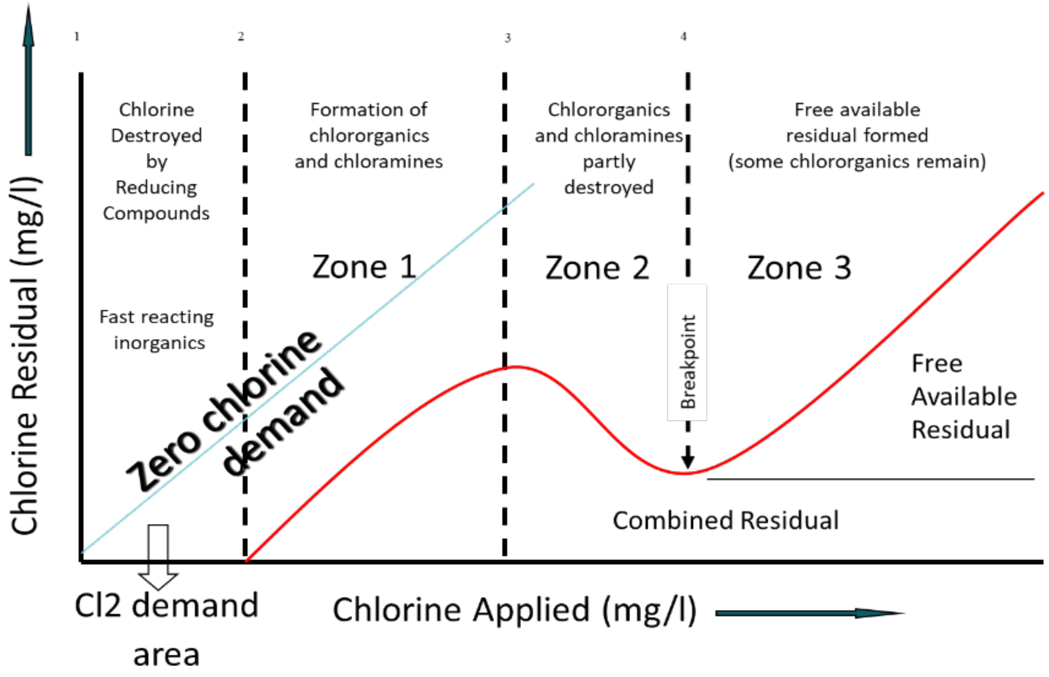
$NHCl2 + HOCl \rightarrow NCl_3 + H_2O$ (trichloramine or nitrogen trichloride)

These compounds are weak disinfectants, about 1/25th as powerful as hypochlorous acid. In addition, disagreeable tastes and odors are often associated with combined chlorine.

Breakpoint Chlorination

The shortcomings of combined chlorine (weak disinfectant with associated tastes and odors) can be minimized through the practice of breakpoint chlorination. This practice involves adding enough chlorine to destroy most of the combined chlorine compounds, leaving residual free available chlorine. This can best be demonstrated by Figure 4.2. In Zone 1, the predominant chlorine forms are monochloramine and dichloramine. In Zone 2, the residual chlorine decreases as the monochloramines and dichloramines are converted to trichloramine (nitrogen trichloride), which is released as a gas. Zone 3 is characterized by a final increase in chlorine residual. Here, an increase in the amount of free available chlorine roughly corresponds to the application of chlorine. The minimum point between the second and third zones is called the breakpoint, and from this point on, any chlorine added should reflect a similar increase in the free residual. In practice, this is known as free residual chlorination which is, by far, the preferred method of chlorination.

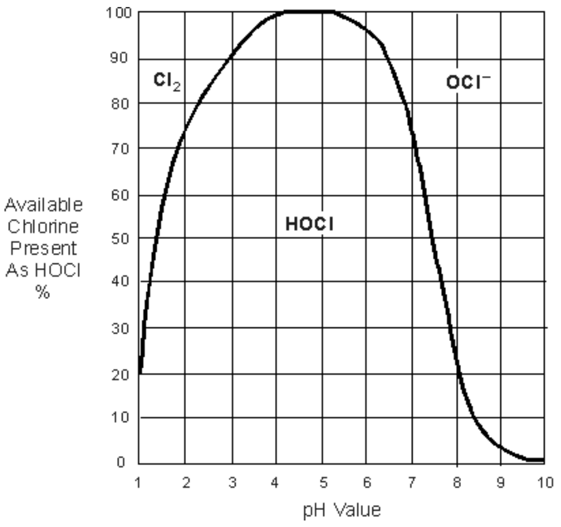
Figure 4.2 Breakpoint Chlorination



Many waters do not have appreciable amounts of nitrogen present and thus do not exhibit a breakpoint. In this case, free residual chlorination is practiced which implies that sufficient chlorine has been added to produce a predominantly free residual, regardless of whether there is a breakpoint.

The practice of maintaining a free chlorine residual throughout the water system establishes a formidable barrier against contamination and is, therefore, prevalent among chlorination systems.

Figure 4.3 Effects of pH on HOCl formation



Factors Affecting Disinfection with Chlorine

So far, we have seen how pH determines the type of free chlorine available (HOCl or OCl^-) and how the presence of ammonia compounds in the water cause the formation of combined chlorine. We have also seen how these two factors, pH and ammonia, can drastically affect the disinfecting power of chlorine. These two factors are reviewed below along with several other factors, which also impact the effectiveness of disinfection.

Time	Chlorine must be in contact with the water long enough for the reaction to occur and to adequately disinfect. The longer the contact time, the more likely the chlorine will have completely reacted.
pH	The higher the pH, the more hypochlorous acid (HOCl) is dissociated into hydrogen (H) and hypochlorite ion (OCl). Although both are free chlorine, hypochlorite ion is a much weaker disinfectant than hypochlorous acid. The lower the pH, the more effective disinfection will be.
Ammonia nitrogen compounds	The more ammonia nitrogen present in the water, the greater the formation of combined chlorine, which is a weaker disinfectant than free chlorine by as much as 25 times.
Temperature	The warmer the temperature, the faster the rate of reaction and the quicker the disinfection will occur.
Impurities	Chlorine will react with certain inorganic and organic compounds such as iron and hydrogen sulfide, as well as with bacteria and viruses. A certain amount of chlorine is used up in these reactions and is referred to as chlorine demand. The more impurities in the water, the greater the chlorine demand and the less effective disinfection is likely to be.
Chemical concentrations	The higher the concentration of chlorine with fewer compounds that exert a chlorine demand, the more effective chlorination will be.

Contact Time

Contact Time (Chlorine residual multiplied by T, or C*T) is defined as the residual concentration of a given disinfectant in mg/L times the disinfectant's contact time in minutes and is used to determine the effectiveness of a disinfectant. The same factors already discussed as affecting disinfection with chlorine affect C*T. The species of chlorine in the residual is important because of the difference in disinfecting power between free chlorine and chloramines. pH and the presence of organic N (ammonia) also play a large role in determining the type of chlorine available for disinfection. The goal of any method of disinfection is the deactivation of pathogens. Virus deactivation requires a very low C*T, while other pathogens, for instance Giardia, require a higher C*T. While C*T calculations are currently only required for Surface Water Treatment Plants, these are important concepts for all treatment operators to understand.

Safety – Chlorine Handling and Storage

Chlorine Gas -- feed and storage areas should be enclosed and separated from other operating areas. The chlorine room should be provided with a shatter resistant inspection window in an interior wall so equipment, chlorine tanks, and meter readings are visible. Each door shall be accessed from the building exterior, be weather-stripped, and equipped with a panic bar and self-closing mechanical device. All other openings between the chlorine room and the remainder of the plant should be sealed. The rooms should be above grade. Floor drains are not allowed unless they terminate outside the building in a safe area for venting. If a door opening to the plant interior is proposed, specific justification must be submitted with the construction plans and specifications.

Full and empty cylinders of chlorine gas should be isolated from operating areas; restrained in position; stored in rooms separate from storage of solvents, organic materials, and ammonia; and stored in areas not in direct sunlight or exposed to excess heat.

Where chlorine gas is used, the room should be constructed to provide the following:

1. A ventilating fan with a capacity to provide at least one complete air volume change per minute.
2. The ventilating fan should take suction near the floor as far as practical from the door and air inlet, with the point of discharge located so it does not contaminate air inlets to any rooms or structures or exit and does not endanger common work areas outside the plant.
3. Air inlets should be through automatically opening and closing louvers near the ceiling.
4. Switches for fans and lights should be outside of the room, at any entrance. A signal light indicating fan operation should be provided at each entrance.
5. Vents from feeders and storage should discharge to the outside atmosphere, above grade.

Chlorinator rooms should be at least 60°F and be protected from excess heat. Cylinders and gas lines should be protected from temperatures above that of the feed equipment including direct light.

Conduits for chemical transport, including lines carrying liquid or gas chlorine (not chlorine solution), should not create the potential of chemical hazards in plant areas outside handling and storage areas.

Calcium Hypochlorite – Containers of calcium hypochlorite should be isolated from operating areas; stored in rooms separate from storage of solvents, organic materials, and ammonia; and stored in areas not in direct sunlight or exposed to excess heat. The storage room should be well ventilated and have a door that opens outward. Provide protection from spillage or splashing from mixing areas and ensure that pumps and lines carrying the chlorine solution to the injection point are properly installed.

Sodium Hypochlorite – Containers of sodium hypochlorite should be isolated from operating areas, stored in rooms separate from storage of solvents, organic materials, and ammonia; and stored in areas not in direct sunlight or exposed to excess heat. The storage room should be well ventilated and have a door, equipped with a panic bar, that opens outward. Provide protection from spillage or splashing from mixing areas and ensure that pumps and lines carrying the chlorine solution to the injection point are properly installed.

Chemicals - Operator Safety

Protective equipment should be provided as necessary to handle and feed the specific chemicals used or available for use in the plant.

Respiratory protection equipment, meeting the requirements of the National Institute for Occupational Safety and Health (NIOSH), should be available where chlorine gas is handled and should be stored at a convenient location, but not inside any room used for chlorine gas feed or storage. The units should use compressed air or oxygen, have at least a 30-minute capacity, be positive displacement type, and be compatible with or exactly the same as units used by the fire department responsible for the plant.

A bottle of ammonium hydroxide, 56 percent ammonia solution, should be available for chlorine leak detection; where ton containers are used, a leak repair kit approved by the Chlorine Institute must be provided.

Chlorine Calculations

Careful records must be kept of the chlorine added to the water system, and the amount of chlorine present in the water must be monitored to avoid over-chlorination while maintaining an effective level of chlorine for disinfection. The measurements are recorded in “parts per million,” or ppm. In water calculations, ppm is normally a ratio of the weight of a substance to million pounds of water. A “milligram per liter" (mg/L) is a ratio of weight to volume and therefore represents weight per quantity for both laboratory and field purposes. Although for some conditions, mg/L more accurately describes the weight relationship than the term ppm, mg/L and ppm are basically the same and are interchangeable. If we note that 1 liter of water weighs 1,000,000 milligrams, then the term mg/L can be expressed as ppm.

When calculating the concentration of a chemical in water, the weight of the chemical is placed on the top part of the concentration formula and the weight of water, expressed in millions of units, is put on the bottom of the formula.

$$\frac{\text{lbs of pure chemical}}{\text{million lbs of water}}$$

The concentration formula can be used with any chemical at any concentration. Listed below are two basic formulas that should be remembered:

$$\text{ppm} = \frac{\text{lbs of pure chemical}}{\text{million lbs of water}}$$

$$\text{mg/L} = \frac{\text{milligrams of pure chemical}}{\text{liters of water}}$$

Example: On a particular day, a treatment plant applies 150 lbs of chlorine, and the flow meter shows that 2,000,000 gallons of water were treated. How many ppm of chlorine were applied?

Solution: Write down the parts per million formula and substitute the values for lbs of chemical and million lbs of water.

$$\text{ppm} = \frac{\text{lbs of pure chemical}}{\text{million lbs of water}} = \frac{150 \text{ lbs chlorine}}{2 \text{ M gal} \times 8.34 \text{ lbs/gal}} = \frac{150 \text{ } \cancel{\text{lbs}}}{16.7 \text{ M}\cancel{\text{Lbs}}} = 9 \text{ ppm}$$

Therefore, 9 ppm of chlorine was applied.

When working problems to determine concentrations, be sure the units in the numerator and denominator are the same. For the above example, we were given gallons of water and needed to convert to "million pounds" (Mlbs). For this, use of the conversion factor (8.34 lbs/gal) was necessary. Water really weighs 8.34 lbs/gal only under standard conditions: 20°C, and no impurities dissolved or suspended in the water. Although standard conditions are rarely encountered in practice, this does not make significant differences in our answers.

SAMPLE PROBLEMS

(1) 3 lbs of chlorine in 7,000,000 lbs water equals what concentration in ppm? In mg/L?

(2) 10 lbs of chlorine in 100,000 lbs of water equals what concentration in ppm?

(3) If 42 lbs of chlorine are added to 4,000,000 gal of water, what is the concentration of chlorine?

(4) 10,000 gallons of water receives 1 pound of chlorine. What is the chlorine concentration?

How we use the parts per million equations to solve a problem depends on how the problem is presented. In some cases, we are told how much chlorine (chemical) is to be dissolved in a certain amount of water. In this case, we simply use the standard equation:

$$\text{ppm} = \frac{\text{lbs of pure chemical}}{\text{million lbs of water}}$$

And substitute in the known values and perform the calculation.

Example: A chlorinator is set to feed 10 lbs of chlorine per day to a flow of 250 gpm. What is the chlorine dose in ppm?

Solution: $\text{ppm} = \frac{\text{lbs of pure chemical}}{\text{million lbs of water}}$

lbs of chemical is given as 10, we need to determine how much water, in M lbs, we are chlorinating.

$$\frac{250\,\cancel{\text{gal}}}{1\,\cancel{\text{min}}} \times \frac{60\,\cancel{\text{min}}}{1\,\cancel{\text{hr}}} \times \frac{24\,\cancel{\text{hrs}}}{1\text{ day}} \times \frac{8.34\ lbs}{1\ \cancel{gal}} = 3{,}002{,}400\ lbs/day$$

Each day, we have 3,002,400 lbs ÷1,000,000= 3.002 M lbs which we round to 3 M lbs

$$\text{ppm} = \frac{10\ \text{lbs}}{3\ \text{M lbs}} = 3.3\ \text{ppm}$$

In other problems, we are given (or are given information that allows us to determine) the ppm and million lbs of water, and we are asked to find the amount of chemical needed. For this type of problem, we use an adaptation of the standard ppm equation:

$$\text{ppm} \times \text{million lbs of water} = \text{lbs of pure chemical}$$

The above equation was derived by solving for the unknown "lbs of pure chemical" using the principles we discussed in Chapter 2. Let us look closer at the units for this equation.

$$\text{ppm} \times \text{million lbs of water} = \text{lbs of pure chemical}$$

$$\frac{\text{lbs}}{\text{Mlbs}} \times \text{Mlbs of water} = \text{lbs pure (100\%) chemical}$$

With these concepts in mind, we can now calculate the amount of chemical needed to provide for a specific rate of application.

Example: A community chlorinates its drinking water. If 1.77 million gallons are pumped each day, how many pounds of 100% available chlorine are needed to produce 1.0 ppm?

Solution: Set up the parts per million equation, make appropriate substitutions, and calculate:

$$\text{ppm} = \frac{\text{lbs of chlorine}}{\text{million lbs of water}}$$
$$1.0\ \text{ppm} = \frac{\text{lbs of pure chemical}}{1.7\ \text{Mgal} \times 8.34\ \text{lbs/gal}}$$

$$1.0\ \text{ppm} = \frac{\text{lbs of chlorine}}{14.2\ \text{Mlbs of water}}$$

Now solve for the unknown pounds of chlorine by clearing the right side of the equation to get the "lbs of chlorine" by itself. We do this by multiplying both sides of the equation by 14.2 Mlbs of water. Because "ppm" is lbs per Mlbs, the Mlbs cancel, and we are left with lbs of chlorine.

$$1.0\ \text{ppm} \times 14.2\ \text{Mlbs of H}_2\text{0} = 14.2\ \text{lbs of 100\% chlorine}$$

In most operations, 100% available chemical is not used (chlorine gas is the exception). Frequently, some other concentration of available chlorine is used. These concentrations are expressed in terms of "percent available chlorine." Typical percents include 5.25%, 10%, 12.5%, and 65% available chlorine.

One way to think of the "percent available" of the compound we are dealing with is as follows: Because percent is "parts per 100 parts" (see Chapter 2 for a review of this topic), "percent available" represents the amount of pure substance, in pounds, per 100 pounds of compound. For a 65% available chlorine compound, we have 65 lbs of pure chlorine in 100 lbs of compound (cmpd). If we know what the “percent available” is, and how many pounds of compound we have, this allows us to easily calculate how many pounds of pure chemical are available.

Example: How many pounds of chlorine are in 4 lbs of a compound that has 65% available chlorine?

Solution: We calculate this by multiplying the weight of pure chlorine in the 65% pure compound, by the number of pounds of compound we have.

$$\frac{4\ \cancel{lbs\ of\ cmpd}}{1} \times \frac{65\ \text{lbs pure chlorine}}{100\ \cancel{\text{lbs cmpd}}} = 2.6\ \text{lbs pure}\ \text{Cl}_2$$

Therefore, 2.6 lbs of pure chlorine are contained in 4 lbs of a compound that has 65% available chlorine.

SAMPLE PROBLEM

(5) How many pounds of chlorine are in 10 lbs of a compound that has 65% available chlorine?

Suppose we are given a situation where a known volume of water is pumped on a daily basis, and we desire to maintain a particular chlorine concentration in a drinking water. If we calculate we need 9 lbs of 100% available chlorine to provide this concentration, how do we calculate how many pounds of 65% available chlorine we need for this? If we think of "X" as the amount of 65% available chlorine needed to equal 9 lbs of 100% available chlorine, then

$$\frac{65 \text{ lbs pure chlorine}}{100 \text{ lbs compound}} \times \text{"X"} = 9 \text{ lbs pure chlorine}$$

Solve for "X" by multiplying both sides by

$$\text{"X"} = \frac{9 \; \cancel{\text{lbs pure}}}{1} \times \frac{100 \; lbs \; cmpd}{65 \; \cancel{lbs \; pure}} \qquad \text{X} = 14 \; lbs \; cmpd$$

Therefore, we need 14 lbs of 65% available chlorine. We need more chemical compound when the percent availability is less than 100% than we do with a chemical compound of 100% availability.

Sometimes the compound that contains the desired chemical is liquid. Before the amount of available chemical is determined, the weight of the compound must be calculated.

Example: How many pounds of chlorine are in 5 gallons of compound that weighs 10 pounds per gallon and has 10% available chlorine?

Solution: 5 gallons of compound x 10 lbs/gal = 50 lbs of compound; and since the compound has a 10% chlorine availability,

$$10\% \times 50 \text{ lbs} = 0.10 \times 50 \text{ lbs} = 5 \text{ lbs of pure chlorine}$$

By combining the various techniques discussed above with volume calculations, we can work computations involving disinfection of water mains.

Example: How many gallons of liquid chlorine (5.25% available chlorine) would be required to apply 50 ppm chlorine to 500 feet of new 6-inch water main? Assume liquid chlorine weighs 10 lbs/gallon.

Solution: First determine the volume of the water main.

$$\text{V} = 0.785 \times \text{d}^2 \times \text{L}$$

Diameter is 6 inches = 0.5 feet and the given length is 500 ft, so:

$$\text{V} = 0.785 \times (0.5 \text{ ft})^2 \times 500 \text{ ft} = 98 \text{ ft}^3 \text{ of water}$$

To determine concentration, we need M lbs, so use the conversion factor of 62.4 lbs of water per cubic ft:

$$\frac{98\ \cancel{\text{ft}^3}}{1} \times \frac{62.4\ \text{lbs}}{1\ \cancel{\text{ft}^3}} = 6{,}100\ \text{lbs},$$

$$\text{then}\ \frac{6{,}100\ \cancel{\text{lbs}}}{1} \times \frac{\text{M lbs water}}{1{,}000{,}000\ \cancel{\text{lbs}}} = 0.061\ \text{M lbs water}$$

We know $\text{ppm} = \frac{\text{lbs chemical (chlorine)}}{\text{Mlbs water}}$

So, $\text{lbs of chlorine} = \text{ppm} \times \text{million lbs water}$

Plug in the numbers:

$$\begin{aligned} 50 \times 0.0061 &= 0.31\ \text{lbs of } 100\%\ \text{chlorine} \\ &= 0.31\ \text{lbs of pure chlorine} \end{aligned}$$

We know how many lbs of pure chlorine we need, but how many lbs of 5.25% available chlorine do we need?

$$\frac{0.31\ lbs\ of\ pure\ chlorine}{1} \times \frac{100\ \text{lbs cmpd}}{5.25\ \text{lbs pure chlorine}}$$

$$= 0.31\ \text{lbs}\ 100\%\ \text{available}\ \text{CL}_2$$

Solving for “X”, we get:

$$50 \times 0.0061 = 0.31\ \text{lbs of } 100\%\ \text{chlorine}$$

Now determine the gallons of liquid chlorine needed.

Since our compound weighs 10 lbs/gal,

$$\frac{5.9\ \cancel{\text{lbs}}}{1} \times \frac{1\ \text{gal}}{10\ \cancel{\text{lbs}}} = 0.59\ \text{gal of } 5.25\%\ \text{liquid chlorine compound}$$

SAMPLE PROBLEMS

(6) How many pounds of chlorine are in 9 gallons of a solution that weighs 10 pounds per gallon and has 5% available chlorine?

(7) How many pounds of calcium hypochlorite (65% available chlorine) would be required to disinfect 800 feet of 8-inch water main with 50 ppm of chlorine?

Chlorine Residual Determination

Chlorine residual test equipment recognized in the latest edition of Standard Methods for the Examination of Water and Wastewater shall be provided and should be capable of measuring residuals to the nearest 0.01 mg/L in the range below 1.0 mg/L, to the nearest 0.1 mg/L between 1.0 mg/L and 2.5 mg/L, and to the nearest 0.2 mg/L above 2.5 mg/L.

Chlorine residuals are measured using two different methods: titrimetric and colorimetric. Both methods use a chemical called diethyl-p-phenylenediamine (DPD) which turns a pinkish color when chlorine is present. In the titrimetric method, the pink color is removed by slowly adding ferrous ammonium sulfate (FAS). The amount of FAS added is directly proportional to the amount of residual chlorine present. In the colorimetric method, actual chlorine residual is determined by comparing the color development with known color standards. Colorimetric test kits are the most commonly used in small system operations.

Figure 4.4 Typical chlorine test kit using the colorimetric method.

DPD is added to the water sample, then the sample is compared to the color wheel to determine the level of chlorine residual. These kits are quite common due to low cost and ease of use, but are less accurate, depending on the operator's ability to see the pink color and make the comparison. The tubes are also prone to discoloration, and if not replaced on a regular basis, may cause inaccurate results.

Figure 4.5 Electronic colorimeter

This test kit is more accurate, providing a digital readout of the chlorine residual. DPD is added to the water sample, then the sample is placed into the unit and covered. The unit generates a light that measures the amount of color in the sample and provides the readout.

It is recommended that all systems use an instrument with a digital readout for the best results. Whatever test kit is used, operators must have the training to use the kit, and the supply must keep the unit in good condition, replacing parts as needed and ensuring that the reagent packets are not expired. Each manufacturer will provide instructions for use of their test kit; in general, the operator will fill a clean sample cell with water from the sample tap, use that cell to zero the unit, then add the packet of reagent to the cell, mix it, and place it back in the unit to take the residual reading.

Monitoring and Maintaining Chlorine Residuals

Any system that treats the water by adding chlorine must determine and record the chlorine residual at the same time and place as the compliance bacteriological sample(s), and any required resamples. In addition, the chlorine residual must be tested at the plant tap and in the distribution system daily. The tests should be done for both free and total chlorine residuals, following the instructions for the specific kit that is used. Automatic chlorine residual recorders should be provided where the chlorine demand varies appreciably over a short period of time.

The target range for a free chlorine residual in the distribution system is at least 0.2 ppm and no more than 2.0 ppm. Lower levels may not provide adequate disinfection, and higher levels will increase chemical costs and customer complaints. The terminology used is maximum residual disinfectant level (MRDL), the highest level of a disinfectant allowed in drinking water; and maximum residual disinfectant level goal (MRDLG), which is the level of a drinking water disinfectant below which there is no known or expected risk to health. The operator must use the chlorine residual information to adjust the chlorine pumps for proper dosages.

Table 4.6 MRDLG and MRDL

Disinfectant	MRDLG	MRDL
Chloramine	4 milligrams per liter (mg/L) or 4 parts per million (ppm)	4.0 mg/L or 4 ppm as an annual average
Chlorine	4 mg/L or 4 ppm	4.0 mg/L or 4 ppm as an annual average
Chlorine Dioxide	0.8 mg/L or 800 parts per billion (ppb)	0.8 mg/L

Chlorine is the most preferred means of disinfecting wells, storage tanks, and water mains after construction or repair has been completed. Recommended procedures for disinfecting a well specify maintaining a chlorine dosage of 250 mg/L in the well for at least 24 hours. A conservative method of chlorinating water mains and water storage tanks is with a concentration of at least 25 mg/L for 24 hours, with a residual of 10 mg/L at the end of the 24 hours. After chlorination, the system must be flushed to remove the excess chlorine residual prior to being placed into customer service.

ANSWERS TO CHAPTER 4 SAMPLE PROBLEMS

(1) 3 lbs of chlorine in 7,000,000 lbs water equals what concentration in ppm? In mg/L?

$$\text{ppm} = \frac{\text{lbs pure chemical}}{\text{Mlbs of water}} \qquad \text{ppm} = \frac{3\text{ lbs chlorine}}{7\text{Mlbs of water}} = 0.43\text{ ppm}$$

$$(\text{mg/L is the same})$$

(2) 10 lbs of chlorine in 100,000 lbs of water equals what concentration in ppm?

$$\text{ppm} = \frac{\text{lbs pure chemical}}{\text{Mlbs of water}} \qquad \text{ppm} = \frac{\text{10 lbs chlorine}}{\text{0.1 Mlbs of water}} = \text{100 ppm}$$

(3) If 42 lbs of chlorine are added to 4,000,000 gal of water, what is the concentration of chlorine?

$$\text{ppm} = \frac{\text{lbs pure chemical}}{\text{Mlbs of water}} \quad \frac{\text{4 M}\cancel{\text{gal}}\text{ water}}{1} \times \frac{\text{8.34 lbs}}{1\ \cancel{\text{gal}}} = \text{33.36 Mlbs water}$$

$$\frac{\text{42 lbs chlorine}}{\text{33.36 Mlbs of water}} = \text{1.26 ppm}$$

(4) 10,000 gallons of water receives 1 pound of chlorine. What is the chlorine concentration?

$$\frac{10{,}0000\ \cancel{\text{gal}}}{1} \times \frac{\text{8.34 lbs}}{1\ \cancel{\text{gal}}} = \text{83,400 lbs of water} \div 1{,}000{,}000$$
$$= \text{0.0834 Mlbs}$$

$$\text{ppm} = \frac{\text{lbs pure chemical}}{\text{Mlbs of water}} = \frac{\text{1 lbs pure chemical}}{\text{0.0834 Mlbs of water}} = \text{12 ppm}$$

(5) How many pounds of chlorine are in 10 lbs of a compound that has 65% available chlorine?

$$\text{lbs available chlorine} = \frac{\text{lbs pure chemical}}{\text{lbs compound}} \times \text{lbs of compound used}$$

$$\frac{\text{65 lbs pure chemical}}{\text{100 lbs compound}} \times \text{10 lb of solution} = \text{6.5 lbs chlorine}$$

(6) How many pounds of chlorine are in 9 gallons of a solution that weighs 10 pounds per gallon and has 5% available chlorine?

$$\frac{9\ \cancel{\text{gal}}}{1} \times \frac{\text{10 lbs}}{1\ \cancel{\text{gal}}} = \text{90 lbs solution} \quad \frac{\text{5 lbs pure chemical}}{\text{100 lbs solution}} \times \text{90 lbs of solution} =$$
$$\text{42.5 lbs chlorine}$$

(7) How many pounds of calcium hypochlorite (65% available chlorine) would be required to disinfect 800 feet of 8-inch water main with 50 ppm of chlorine?

$$\mathrm{V} = 0.785 \times \mathrm{d}^2 \times \mathrm{L} = 0.785 \times 0.45 \times 800 = 283\ \mathrm{ft}^3$$

$$\frac{283\cancel{\mathrm{ft}}^3}{1} \times \frac{62.4\ \mathrm{lbs}}{1\ \cancel{\mathrm{ft}^3}} = \frac{17{,}659\cancel{\mathrm{lbs}}}{1} \times \frac{\mathrm{Mlbs\ water}}{1{,}000{,}000\ \cancel{\mathrm{lbs}}} = 0.018\ \mathrm{Mlbs\ water}$$

$$\mathrm{lbs\ of\ chlorine} = \mathrm{ppm} \times \mathrm{million\ lbs\ water}$$

$$50\mathrm{ppm} \times 0.018\mathrm{Mlbs\ water} = 0.9\ \mathrm{lbs\ pure\ chlorine}$$

$$\frac{0.9\ \cancel{\mathrm{lbs\ of\ chlorine}}}{1} \times \frac{100\ \mathrm{lbs\ compound}}{65\ \cancel{\mathrm{lbs\ pure\ chlorine}}} = 1.38\ \mathrm{lbs\ compound}$$

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CHAPTER 5 - Pumps, Motors, Wells, Well Houses, and Storage

PUMPS

There are several types and classifications of pumps. The three basic types used in municipal water supply systems are centrifugal, positive displacement, and jet.

Centrifugal Pumps

This is a very broad category for pumps and covers basically all the main pumps used in the water works industry today. There are many types of centrifugal pumps. They can be classified by either the type of impeller design or by their function within the system.

In a centrifugal pump, a spinning wheel with curved vanes within a tight casing moves water from the center to the outside of the impeller. This spinning, or centrifugal motion, imparts energy, or head, to the water and results in the pumping actions. When additional energy or head is needed, the discharge of one impeller can go into the inlet of a second impeller, which would add additional energy or head to the system. When more than one impeller is used, the impellers are referred to as stages. Some terms necessary to understand centrifugal pumps are given below:

Suction head or lift - the vertical distance between the center line of the pump and the free surface of the liquid to be pumped. Can be either positive or negative.

Static discharge head - the vertical distance between the center line of the pump and the free surface of the discharge tank or the point of free discharge in the system.

Total dynamic head (TDH) - The vertical distance between the free surface of the liquid to be pumped and the free surface of the discharge tank or system, plus the head loss in the suction and discharge lines and remaining velocity head.

Prime - the condition when the pump casing is filled with liquid so that the pump may begin to develop suction at the eye of the pump. If there is air in the casing, a suction lift cannot be developed for a pump where the liquid being pumped is below the center line of the pump.

Impeller - a circular wheel with vanes that by spinning adds energy to a liquid through centrifugal motion.

Casing or case - the casing surrounding the impeller, which forms a smooth volute, or spiral, which directs the water discharge from the impeller.

Shaft - the device on which the impeller is centered. It spins the impeller. Since the shaft must protrude through the watertight casing, the point at which it penetrates the casing must be made watertight, but the shaft must still be able to rotate. This is accomplished by packing material between the shaft and the casing, minimizing wear on the shaft and maintaining a watertight or airtight seal.

Lantern ring - a ring located between the packing rings on a pump shaft providing a positive seal by directing water through the ring to the packings. This also lubricates the packing. This water seal prevents air from entering the water stream if there is a high suction lift and provides additional lubricant for the packing.

Packing gland – is a braided rope-like material used around the shaft of a pump to fill the void space preventing excessive fluid loss. A small amount of leakage is considered normal during operation. As water saturates the packing it also acts as a coolant to the pump shaft to prevent excessive wear due to heat.

Shaft sleeves - prevent excessive wear on the shaft due to rubbing against the packing. Shaft sleeves are attached to the shaft to take the wear and these sleeves are periodically replaced.

Wear rings - these are located between the impeller and the casing housing, isolating the suction from the impeller discharge. Wear rings are usually attached to the casing and to the impeller and are machined so the running clearance between the two effectively restricts leakage from the impeller discharge to the suction.

Types of Centrifugal Pumps Commonly Used in Water Works

Vertical turbine pumps are one of the more common types of centrifugal pumps used in the water works industry. A majority of municipal type well systems use vertical turbine pumps to pump the water from the ground into either the water system or to a central collection point. In vertical turbine pumps, the impeller is located on a shaft, which extends to the motor above. When a vertical turbine is located in a well, the water is discharged through the discharge piping which is centered in the well casing. The shaft, which runs from the impeller to the motor, is centered in the discharge piping.

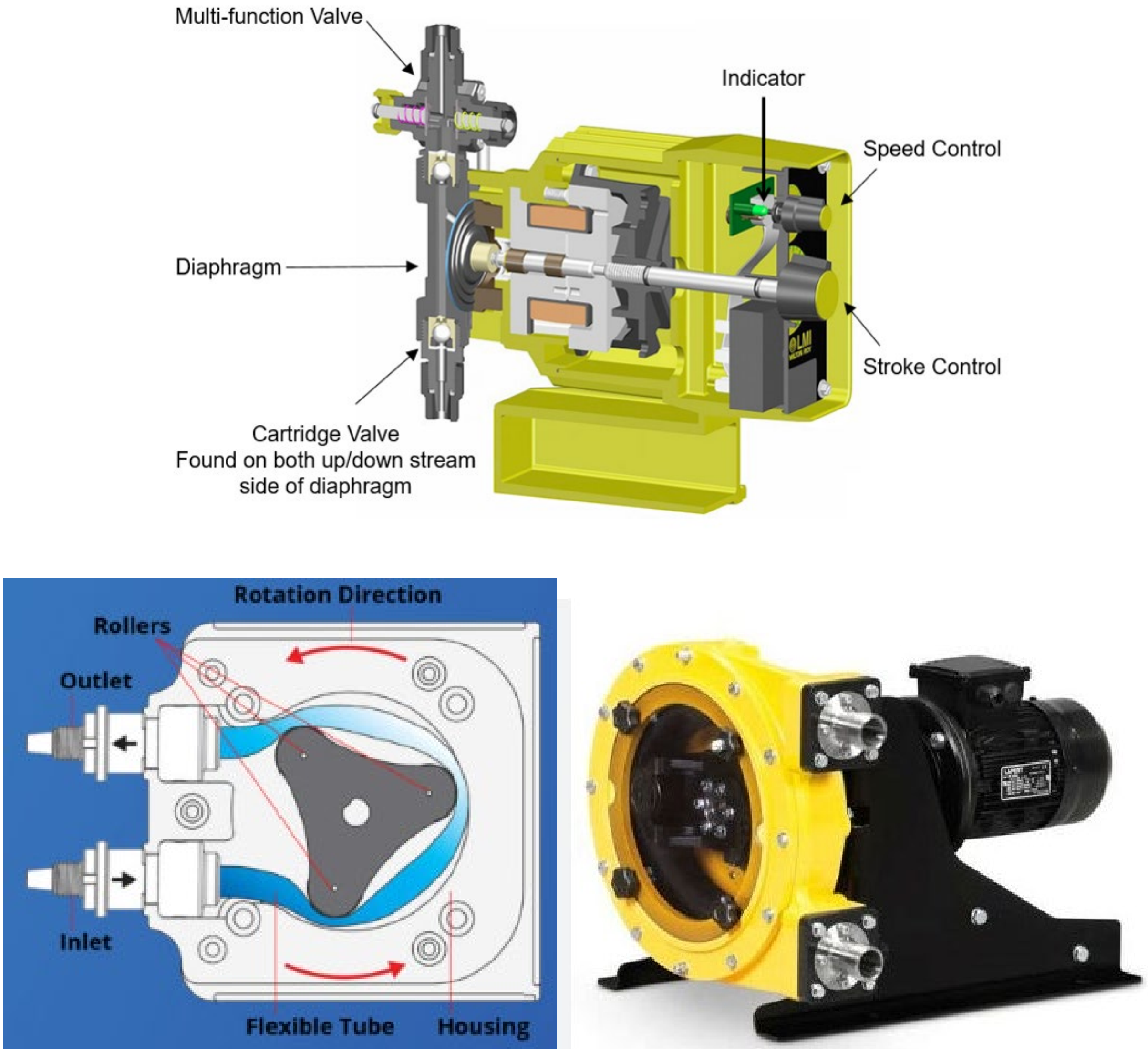
Horizontal centrifugal pumps are normally used in water treatment plants as high service pumps; booster pumps; and in some situations, low service pumps if priming is not a problem. A horizontal centrifugal pump is similar to a vertical turbine except the horizontal centrifugal pump is rotated 90° with the motor being horizontally adjacent to the pump. Normally, the shaft of the horizontal pump is relatively short.

Submersible pumps are a form of centrifugal pump quite common in municipal type wells. A submersible pump is a form of a vertical turbine pump except the motor is located immediately below the pump bowls or impellers, down in the well. The motor is located below the static water level of the well, and is cooled by the water within the well.

Positive Displacement Pumps

Positive displacement pumps are used mostly for small capacity discharge into high pressure pipes. These pumps are used almost exclusively for chemical addition into pressurized water works systems, such as chemical injection at well houses, treatment plants, or into pressurized mains. There are two main types of positive displacement pumps, a diaphragm pump and a peristaltic pump. The diaphragm positive displacement pump works with a diaphragm, a system of check valves, and a shaft extending from the motor to the diaphragm. The motor moves the shaft, pulling back the diaphragm and closing the discharge inlet with a check valve. This action creates a suction in the head of this pump, which draws fluid into the head through an inlet from a solution barrel. On the next stroke, the diaphragm is pushed into the pump, a check valve closes the inlet from the solution barrel, and the solution is forced out the discharge inlet into the pressurized system.

Figure 5.1 Typical Displacement Pumps Example



A peristaltic pump is the other type of positive displacement pump pictured in Figure 5.1. This pump is commonly used in the water treatment industry. It works by drawing a specific volume of fluid into the rolling tube apparatus. As the rollers rotate, they continuously draw fluids in and out of the rolling tube. This is accomplished by the rollers making a rotary motion and are turned by a motor. The speed of the pump can be adjusted to increase or decrease the amount of chemical feed into the system. The roller tube does need to be monitored and replaced periodically as it does wear out. That is the most common maintenance required for these types of pumps.

Jet Pumps

Jet pumps are a combination of a horizontal centrifugal pump and a jet which is either located at the pump head or in the well casing itself. The jet acts through venturi action and momentum changes to carry water from the well. High velocity, low volume water is pushed into the well through the jet bringing lower velocity, higher capacity water back up out of the well through the discharge piping. Jet pumps are inefficient but are also inexpensive and were used quite frequently in small, domestic type wells. They have largely been replaced by submersible pumps.

MOTORS

A motor which drives a turbine pump is located either vertically above the pump (vertical turbine) or located horizontally adjacent to the pump (horizontal centrifugal pump). The motors for the large vertical turbine pumps associated with municipal water works installations are normally three phase 220/440 volt motors. Some larger motors have induction motors (similar to the starter on a car motor) to start the pump motor itself but these are on large installations. The bearings in the motors may be grease filled or oil filled, depending on the manufacturer. Some may be permanently sealed and may not require maintenance. Others may be oil filled and need to be checked periodically. To determine the maintenance requirement for a particular motor, consult the specifications.

WELLS

A well may be defined simply as “a hole dug in the ground to get water.” Dug wells were very common - dug by hand with the use of a horse-powered drilling rig or, in later years, dug with a backhoe. By nature, shallow and lined with rocks or other porous, unsealed materials, they were also easily subject to contamination. Wells installed today are drilled wells, and may be constructed using auger, cable tool, or rotary style drilling rigs.

Well Construction

A well installed using a cable tool machine will have a steel casing that is hammered into the ground, without an oversized borehole. The well is grouted by pouring granular bentonite around the casing and allowing the casing to “pull” the grout with it as it is pushed into the ground. Wells constructed in this fashion may be more susceptible to contamination as the grout does not form an even barrier around the entire casing.

Wells constructed using an auger or rotary style machine will have steel or plastic casing that is placed into an over-sized borehole, leaving an annular space all around the casing which is pumped full of cement or bentonite grout. This method of grouting provides the greatest protection for a well. Cement grout is required for Type I well installations.

Groundwater wells in Michigan can be “rock” wells which means they are drilled into bedrock and do not have a screen at the bottom of the casing or “screened” wells which terminate in the glacial drift layers of sands and gravels. These wells have a screen installed at the bottom of the casing to keep the borehole from collapsing and to keep sand out of the well.

Well casings must extend a minimum of 25 feet below the ground surface, a minimum of 12 inches above ground level, and must have a properly sealed and vented well cap.

Well Maintenance

Wells must be properly located, constructed, and maintained in order to protect the water source. Failing to locate a well away from sources of contamination could result in the water supply running into contaminants in their source water that could require costly treatment systems, MCL violations, or even in being required to abandon the well. Construction issues could result in a damaged screen, slumped grout, or early pump failure. Lack of maintenance can result in plugged vents, well seal failure, a cracked casing, or poor production.

Table 5.2 Well Maintenance

Recommended O&M schedule for groundwater sources	
	Daily or weekly
☐	Check well house interior and grounds for general cleanliness and condition, and for any threats to water quality.
☐	Check any warning lights or alarms – low water level in the well, intrusion, power outage, pump failure, and so on.
☐	Read source water meter. Record water-production data in well house log.
☐	Read pump run hour meters and record data in well house log (unless automatic data storage is available).
☐	Check pump-cycling rate. If it runs continuously or cycles more than 6 times per hour, see pump troubleshooting.
☐	Check well house buildings for signs of security problems – graffiti, vandalism, doors or locks damaged, entry, etc.
☐	Check wells source site after any adverse weather – high winds, heavy snow, ice, rains, and so on.
	Monthly
☐	Check well water level if source capacity is marginal or there are drought conditions.
☐	Check area for excessive vegetation or dangerous conditions – uncut grass, brush, dead trees, fire hazard, etc.
☐	Check well house control valves for proper positions, open or closed. You should post this information.
☐	Check source control system – pressure switch settings, cycling, pressure tanks, storage tank water levels, etc.
☐	Check well house control valves for damage or leaks.
☐	Check for leaks – read source meter when you expect the water usage to be zero.
☐	Check source pump cycling and pressure switch settings, on/off pressures and line pressures.
	Annually or seasonally
☐	Check well site for water ponding, poor drainage areas, excessive vegetation, unhealthy trees, fire hazards, etc.
☐	Check source facilities conditions – corrosion, vent screens, vehicular or other damage, animal activity, etc.
☐	Check cold weather protection – insulation, heating system, alarm system, and so on.
☐	Verify sanitary integrity of the sources – screened vents, no unprotected openings, electrical box sealed, etc.
☐	Evaluate source use designations (permanent, seasonal, emergency, or inactive). See ***Emergency drinking water sources*** (331-317).
☐	Exercise valves and test run emergency source wells to waste. Do not supply distribution system without WQ tests.
☐	Evaluate Emergency Response Plan and update as required.
☐	Review source related customer complaints and evaluate corrective actions and planning.
☐	Implement seasonal start-up or shut-down procedures as outlined in your Seasonal Operations Plan.
☐	Review Wellhead or Watershed Protection Plans and check for new Sanitary Control Area threats.
☐	Review source water quality test results for trends, such as increasing nitrate or seasonal coliform problems.
	Less than once a year
☐	Measure source pump capacity in gallons per minute (GPM) to detect pump output problems.
☐	Evaluate general source capacity to meet water system demand. Use water use and production records.
☐	Evaluate capacity of source water to provide water of a reliable quantity and quality acceptable to customers.
☐	Consider television inspection of the well interior and the well screens.
☐	If the source capacity is marginal or drought conditions are present, develop and implement a Conservation Plan.

Proper well maintenance is a combination of physical action and recordkeeping. Physical maintenance items such as: replacing packing, changing oil, adding grease to the bearings, etc. must follow the manufacturers specifications. Normally, packing must be replaced about once a year. The oil in oil-filled motors must also be changed once a year. Most motor bearings must be greased at least twice a year if they are not permanently sealed. Impellers become worn over time and will need to be replaced.

Maintaining proper well and pump records is probably the most important phase of well maintenance. By comparing these records over a long period of time, well efficiency can be evaluated and the need for well inspections can be determined. The appurtenances needed for obtaining these records consist of an air line or electric probe for measuring water level, a flow meter for measuring pump discharge capacity, and a pressure gage to measure the discharge pressure. These items are discussed further under wellhouse appurtenances.

Water level measurements should be taken during static conditions (when the well has not been pumped for several hours). Static water levels over a period of time give a general idea of the condition of the aquifer.

Pumping levels should be recorded while the well is in operation and has been pumping for a period of time at its normal discharge rate. Changes in the pumping level can indicate several things that could be happening to the well. Some of these are a plugged screen, interferences from other production sources, or inadequate recharge to the aquifer.

By recording the electric meter readings, the kilowatt hours used per thousand gallons pumped can be calculated. This figure is the measure of the electrical efficiency of the total well system and if the figure begins increasing significantly, either the well, pump, or motor is becoming more inefficient and should be checked.

Some common signs of well trouble given on the “Lane Pump and Well Maintenance Chart” are: 1) low water pressure or a significant change in pump capacity; 2) pumps running longer to provide the same amount of water; 3) excessive water around the stuffing box; 4) increase or change in shaft or motor vibrations; 5) unusual noises when pump starts or stops; 6) unusual noise during pump operation; 7) changes in quality of water; 8) presence of sand in the water; and 9) cloudy water.

The well discharge should be recorded periodically to determine how much the well is pumping per unit time. Changes in the discharge could mean the pump or well screen have become encrusted, the pump bowls have become worn, the pump is breaking suction, or there are restrictions in the discharge piping. The discharge pressure, which the well is pumping against, should be recorded to see how the well is interacting with the distribution system. Different pressures could be imposed on the well pump to determine if it is reacting as it should, according to its pump curve. These pressures can be imposed on the well pump by throttling the discharge valve.

These items can all be used to determine when an operator should consult with their well drilling firm or consulting engineer to schedule routine inspection and maintenance on the well. Normally, municipal type well pumps should be pulled and checked on the average of every five to ten years depending on the condition of the water being pumped, the amount of use, and any indications of reduced production. Complete maintenance records must be kept as a record of maintenance history for each individual well.

Note that when a pump has to be replaced, a permit is not required for an exact replacement, but a pump record must still be filed with EGLE. Any change in a pump installation, such as extending the drop pipe or increasing/decreasing capacity, will require a permit. Consult with an EGLE district office for further guidance.

Well Abandonment

When a well is no longer needed or has reached the end of its useful life span, it must be properly abandoned. This means that a registered well driller must be contracted to seal the well shut with cement, and an abandonment log must be submitted to EGLE. Failure to properly abandon an unused well not only can create a safety hazard, but also jeopardizes the aquifer by providing a route for contaminants to enter the water. Note that when a well is abandoned, the well number goes with it and cannot be used as the number for the new well. For example, a community had two older wells, WL001 and WL002, which were abandoned, and three new wells were drilled. The new wells must be numbered WL003, WL004, and WL005, in the order in which they were drilled.

WELLHOUSES and APPURTENANCES

Some wells are located inside the wellhouse; some are located outside. Either way, wellhouses provide a place for electrical controls, pressure tanks (for smaller systems), chemical injection points, sampling taps, etc. that can be secured against unauthorized access. Wellhouses should be weathertight, have adequate room for chemical storage, plumbing, control systems, and have adequate drainage. The wellhouse is home to all of the “appurtenances” that are required for a municipal water supply well.

The following appurtenances are to be included in the design of a wellhouse:

A *plant tap*, which is a sample tap installed at the point where the finished water leaves the wellhouse and goes into distribution. This is the point to be sampled for water chemistry for compliance purposes and for monitoring residuals, such as chlorine and phosphate.

Gate valves are used to isolate each well so that it can be shut off or pumped to waste without interfering with normal operations.

Pump-to-waste piping to allow pumping of each well to waste when work or maintenance has been performed on the well. When pumping the well to atmospheric discharge, be sure the well is not overloaded since the pump is not pumping against system head. The gate valve on the discharge line to the system can be used as a throttling valve if the well is breaking suction; but this is not a recommended practice since it is an inefficient mode of operation.

Raw water sampling taps are to be provided for each well prior to any storage or treatment.

A *meter*, which measures the well pumpage. This should be installed upstream of storage and the pump-to-waste piping. This allows determination of the well pumping rate against system head and also records pumpage to waste when well testing is being performed. *Chemical injection points* are to be located prior to storage and must be installed on the system side of the check valve and the air vacuum relief valve. The injection points should be in the 4- or 7-o'clock position on the pipe so that any chemical leakage will drain onto the floor instead of pooling on the plumbing and causing corrosion. Chemical injection points are required for every system, even if not currently treating. Chlorine and phosphate injection points should be a minimum of 20 feet apart to facilitate mixing.

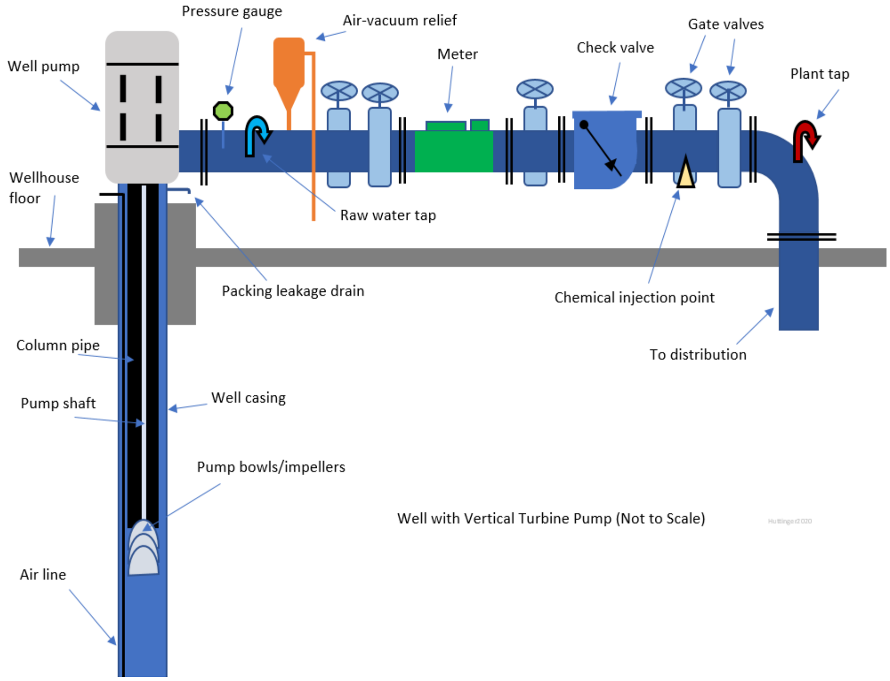
A *check valve* is provided which prevents system pressure from forcing water through the pumps, back down into the well, and into the water-bearing formation. An air vacuum relief valve should be located between the pump and the check valve. This expels the air in the column piping above the water level when the pump is first turned on. This valve is usually operated by a ball check, which closes when water rises up to the level of the mechanism. When the pump is shut off and the check valve seats, water runs back into the well from the column piping. As this water returns to the formation, air must be brought into the system to replace the space that the water occupied. When this occurs, the vacuum release on the vacuum relief valve activates, the ball check drops, and air is drawn in through this point. If the mechanism is not provided, air is brought back through the packing glands and contamination could possibly be brought back into the well.

Pressure gauges are required to monitor system pressure. Most smaller systems should maintain a pressure between 40 and 60 psi.

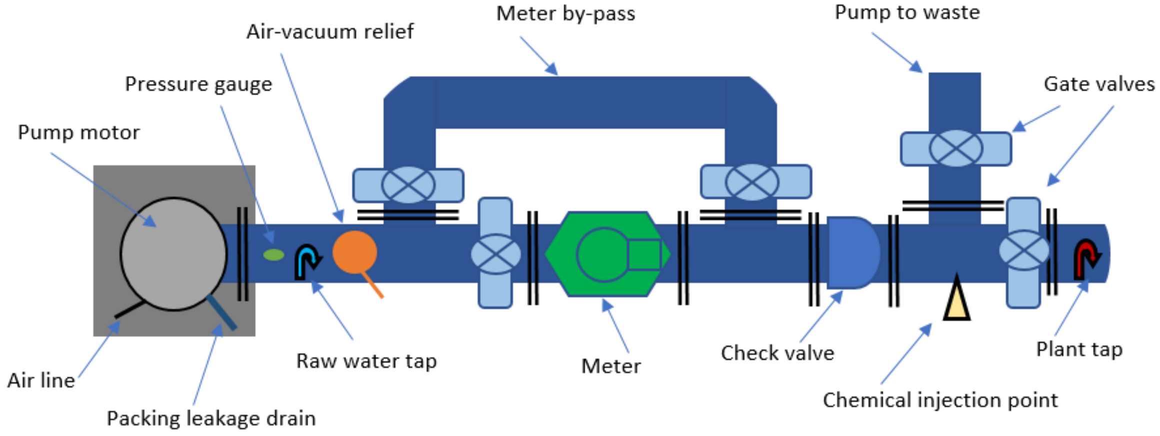
A *pressure relief valve* is required to provide emergency pressure release in the case of over pressurization to prevent damage to the system.

A *casing vent* is normally provided at the motor base at the top of the casing, or in the case of a submersible pump installation, in the well cap. This provides venting of the casing. When the well is activated and the water level drops, air must be brought into the casing to replace the water in the casing as it is drawn down. When the pump is shut off, the water level rises in the casing forcing the air out of the vent. An air line in the well is used for measuring water levels in the well during static and pumping conditions. This line is usually located near the pump setting. As air is forced into the line, it requires a certain amount of pressure to bubble air out the bottom of the line. The amount depends on the level of water above the line. To clarify this, consider a situation where there is 10 feet of water above the bottom of the air line. It would require 10 feet of head or 10 feet ÷ 2.31 ft/psi, which is equal to 4.3 psi, to bubble air out of the bottom of the line. Thus, if the operator pumps the air line up and reads 4.3 psi on the air gage, he knows there is 10 feet of water above the bottom of the air line (0.43 psi/ft x 10 ft = 4.3 psi). Knowing the setting of the air line and subtracting the amount of water above the air line gives the water level in the well. Many of the gages located on the air line are reverse acting gages, which record water level directly.

Figure 5.3 Typical Vertical Turbine Installation



Well with Vertical Turbine Pump (Not to Scale)



Well with Vertical Turbine Pump (Not to scale)

Figure 5.4 Typical Submersible Pump Installation

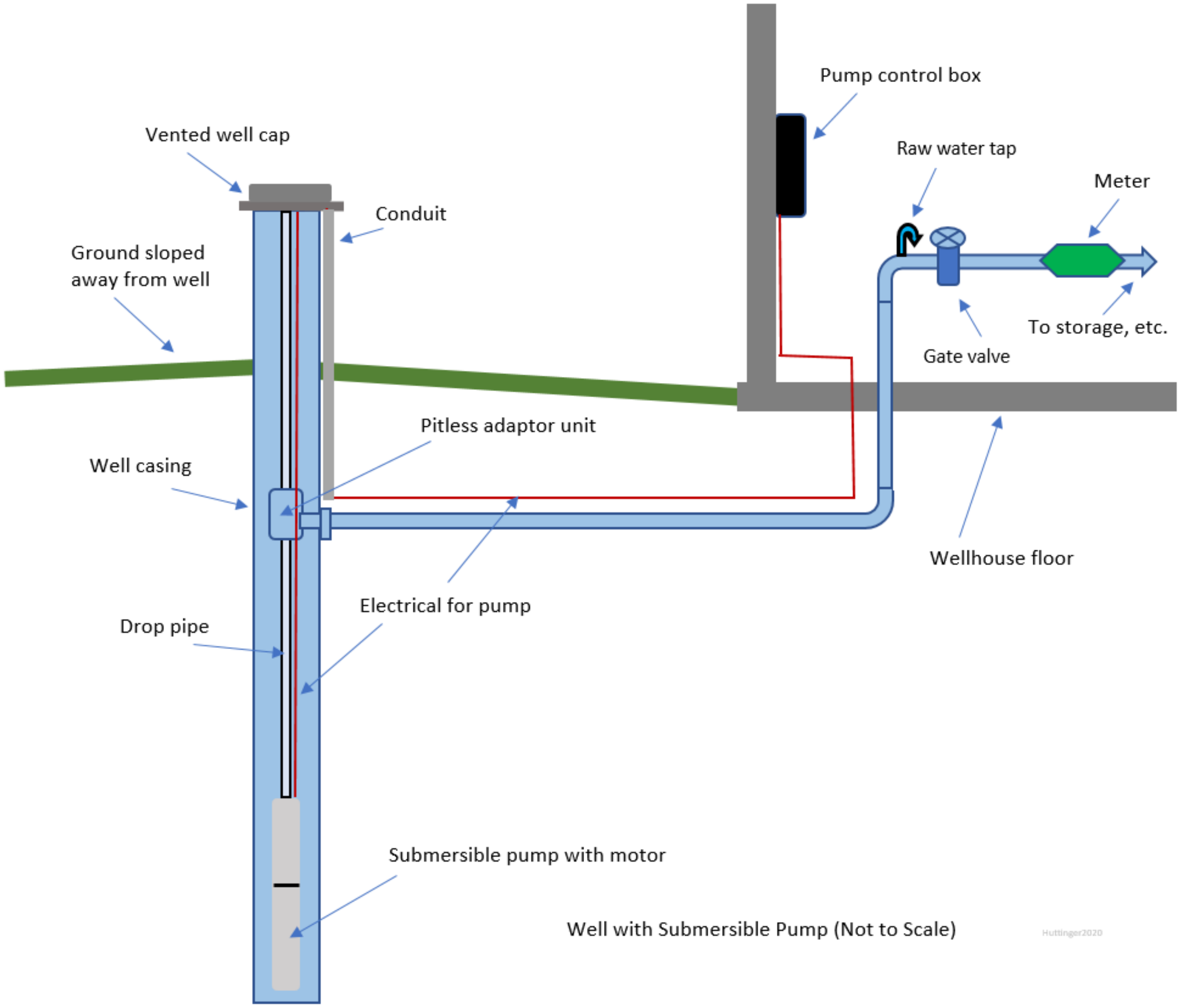
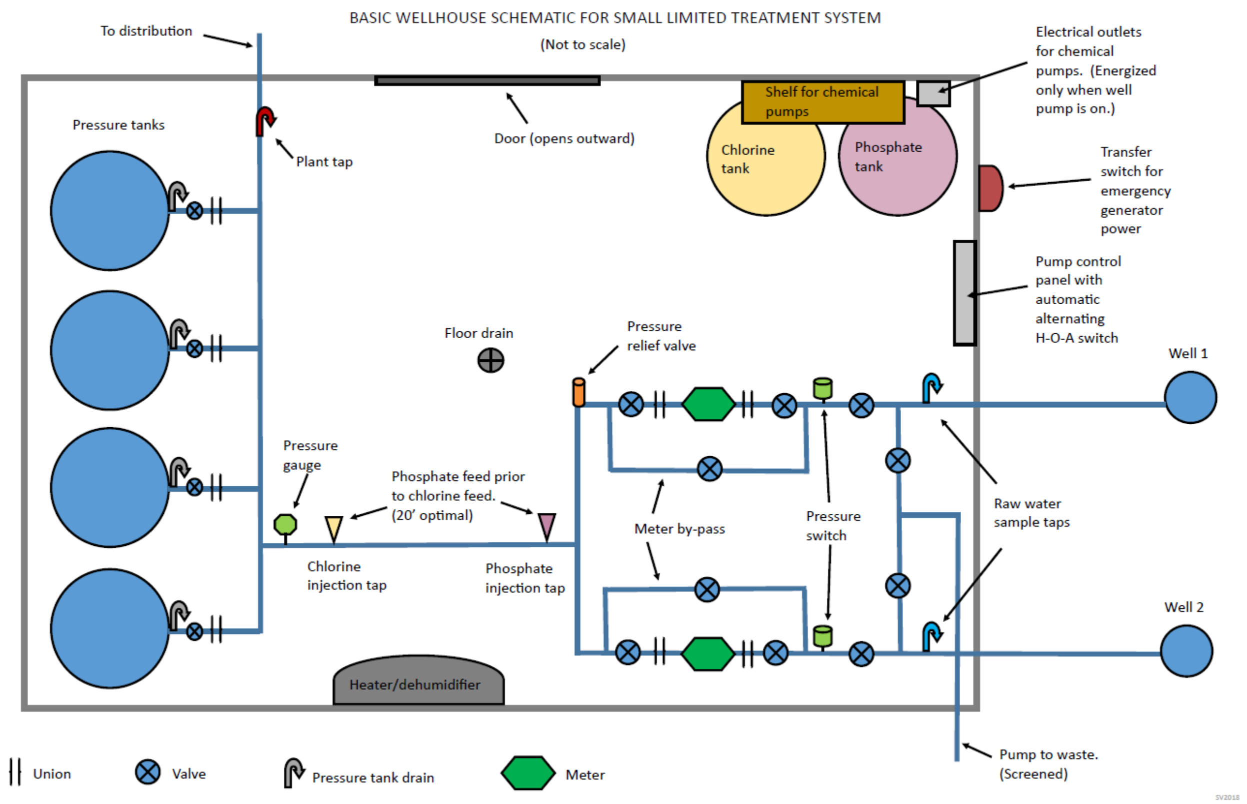
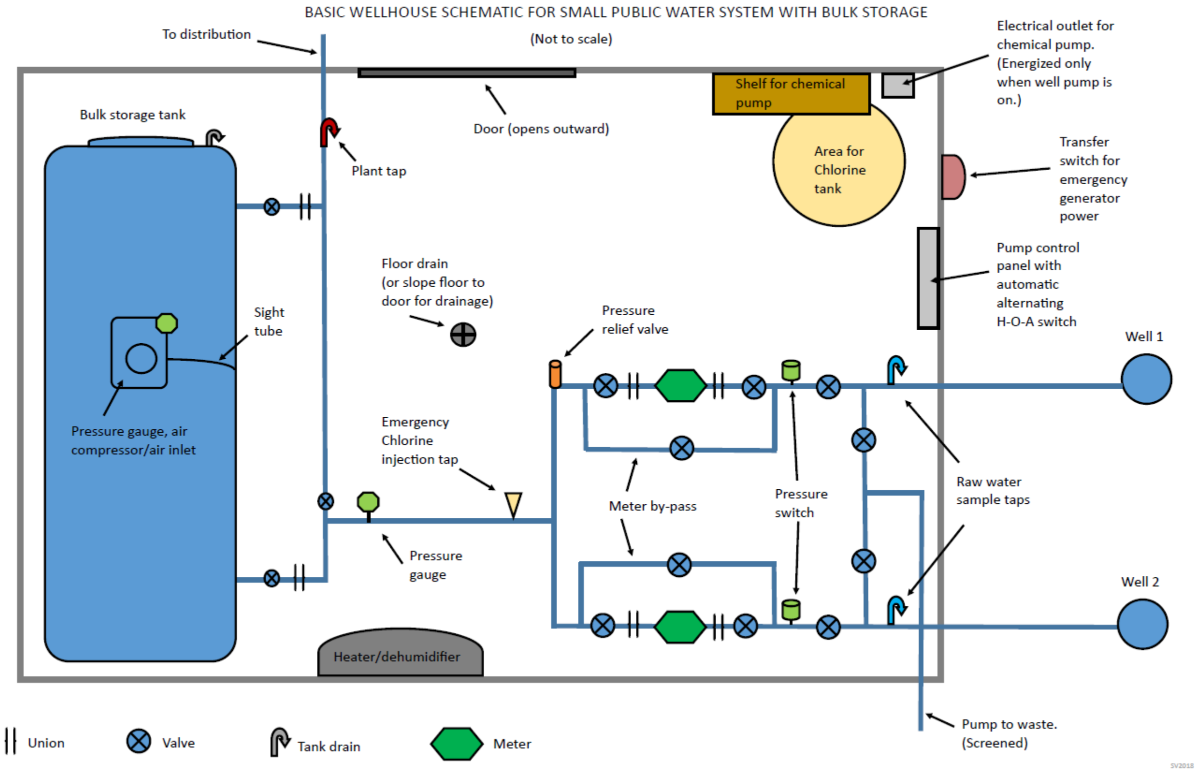


Figure 5.5 Typical Wellhouse Schematics





STORAGE TANK MAINTENANCE

Pressure tanks/bulk tanks

Smaller systems may rely on a series of pressure tanks or a bulk tank to provide storage. Pressure tanks should be routinely checked to ensure that they are maintaining the proper air pressure and have not become waterlogged. Each tank is to be connected to the wellhouse common header with a valve and union that will allow individual tanks to be flushed or changed out without interrupting normal service. Bulk storage tanks will make use of an air compressor to maintain pressure. The compressor should be oil less and have filters in place that will prevent contamination from entering the tank. Bulk tanks must have a sight tube to monitor water level and a valve to allow for draining the tank.

Elevated Tanks

Maintenance on an elevated tank by an operator is usually limited in scope. Most municipalities rely on elevated tank contractors for performing routine inspections and maintenance of their elevated tanks due to the nature of the inspection and the type of work. Some communities may periodically lower the water level in their elevated tank and inspect it themselves, but generally it is better to call a reputable elevated tank contractor.

Prevention of corrosion is the main goal of elevated tank maintenance and there are two basic methods for this. One method is the application of a solid coating such as paint, an asphaltic base compound, or epoxy coating, to prevent oxidation of the metal surface. Once a protective coating becomes pitted or abraded, localized corrosion is accelerated in that area.

Another method used to protect metallic tanks is cathodic protection. Since the tank and water act as an electrical cell with a cathode and an anode, protection of the tank is achieved through either a sacrificial element, which corrodes more readily then the tank or induces current, which eliminates the corrosion effects of the electric cell. Ice damage is the major cause for failure of both systems. Protective coatings must be inspected periodically to see that they have not become abraded or scoured away, and the metal and cathodic systems must be inspected for damage to the electrodes.

Since water demands are usually reduced during winter and spring, these times are good for scheduling routine well maintenance and repair.

Wintertime Operation

Wintertime operation of wells is similar to summertime operation except that care must be taken to prevent freezing of pipes, controls, etc., in the well house, and access to some well houses may be difficult. Most well houses have some form of heat source such as electric heater, stove, etc. Maintenance of an elevated tank during the wintertime can be very difficult depending on the water demand of the local community.

If the local community demand approaches zero during the nighttime hours, the elevated tank may be subject to freezing. To prevent this, some communities sacrifice storage volume in the wintertime. For example, they may lower the level at which the well shuts off and only maintain half an elevated tank in the winter to reduce the amount of water in the elevated tank.

The operator may also alter the length of pump cycle by changing the control level in the tank. In doing this, the operator must be certain that the operating cycle is long enough to allow warmer source water to be pumped into the tank but short enough to allow for frequent cycling. According to an article by Courchaine and Erickson, a daily circulation of about 30 percent of volume is normally sufficient to prevent freezing in elevated tanks.

Another method used to prevent elevated tank freeze up is accomplished using a temperature recorder. When the water temperature in the tank drops to a certain point, water is either wasted or circulated within the tank to prevent freezing. Small recirculation pumps have been installed on some tanks to continuously re-circulate water from the bottom of the riser to the top of the tank to prevent freezing. Some communities routinely waste considerable volumes of water in the wintertime to provide sufficient circulation within the elevated tank when daily temperatures drop to a certain level.

Systems which use altitude valves are more likely to freeze an elevated tank if proper care is not taken. An altitude valve activates when the system pressure exceeds the pressure exerted by the elevated tank. When this happens, the water is essentially "locked" in the elevated tank without circulation. If this situation exists for more than a period of several hours during extremely cold weather, the tank riser could freeze closed. Altitude valves are normally hydraulically operated through pilot control valves. If the pilot valve freezes, the altitude valve could remain in the closed position again "locking" the water in the elevated tank. An altitude valve that remains operational during the winter should be checked routinely.

Overflows, vents, screens, and any other access devices within the tank should be checked prior to the start of wintertime operation. Interior supports, ladders, etc. are normally damaged by ice and may cause additional tank damage during ice movement. Screens on overflows and vents may be frozen in the wintertime becoming plugged. This can prevent the release of overflow water or adequate venting, creating a vacuum within the structure. If the tank is overflowed in the wintertime, the overflow should be checked. If venting problems have occurred in the past, corrections should be made to the vent to prevent them in the future.

If freezing does occur, various methods and devices are available to assist in the thawing of the tank. Several methods have been used to thaw out elevated tanks in the past in Michigan. Steam jenny's, which circulates warm steam from the bottom of the riser to the point of blockage, have been used successfully on several occasions. In one instance a steam jenny was used to try to pump steam to the top of the tank and thaw from the top down. This effort was unsuccessful due to condensation of the steam when it was pumped up the outside of the tank through a hose. Dry air thawing has been tried but with limited success due to the inability to effectively transfer the warm air to the point desired for thawing. Auguring through the ice buildup has been tried on at least one occasion but was unsuccessful. Some communities have simply removed their tank from service and waited for natural thawing. If an elevated tank freeze-up is encountered, reliable contractors or people experienced with thawing elevated tanks should be contacted for assistance.

Thawing Mains and Services

During severe winters in northern climates, frozen water mains and services are not uncommon. To prevent freezing, several precautions can be taken during installation. Frost lines seldom penetrate below the five-foot depth in Michigan, so water mains and services installed below this level are not normally subject to freezing. Many times, service line installations tend to rise above the five-foot level and freezing problems are encountered under areas that do not normally have a snow cover such as sidewalks, driveways, or roadways. Water utilities should keep records of water mains and services that freeze so precautionary measures can be taken prior to the onset of cold weather. Notices can be sent to customers with services that have frozen in the past, advising them to allow water to trickle at one tap within the home during the cold months to prevent freezing. Service lines that historically freeze could be scheduled for replacement and lowering as time allows.

Thawing Frozen Water Mains

Steam Jenny's are used to thaw a majority of distribution mains. Once the frozen area has been located, an excavation is made to the main and a fitting on the main is removed. Steam is then pumped into the frozen water main and pushed through the line with a steam lance until the ice is thawed. Once the blockage is released, water under pressure will come through the opening. Therefore, it is important that a person be stationed at the closest shut off valve to shut the water off until the main is reconnected. If the steam lance was inserted very far into the main, some limited chlorination and flushing may be necessary. Some communities use this same method but instead of steam, pump hot water or hot air into the main to produce the thawing effect. Hot water is usually successful but due to the limited heat carrying abilities of air, hot air is not generally successful for very extensive thawing.

On occasion, some communities have isolated a frozen section and jumped this section through fire hoses connected to fire hydrants. If this method is used, the freezing of the hydrants and the fire hose becomes a very real possibility. One way to prevent this is to allow sufficient flow of water through the hose during use by wasting some water downstream at a controlled point.

Thawing Frozen Service Lines

Some water utilities have used hot water for thawing service lines. They accomplish this by using a small positive displacement pump to pump hot water through a flexible, plastic line, which will fit within the service line. First the meter is removed, and the small line is shoved into the service line up to the point of ice blockage. Hot water is then pumped into the small line and thawing begins to take place in the service line. As thawing is accomplished, the hot water line is pushed further into the service line until all the ice is melted. A container must be provided to collect the water as it returns after being pumped into the main. Since water will flow after the ice is melted, the curb stop should be closed as soon as possible after the ice is cleared.

Steam can be used much the same way as the hot water thawing except, instead of hot water, steam is pumped into the line. If the service line has many elbows or bends these methods of thawing become difficult since the hot water line or steam lance must be pushed back through the service line. If the ice blockage is a long distance from the home, a long insertion line is needed, and this method may not be successful.

One community combats freezing problems in customer service lines by simply shutting the frozen service line off and connecting the home to an adjacent home through an insulated hose system. The community maintains a stock of insulated hoses, which can be readily connected and attached to outside faucets. By adjusting the meter billings of the two homes, the home with the frozen service line can maintain service until natural thawing occurs in the spring. If a home routinely experiences freezing, notices are sent by the city recommending that replacement of the service line be considered.

These methods described above are by no means the only possibilities available for thawing water mains. Water superintendents and distribution personnel, through their own ingenuity, have developed various methods for combating freezing problems throughout the years.

CHAPTER 6 – Cross Connections

Historically, the waterworks industry has made a determined effort to provide the consumer with an unlimited quantity of high-quality water. Much of this effort, however, has been concentrated on the production of a quality treated water with insufficient attention paid to protecting the quality of water within the distribution system. The cross connection of various contaminants or potential contaminants with the potable water supply is encountered on all PWS distribution systems to some extent. The control of this problem is difficult since it demands the inspection and necessary re-inspection of industrial and commercial establishments as well as access to and some control of private dwellings.

A cross connection is a connection or arrangement of piping or appurtenances connecting a non-potable source to a potable source through which backflow could occur. Backflow is when water of questionable quality, wastes, or other contaminants enter a PWS system due to a reversal of flow. Two conditions are required for this to occur: (1) a link must exist between the potable system and the non-potable one; and (2) the resultant flow produced by the differential pressure must be toward the potable system.

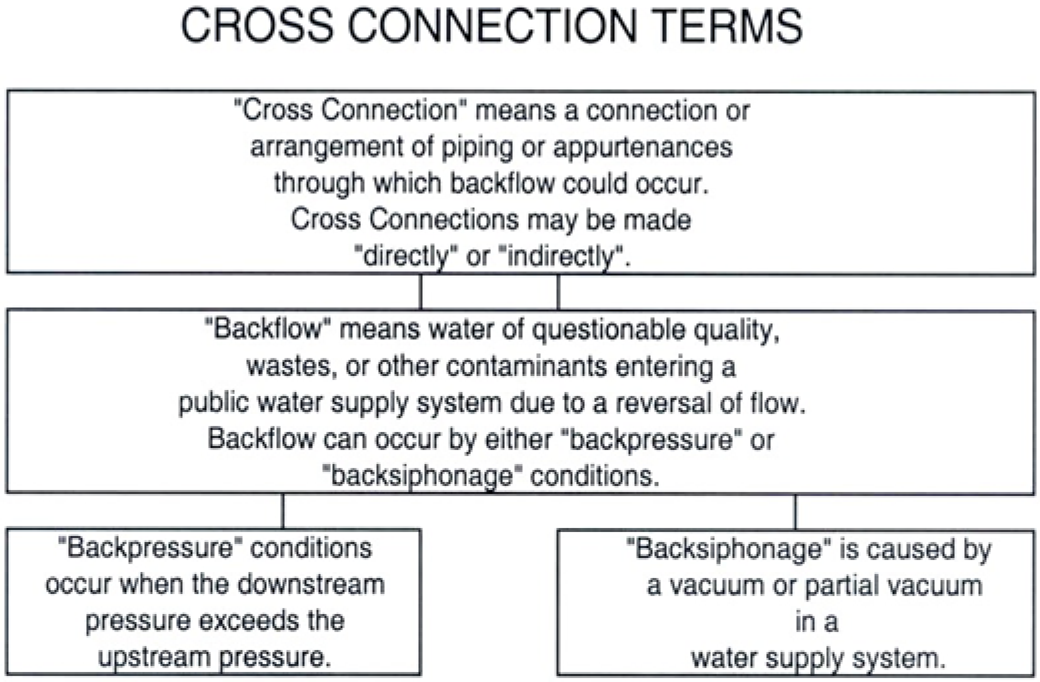
The first condition (the link) is the actual cross connection. The cross connection may be a direct or indirect connection. A direct connection is a permanent or semi-permanent connection between systems, i.e., a potable system piped to a boiler, an air conditioning unit, a fire sprinkler system, a wastewater system, a chemical make-up tank, or the like. An indirect connection is more like a temporary connection. A hose connected to a tap and dangling into a sink basin, chemical feed or make-up tank, or a hose in a ditch or pit are examples of indirect cross connections.

The second condition necessary for backflow to occur deals with a change in water pressure, a pressure differential. We know water moves from areas of high pressure to low pressure. (Pumps move water by creating high pressure at the pump and move the water down the lower pressure pipeline.) Two conditions cause the pressure differential in cross connection situations: (1) backpressure; and (2) backsiphonage. Backpressure conditions occur when the downstream pressure exceeds the upstream pressure. Backsiphonage is caused by a vacuum or partial vacuum in a water supply system.

Backpressure situations may develop when a potable water supply system is directly or indirectly connected to heating systems, elevated tanks, pressure-producing systems, individual water supply systems, and the like. For example, if a boiler used in conjunction with a heating system is operating at 45 psi pressure and the potable water supply system is operating at 50 psi, and something happens to reduce the pressure in the potable water supply system, the water pressure from the boiler will exceed the system pressure. Since water flows from high pressure to low pressure, the backpressure situation would allow boiler water to flow into the potable system.

Whenever a condition in the potable water supply system develops which reduces the system pressure to atmospheric or below, a backsiphonage situation can develop. Heavy water demands, such as those created by firefighting, repairs or breaks in municipal mains, and others, may create this backsiphonage situation. Under these conditions, hoses dangling in laboratory sinks, janitor slop sinks, or other systems can provide the connection through which backflow (by backsiphonage) can occur.

Table 6.1 Cross Connection Terms



CROSS CONNECTION TERMS

"Cross Connection" means a connection or arrangement of piping or appurtenances through which backflow could occur. Cross Connections may be made "directly" or "indirectly".

"Backflow" means water of questionable quality, wastes, or other contaminants entering a public water supply system due to a reversal of flow. Backflow can occur by either "backpressure" or "backsiphonage" conditions.

"Backpressure" conditions occur when the downstream pressure exceeds the upstream pressure.

"Backsiphonage" is caused by a vacuum or partial vacuum in a water supply system.

The Safe Drinking Water Act requires municipalities to have a cross connection control program to eliminate and prevent all cross connections. Cross connection control programs must include six elements, including program administration and authority, inspections and reinspections, methods for protection of the water supply, testing of backflow preventers, allowable timeframe for correcting cross connection, and a recordkeeping system. Each of these elements is designed to find, eliminate, and prevent cross connections. A cross connection rules manual was developed by the Division of Water Supply in 1974 and a fourth edition was published in 2008 and is available on the EGLE Drinking Water website. The manual includes templates for cross connection control plans and other useful forms that can be adopted by water supplies and provides lists of approved backflow/backsiphonage prevention devices and assemblies. It is recommended that each supply develop and implement an ordinance to regulate cross connections and establish inspection/testing schedules.

Figure 6.1 Example Small System Cross Connection Control Plan

Cross Connection Control Program for the
Candy Land Water Supply, Chocolate County
PWSID: 09999

In accordance with the requirements set forth by the Michigan Department of Environment, Great Lakes, and Energy (EGLE), the Candy Land water system agrees to implement the State of Michigan cross connection control rules to protect the Candy Land water supply system from cross connections.

"Cross Connection" is defined as a connection or arrangement of piping or appurtenances through which a backflow could occur.

"Backflow" means water of questionable quality, waste, or other contaminants entering a public water supply system due to a reversal of flow.

I, James Hasbro the Superintendent of the Candy Land water supply system, hereby stipulate to develop a comprehensive program for the elimination and prevention of all cross connections by the following actions:

1. Comply with the Water Supply Cross Connection Rules of EGLE being R 325.11401 to R 325.11407 of the Michigan Administrative Code and the EGLE Cross Connection Rules Manual.
2. Authorize Candy Mann to inspect all properties served by the public water supply where cross connections with the public water supply are deemed possible. Individuals responsible for carrying out the cross-connection inspections and re-inspections shall have obtained necessary training through any available manuals on cross connection prevention, including the Cross Connection Rules Manual as published by EGLE, and attendance at cross connection training sessions sponsored by EGLE, or other recognized agencies.
3. Initially survey each building and periodically conduct re-inspections based upon the degree of plumbing hazards associated with their drinking water plumbing.
4. Eliminate any potential and/or existing cross connections in compliance with all applicable codes and rules.
5. Authorize James Hasbro to establish the time frame for compliance with any order for the installation of backflow prevention devices, assemblies, or re-plumbing.
6. Accept only the methods outlined in Chapter 4 of the Cross Connection Rules Manual to protect against the hazards of cross connections.

7. Re-inspections shall be in accordance with the schedule as noted in Chapter 13 of the Cross Connection Rules Manual. Candy Land water system will re-inspect/test:
    a. Annually for high hazard accounts.
    b. Every _3__ years for low hazard accounts.
    c. Low Hazard residential lawn irrigation accounts every 5 years.
    d. Re-inspections shall be based upon the complexity of the building's internal plumbing, plumbing change frequency, and the potential for backflow of contaminants/pollutants into the potable water supply.
    e. Re-inspections of the premise will be made whenever it is suspected or known that modifications have taken place with piping systems serving a particular water customer.
8. All testable assemblies deemed high hazard shall be tested at least annually, and low hazard assemblies shall be tested once every three years. Additionally, all testable backflow prevention assemblies shall be tested at the time of installation or relocation and after any repair. Records of test results shall be maintained by the water system owner. Only individuals that hold a valid ASSE 5110 certification shall perform such testing.
9. The water system owner shall maintain sufficient and accurate records of its local cross connection control program and report annually on the status of the program to EGLE on a form provided by the department.

OWNERS CERTIFICATION
By signing below, I hereby certify to implement and maintain an active cross connection control program in accordance with the provisions listed in this document.

____
Signature of Water System Owner or Designated Representative

____
Typed or Printed Name of Water System Owner or Designated Representative

____
Date

This cross-connection control program will take effect immediately upon approval of EGLE.

Once a cross connection is discovered, its elimination first involves determining the means by which backflow might occur in that situation, and the risk associated with the connection. If a physical connection is discovered that cannot be eliminated, then a backflow prevention preventor must be installed and a timeframe for testing established and tracked. It is always possible to eliminate the cross connection or prevent the possibility of backflow. If backflow can only occur by backsiphonage, then a particular backflow prevention assembly may be required. If, however, backflow could occur by either backsiphonage or backpressure, then some backflow preventers may not be appropriate. The risk of contamination also varies depending on the type of cross connection. High risk examples are those with potential contaminants that could cause illness or death. Low risk examples are those with pollutants that are undesirable but not considered to pose a risk of illness or death.

The principal backflow prevention methods include the following:

Method	Back Pressure?	Back Siphonage?	High or Low Hazard?
Air Gap (AG)	Yes	Yes	High
Reduced Pressure Principle Backflow Preventer (RPZ)	Yes	Yes	High
Pressure Vacuum Breaker (PVB)	No	Yes	High*
Double Check Valve Assembly (DCVA)	Yes	Yes	Low
Atmospheric Vacuum Breaker (AVB)	No	Yes	Low*

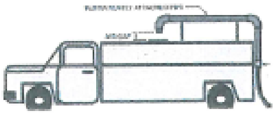
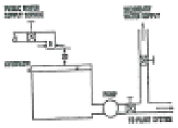
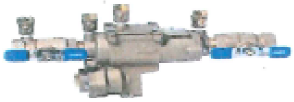
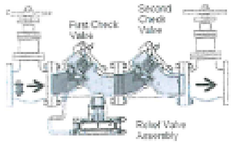
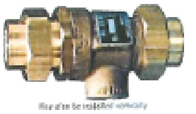
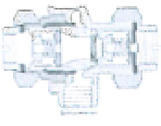
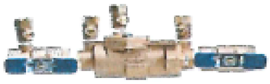
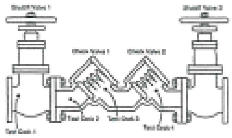
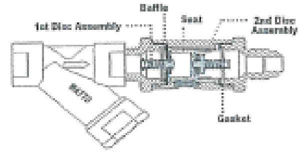
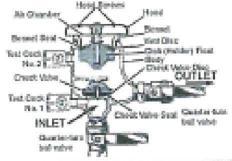
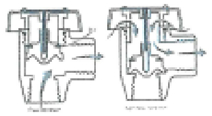
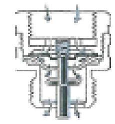
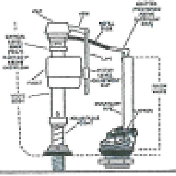
**Some PVB and AVB applications may vary, consult available resources*

Certain cross connections pose a difficulty in assessing risk due to the unknowns associated, such as an exterior hose bib. It is important to consult the available literature and resources in making these determinations. Always consult the manufacturer when considering application of a backflow preventor. In addition, all backflow preventers should be certified by the American Society of Sanitary Engineers (ASSE), except for an air gap.

A double check valve assembly is sometimes used for prevention of backflow. This device consists of two independently acting, internally loaded check valves. This device may be used for backpressure or backsiphonage situations only if the cross-connection protection is from substances that do not constitute a health hazard. Generally, a double check valve assembly is not the recommended backflow prevention device.

While AVB and AG methods are not able to be tested, other backflow preventors are constructed to facilitate testing. Periodic testing of mechanical backflow preventers is required to ensure continued functionality and protection. All tests completed on backflow preventors must be completed by individuals who are master plumbers or journeymen plumbers also holding a valid 5110 certificate from the ASSE.

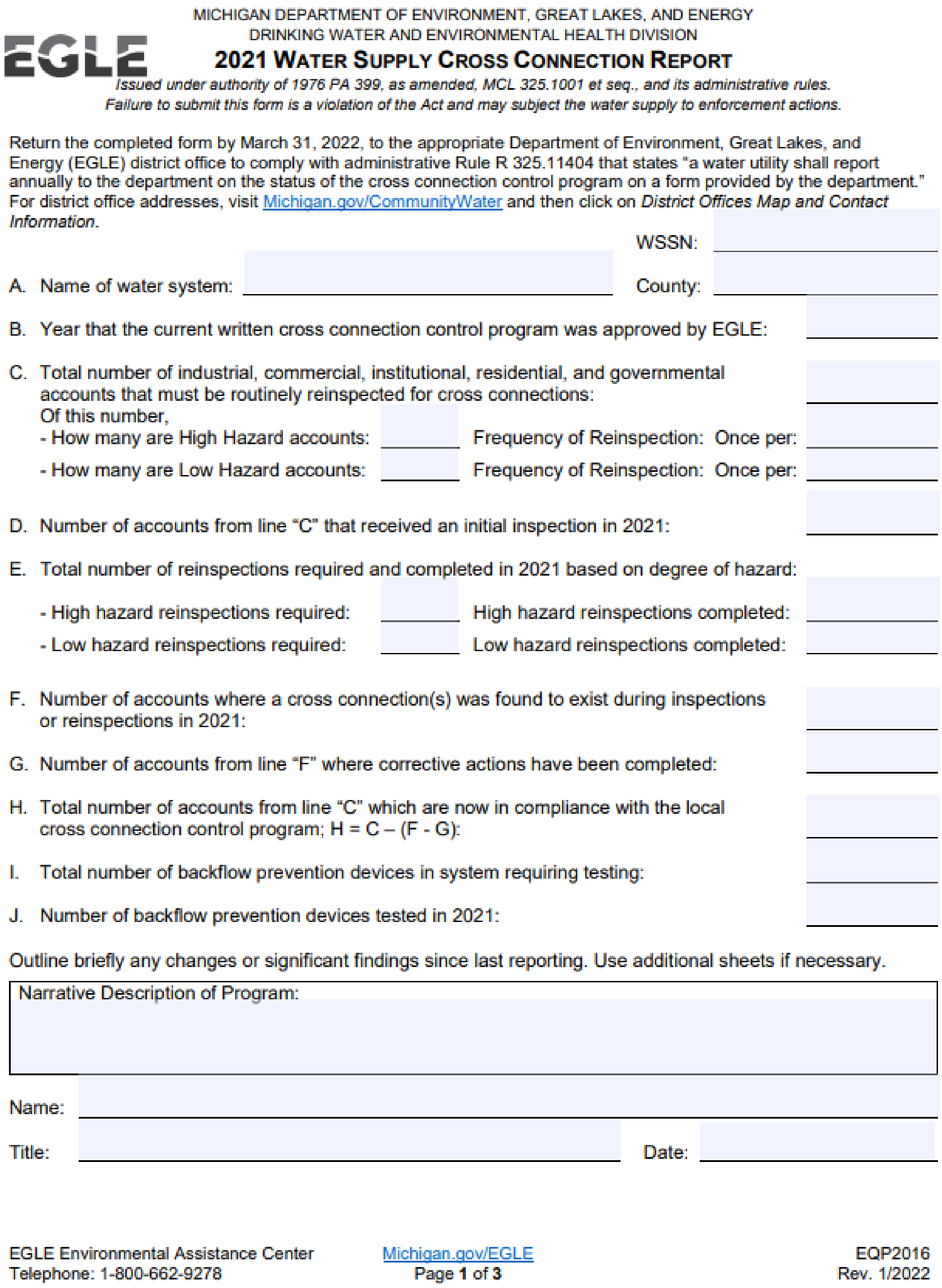
Figure 6.2 Illustrated Chart of Backflow Preventers

Type of Backflow Prevention	Picture/Illustration
Air Gap	 
Reduced Pressure Principle Backflow Preventer (RPZ)	 
Dual Check Valve w/Intermediate Atmospheric Vent	 
Double Check valve assembly	 
Backflow Preventer for Beverage Dispensing Equipment (carbonated & non-carbonated)	 
Pressure Vacuum Breaker Assembly	 
Atmospheric Vacuum Breaker	 
Hose Bib Vacuum Breaker	 
Anti-siphon type water closet flush tank	 

This department does not endorse any specific brand name backflow device.

All Type I supplies are required to submit a cross connection report by March 31 of each year. This report details the cross-connection prevention activities completed by the supply to fulfill the requirements of the Cross Connection Plan.

Figure 6.3 Template for Standard Annual Cross Connection Inspection Report



MICHIGAN DEPARTMENT OF ENVIRONMENT, GREAT LAKES, AND ENERGY
DRINKING WATER AND ENVIRONMENTAL HEALTH DIVISION

2021 WATER SUPPLY CROSS CONNECTION REPORT

Issued under authority of 1976 PA 399, as amended, MCL 325.1001 et seq., and its administrative rules.
Failure to submit this form is a violation of the Act and may subject the water supply to enforcement actions.

Return the completed form by March 31, 2022, to the appropriate Department of Environment, Great Lakes, and Energy (EGLE) district office to comply with administrative Rule R 325.11404 that states "a water utility shall report annually to the department on the status of the cross connection control program on a form provided by the department." For district office addresses, visit Michigan.gov/CommunityWater and then click on *District Offices Map and Contact Information*.

WSSN: __________

A. Name of water system: __________ County: __________

B. Year that the current written cross connection control program was approved by EGLE: __________

C. Total number of industrial, commercial, institutional, residential, and governmental accounts that must be routinely reinspected for cross connections: __________
Of this number,
- How many are High Hazard accounts: _____ Frequency of Reinspection: Once per: __________
- How many are Low Hazard accounts: _____ Frequency of Reinspection: Once per: __________

D. Number of accounts from line "C" that received an initial inspection in 2021: __________

E. Total number of reinspections required and completed in 2021 based on degree of hazard:
- High hazard reinspections required: _____ High hazard reinspections completed: __________
- Low hazard reinspections required: _____ Low hazard reinspections completed: __________

F. Number of accounts where a cross connection(s) was found to exist during inspections or reinspections in 2021: __________

G. Number of accounts from line "F" where corrective actions have been completed: __________

H. Total number of accounts from line "C" which are now in compliance with the local cross connection control program; H = C – (F - G): __________

I. Total number of backflow prevention devices in system requiring testing: __________

J. Number of backflow prevention devices tested in 2021: __________

Outline briefly any changes or significant findings since last reporting. Use additional sheets if necessary.

Narrative Description of Program:

Name: __________

Title: __________ Date: __________

EGLE Environmental Assistance Center
Telephone: 1-800-662-9278

Michigan.gov/EGLE
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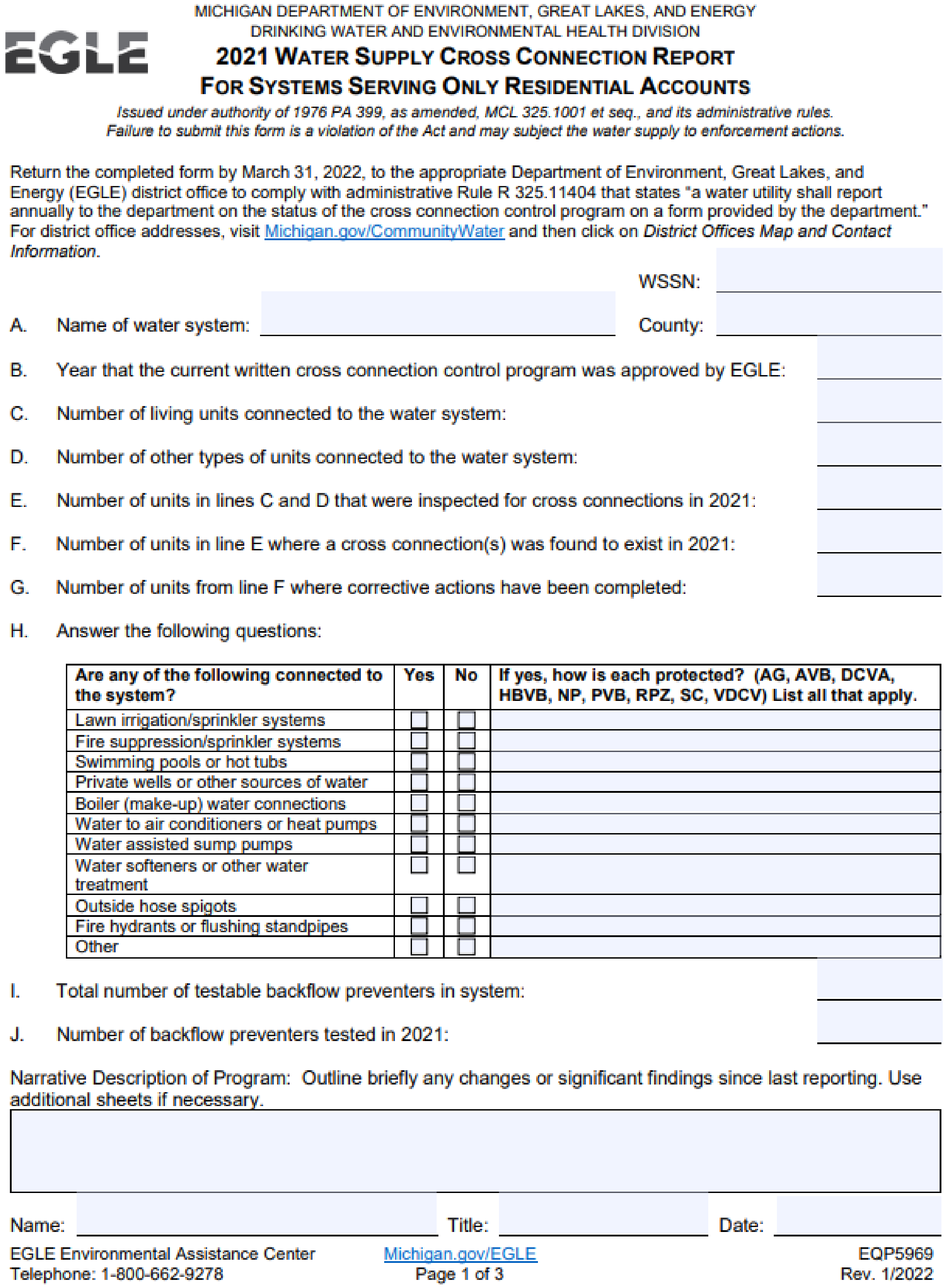
Rev. 1/2022

Figure 6.4 Template for Residential-Only Annual Cross Connection Inspection Report



MICHIGAN DEPARTMENT OF ENVIRONMENT, GREAT LAKES, AND ENERGY
DRINKING WATER AND ENVIRONMENTAL HEALTH DIVISION

2021 WATER SUPPLY CROSS CONNECTION REPORT
FOR SYSTEMS SERVING ONLY RESIDENTIAL ACCOUNTS

Issued under authority of 1976 PA 399, as amended, MCL 325.1001 et seq., and its administrative rules.
Failure to submit this form is a violation of the Act and may subject the water supply to enforcement actions.

Return the completed form by March 31, 2022, to the appropriate Department of Environment, Great Lakes, and Energy (EGLE) district office to comply with administrative Rule R 325.11404 that states "a water utility shall report annually to the department on the status of the cross connection control program on a form provided by the department." For district office addresses, visit Michigan.gov/CommunityWater and then click on *District Offices Map and Contact Information*.

WSSN: ________

A. Name of water system: ________ County: ________

B. Year that the current written cross connection control program was approved by EGLE: ________

C. Number of living units connected to the water system: ________

D. Number of other types of units connected to the water system: ________

E. Number of units in lines C and D that were inspected for cross connections in 2021: ________

F. Number of units in line E where a cross connection(s) was found to exist in 2021: ________

G. Number of units from line F where corrective actions have been completed: ________

H. Answer the following questions:

Are any of the following connected to the system?	**Yes**	**No**	**If yes, how is each protected? (AG, AVB, DCVA, HBVB, NP, PVB, RPZ, SC, VDCV) List all that apply.**
Lawn irrigation/sprinkler systems	☐	☐	
Fire suppression/sprinkler systems	☐	☐	
Swimming pools or hot tubs	☐	☐	
Private wells or other sources of water	☐	☐	
Boiler (make-up) water connections	☐	☐	
Water to air conditioners or heat pumps	☐	☐	
Water assisted sump pumps	☐	☐	
Water softeners or other water treatment	☐	☐	
Outside hose spigots	☐	☐	
Fire hydrants or flushing standpipes	☐	☐	
Other	☐	☐	

I. Total number of testable backflow preventers in system: ________

J. Number of backflow preventers tested in 2021: ________

Narrative Description of Program: Outline briefly any changes or significant findings since last reporting. Use additional sheets if necessary.

Name: ________ Title: ________ Date: ________

EGLE Environmental Assistance Center
Telephone: 1-800-662-9278

Michigan.gov/EGLE
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EQP5969
Rev. 1/2022

These templates and more information are available on the EGLE website, Michigan.gov/EGLE. Click on "Water," then "Drinking Water," then "Community Drinking Water." They are at "Reporting Forms" in the "Manuals, Forms and Brochures" section at the bottom of the page.

CHAPTER 7 – Safety

Two good references are available for information on water distribution system safety: the *"Water Distribution Operator Training Handbook"* and the *American Water Works Association manual, M3 ("Safety Practices for Water Utilities")*. The important thing to remember in discussions about safety is that accidents do not just happen, they are caused. It is important that every individual working for a municipality contribute to the provision of a safe working atmosphere. When tools are left lying around the work area or when spills are left for someone else to clean up, accidents are possible. It is important for supervisors to remind workers of safety hazards, but it is equally important for workers to take on the responsibility themselves.

The federal government has established minimum health safety standards under the Occupational Safety and Health Act of 1970 (OSHA). In Michigan, the Michigan Occupational Safety and Health Administration (MIOSHA) has been passed by the Legislature. The standards refer to proper techniques for entering manholes and other confined spaces. They also involve proper trenching and other construction practices. Information about the MIOSHA regulations can be obtained from the Michigan Department of Labor and Economic Opportunity.

A broad range of personal protection equipment is now provided by most water utilities for their distribution system personnel. This equipment has been quite successful in preventing serious on-the-job injuries. The items listed below are designed specifically to protect a particular area of the body or to protect the breathing of the user.

- Hardhats
- Safety goggles
- Steel-toed safety shoes
- Face shields
- Corrugated sheet metal foot guards
- Gloves
- Safety belts
- Heavy-duty overalls
- Aprons
- Ear protection
- Respiratory equipment
- Respirators: filter, canister, and cartridge type
- Supplied air respirators
- Air or oxygen breathing apparatuses
- Oxygen and gas detectors

Confined Spaces

Work in manholes and other underground structures (storage tanks) must never begin until the worker is certain that the air is safe. There is always the possibility in confined spaces that the oxygen supply may be of insufficient quantity or that harmful gases may be present. Use of oxygen and gas detectors allow a check to be sure oxygen levels are safe and harmful gas levels are below recommended limits. If the air supply is unsafe, the structure should be ventilated until proper air quality is achieved. All harnesses and rescue equipment must be used properly to ensure the safety of the person entering. In extreme cases, self-breathing apparatuses are needed to enter a confined space. These types of spaces require a permit for entry and a competent person must be in charge of the area. There are suggested rules for ventilating manholes available in the texts referred to at the beginning of this chapter.

Trench Construction

Persons working in trenches must wear a hardhat and other necessary safety equipment. This would include adequate eye and foot protection for personnel using jack hammers or others who are exposed to flying particles. If the trench is being excavated with mechanical equipment, workers should be located so they face the equipment. Also, the material excavated from the trench must be stored at least two feet from it. If a trench is to be five feet or more in depth, it must be properly shored unless the bank is cut back at an acceptable angle of repose. Trench boxes are the most used shoring equipment for small repairs such as main breaks and valve replacement. They are known for their ease of use and quickness of installation. Some trenches shallower than five feet, if located in soft soil, may need to be shored and braced as well. If a trench is four feet deep or more, a ladder, steps, or other means of exit must be provided within 25 feet from an area where employees are working. In long open cut trenches, ladders must be placed every 25 foot and extend a minimum of 3 feet above the edge of the trench.

Barricades and Warning Signs

When working in traffic areas, barricades, warning signs, traffic cones, and flashing lights should be used by water utility personnel. Placement of these devices is to be such that the traffic is adequately warned of the work or hazard ahead. Flag persons might also be necessary, as might be the use of bright reflective dress for all persons working in the area. There are OSHA standards for barricade and sign color and placement that all water supplies should adopt.

The information below on safety (Electrical, Safety Around Wells, Pump Safety, Confined Spaces) was taken from "Small Water Systems Operation & Maintenance" text, California State University, Sacramento, Fourth Edition, page 355-359.

Electrical

Electrical safety is very important to your life. Whenever you must work on electrical equipment or equipment that is run by electric motors, be sure to lock out and tag all of the electrical switches. Only the person who placed it should ever be allowed to remove a lockout device and tag that they have installed. Also, you should never remove a tag or lockout device installed by another operator.

Water with minerals is a good conductor of electricity. Do not stand in water when working on electrical equipment. Many water supply and water treatment devices used for monitoring, measuring, and as control systems are electrical. Always be very careful when working around or troubleshooting these instrumentation systems.

Safety Around Wells

Safety around wells is important for two reasons:

- Control around the well site is necessary to prevent contamination or pollution of the well which could affect the health and safety of the consumer, and
- Housekeeping of the site will help prevent an accident to operators or employees working near or around the well.

The well operator has the responsibility to preserve the quality of the well through preventive maintenance of the area where the well is located.

Well Chemicals

Acid Cleaning: An acid treatment may be necessary to loosen incrustations from a well casing and well. Normally, hydrochloric acid is used. Hydrochloric (HCl) acid should be used at full strength. If hydrochloric acid (muriatic acid--industrial name) is used, be careful! The pH of hydrochloric acid is approximately 1.0. This acid is very corrosive. Inhalation of hydrochloric acid fumes can cause coughing, choking, and inflammation of the entire respiratory tract. Swallowing even a small amount of this acid can cause corrosion of mucous membranes, the esophagus, and stomach; difficulty swallowing; nausea and vomiting; intense thirst; and diarrhea. Circulatory collapse and death may occur. Hydrochloric acid causes severe skin burns. Spills, splashes, or fumes may affect the eyes and could cause permanent eye damage.

Another common chemical used in cleaning wells is liquid bleach. Often times, well screens can become plugged if the well is contaminated with iron bacteria. Bleach is often added with high concentrations and left to sit for 24 hours before flushing out. This cleaning should be conducted by a licensed pump installer/well driller. This method can also be used to disinfect the well before going into the service or for any positive coliform test.

Pump Safety

When we think of pumps, we commonly think of pumping water. Pumps can do many things, as is illustrated by the following definitions of a pump:

- An apparatus or machine, which forces liquids, air, or gas into or out of things.
- A machine which increases the static pressure of fluids (air and water).
- Pumping is the addition of energy to a fluid which is used mainly for the purpose of moving the fluid from one point to another.

A pump has moving parts. Where there are moving parts, there is potential danger. All mechanical action or motion is hazardous, but in varying degrees. Rotation member, reciprocating arms, moving parts, and meshing gears are some examples of action and motion requiring protection on pumps.

Any rotating device (pump shaft) is dangerous. Whatever is rotating can grip clothing or hair and possibly force an arm or hand into a dangerous position. While accidents due to contact with rotating objects are not frequent, the severity of injury is very high.

Whenever hazardous machine actions or motions are identified, a means for providing protection for operators is essential. Enclosed guards are used to protect operators from rotating parts on pumps. The enclosed guard always prevents access to dangerous parts by enclosing the hazardous operation completely. These should be inspected regularly for structural integrity due to being placed in environment often exposed to moisture. Moisture tends to accelerate degradation of these protectors by oxidation. The basic requirement for an enclosed guard is that it must prevent hands, arms, or any other part of an operator's body from making contact with dangerous moving parts.

Safety information, forms, reporting guidelines, and other information is available from MIOSHA.

Michigan Occupational Safety & Health Administration
Michigan Department of Licensing and Regulatory Affairs
www.michigan.gov/miosha

Consultation Education & Training Division
(517) 284-7720

Construction Safety and Health Division
(517) 284- 7680

MIOSHA

PART II

CHAPTER 8 – Basic Hydraulics

HYDRAULICS

Hydraulics is the study of liquids, both at rest and in motion. Water treatment and distribution personnel are most interested in the hydraulics of water. Water is not a perfect liquid, but for practical purposes, it may be assumed to be. Water takes the shape of its container; has weight, density, and exerts pressure.

Weight

Weight is defined as the force of the earth's gravitational pull upon a body. The effect of the earth's gravitational pull is generally expressed as "g." A falling body increases its speed as it falls due to this effect. As a result, there is a gradual increase in speed generally taken as 32.2 feet per second per second ("g"), which means that a falling body will increase speed 32 feet per second every second that it falls.

We are frequently concerned with the weight of a substance, or a definite quantity of fluid. The attraction of the earth for the substance will cause the material to have weight and this weight is considered to be the same wherever this material is placed and regardless of any change in its physical shape. The unit in which weight is most frequently expressed is the pound, and for large weights, the ton (which is 2,000 pounds).

Volume is a most important aspect of a fluid, and is used for many calculations, often in "cubic feet." The concept of the cubic foot is merely a box, one foot on each side. In the study of hydraulics, the student is forced to jump back and forth between cubic feet of water and pounds of water. We previously discussed the conversion factor for doing this.

Example: A container of water weighs 160 lbs. One cubic foot of water weighs 62.4 pounds. To determine the volume of the container, calculate how many cubic feet of water are in 160 lbs of water.

$$\frac{160\ \cancel{\text{lbs}}}{1} \times \frac{1\ \text{ft}^3}{62.4\ \cancel{\text{lbs}}} = 2.56\ \text{ft}^3$$

Density

The weight of a substance per unit volume is defined as its *density.* Thus, the density of water is 62.4 pounds per cubic foot. Most fluids other than water can be compared to pure water with regard to their weight per unit volume. This comparison is known as *specific gravity,* and it is a ratio of the weight per unit volume of the other fluid compared to water.

If the answer is over 1, it infers that the substance will sink in water, and if the answer is under 1, the substance will float in water. Specific gravity has no units associated with it.

Example: Mercury, which is sometimes used in water works instrumentation, weighs 849 pounds per cubic foot. Calculate the specific gravity.

$$\frac{849\ \cancel{\text{lbs}}}{1\ \cancel{\text{ft}^3}} \times \frac{1\ \cancel{\text{ft}^3}}{62.4\ \cancel{\text{lbs}}} = 13.6$$

Elevation

The term elevation is often encountered in water works practice. It usually means the height of a point, this height being measured in feet above a datum plane, usually mean sea level. Thus, an elevation of 860 means 860 feet above sea level. In the case where no known reference to sea level is available, some other easily obtained data point is used as the elevation reference. It must be noted that no matter whether the datum is sea level or merely an arbitrary assumed value, the actual vertical distance in feet between two points is given by subtracting the lower elevation from the higher elevation.

Pressure Calculations

Water weighs approximately 62.4 lbs/ft^3 and exerts pressure equally in all directions. The force (pressure) water exerts over a unit area is expressed in terms of pounds per square foot or pounds per square inch (psi). For example, a tank 10 feet wide, 20 feet long and 6 feet deep will hold about 8,976 gallons of water when full. The weight of this water creates a certain amount of pressure on the 10’ by 20’ (200 sq. ft.) bottom area of the tank, which can be calculated, starting by finding the weight of the water:

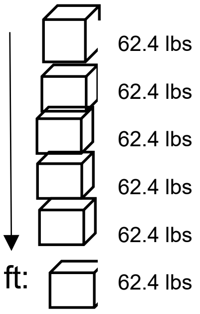
$$\frac{8976\cancel{gal}}{1} \times \frac{8.34\ \text{lbs}}{1\ \cancel{\text{gal}}} = 74{,}860\ \text{lbs}$$

Then finding the weight of water per square feet of bottom area:

$$\frac{74{,}860\ \text{lbs}}{200\ \text{ft}^2} = 375\ \ \text{lbs/ft}^2$$

Pressure calculations similar to this can be determined by thinking of "cubes" of water stacked one on top of the other. Each cube weighs 62.4 lbs. and exerts pressure on a one square foot area. With a water height of 6 feet, the pressure is:

$$6\ \text{ft}\ \times 62.4\ \ \text{lbs/ft}^3 = 375\ \ \text{lbs/ft}^2$$



The weight of the column of water is creating 375 lbs of pressure on the 1 ft^2 area at the bottom of the column.

Pounds per square inch (psi) is a common pressure measurement. Calculating the lb/in^2, or psi in our example, start with the inches per square ft:

$$1\ \text{ft}^2 = 12\ \text{in.} \times 12\ \text{in.} = 144\ \text{in}^2$$

$$\frac{375\ \text{lbs}}{1\ \cancel{\text{ft}^2}} \times \frac{1\ \cancel{\text{ft}^2}}{144\ \text{in}^2} = 2.6\ \text{lbs/in}^2 = 2.6\ \text{psi for 6 feet of water, and}$$

$$\frac{62.4\ \text{lbs}}{1\ \cancel{\text{ft}^2}} \times \frac{1\ \cancel{\text{ft}^2}}{144\ \text{in}^2} = 0.433\ \text{lb/in}^2 = 0.433\ \text{psi for 1 foot of water}$$

The relationships derived from this

$$0.433\ \text{psi} = 1\ \text{ft of water pressure (head)}$$

and

$$1\ \text{psi} = 2.31\ \text{ft of water pressure (head)}$$

are used frequently in hydraulic calculations and worth remembering.

SAMPLE PROBLEMS

(1) What would the pressure be at the base of an elevated tank with a water level 150 feet above the ground?

(2) What would be the water level in a storage tank if a gauge at its base reads 16 psi?

Friction and Head Loss

Friction is defined as the forces resisting motion, which result from the contact between a moving body and a stationary body. Friction in water flow results from the motion of water along a stationary pipeline wall. The degree of friction is influenced by the roughness of the pipeline wall, with increasing roughness resulting in increasing friction in a fashion similar to the condition one can envision sliding a weighted block across a horizontal surface. The block will slide easily across a smooth surface but may be impossible to move on a rough surface. Similarly, water moves with the least friction resistance through an extremely smooth walled pipeline and with the greatest friction being imposed by a very rough walled pipeline. Hydraulics science has established that the friction resistance (head loss) due to motion in a pipeline increases with the square of the velocity in the pipeline and is expressed as a function of the velocity squared, the length, the diameter, and the roughness of the internal pipe surface. This is known as the Hazen-Williams equation. The Hazen-Williams Equation is: $V = 1.318CR^{0.63}S^{0.54}$

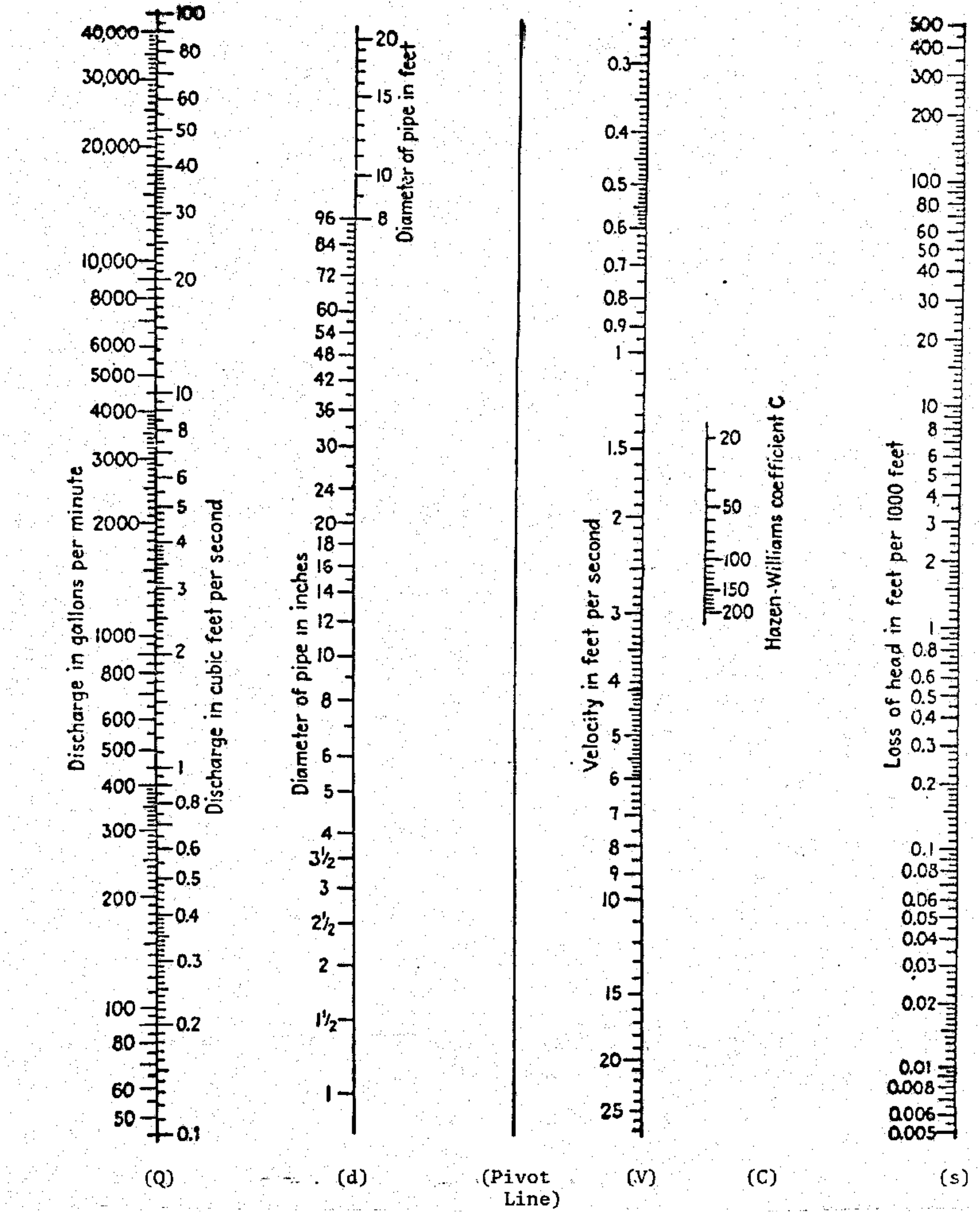
Where V = velocity of flow in feet per second
C = roughness coefficient
R = hydraulic radius (area of the pipe divided by the wetted perimeter)
S = feet of head loss per foot of conduit

The friction factor for the Hazen-Williams Equation is the roughness coefficient C. The C factor is most commonly used for expressing the relative roughness of the inside of a pipe. Typical "C factors" for water mains are normally in the range of 80 to 140. The lower the roughness of the pipe, the higher the C factor. Table 8.1 lists some C factors for various pipes. There are also charts and nomographs available for determining head loss in water mains. One of these is the Hazen-Williams Alignment Chart shown in Figure 8.2.

Table 8.1 Hazen-Williams Roughness Coefficient for Various Types of Pipes

PIPE DESCRIPTION	C FACTOR
Asbestos Cement	140
Brass or lead, new	140
Cast iron, uncoated, new	130
Five years old	120
Ten years old	110
Fifteen years old	100
Twenty years old	90
Thirty years old	80
Concrete, very smooth, excellent joints	140
Smooth, good joints	120
Rough	110
Steel, welded, new	130
Five years old	120
Ten years old	110
Fifteen years old	100
Twenty years old	90
Thirty years old	80
Wood or wood stave	120
Wrought iron or standard galvanized steel, diameter 12” and larger	110
4” to 12”	100
4” and smaller	80

Figure 8.2 Hazen-Williams Alignment Chart



Example: A 24-inch, 15-year-old, uncoated cast iron pipe carries a total flow of 6,000 gallons per minute.

a. What is the velocity of flow in the pipe?

b. What is the head loss due to friction per 1,000 feet of the pipe?

c. What is the value of "s" (head loss per foot)?

d. If the pipe is 10,000 feet long, what is the total head loss?

Solution: From Table 8.1, a 15-year-old uncoated cast iron pipe has a Hazen-Williams coefficient of C = 100. Now in Figure 8.2, draw a straight line connecting 6,000 gpm on the flow scale (Q) and 24 inches on the diameter scale.

Extend this line to the velocity scale and read off velocity. Mark point where this line crosses the pivot line. Now connect this point with C line and extend to cross the loss of head line. Read off the head loss scale--the value for head loss where the line crosses that scale.

a. From Figure 8.2, V = 4.2 feet per second.

b. From Figure 8.2, head loss/1,000 feet = 3.9 feet/1,000 feet

c. s = head loss per foot = 3.9/1,000 = 0.0039 feet per foot

d. If the pipe is 10,000 feet long, the total head loss is

$$(\mathrm{H_L})_\mathrm{P} = \frac{0.0039}{\mathrm{ft}} \times 10{,}000\ \mathrm{ft} = 39\ \mathrm{ft}$$

Example: What is the value of "C" for an old 10-inch pipe, which is found to carry a flow of 2,000 gpm with a head loss of 110 feet per 1,000 feet?

Solution: Connect 2,000 on the "Q" scale in Figure 8.1 with 10 inches on the "d" scale. Extend to cross pivot line. Connect point on pivot line with 110 on head loss scale. From the velocity scale, we can also determine that V = 8.2 feet per second.

Hydraulic Gradient or Slope

We use the word "slope" to describe the vertical rise or fall of something, such as a water main, with respect to horizontal distance. This vertical rise or fall is measured in feet. If the elevation of each end is known, the rise or fall can be found by subtracting one elevation from the other. Thus, a pipe, one end of which is one foot higher than the other end, is said to slope. One way of expressing the slope is as a percent. If the pipe mentioned above is 20 feet long, the rise or fall (1 ft) occurs in a horizontal distance of approximately 20 feet (the length of the pipe), and its slope, 1/20, as a percent is 5 percent.

Continuity Equation

When water flows in a pipe, it moves at a certain speed or velocity. The velocity of flow through pipes changes with the pipe diameter. For a fixed rate of flow through pipes of different diameters, the velocity will be greatest in the smallest diameter.

The "Equation of Continuity" relates the quantity of water (Q) flowing through a pipe with the velocity (V) and the pipe's cross-sectional area (A). Algebraically, this can be written as

$$\mathrm{Q} = \mathrm{V} \times \mathrm{A} \qquad \text{where } \mathrm{Q} = \text{rate of flow } (\mathrm{ft}^3/\mathrm{sec})$$

A = cross-sectional area of the pipe (ft^2)
V = velocity of flow (ft/sec)

Example: What is the velocity of water through a 12-inch main when the rate of flow (Q) is 3.0 million gallons per day?

Solution: Convert (Q) in million gallons per day to cubic feet per second ($\mathrm{ft}^3/\mathrm{sec}$) and calculate (A).

$$\mathrm{Q} = \frac{3.0\ \cancel{\text{million gallons}}}{1\ \cancel{\text{day}}} \times \frac{1\ \cancel{\text{day}}}{86{,}400\ \text{sec}} \times \frac{1{,}000{,}000}{\cancel{\text{million}}} \times \frac{1\ \mathrm{ft}^3}{7.48\ \cancel{\text{gal}}} = 4.36\ \mathrm{ft}^3/\mathrm{sec}$$

$$\mathrm{A} = \frac{\pi(\text{diameter}^2)}{4} \times \frac{3.14\ (1\ \mathrm{ft}^2)}{4} = 0.785\ \mathrm{ft}^2$$

$$\text{If } \mathrm{Q} = \mathrm{VA}, \text{ then } \frac{\mathrm{Q}}{\mathrm{A}} = \mathrm{V}$$

$$\text{Therefore:} \quad \frac{4.63\ \cancel{\mathrm{ft}^3}/\mathrm{sec}}{0.785\ \cancel{\mathrm{ft}^2}} = \mathrm{V} = 5.9\ \mathrm{ft}/\mathrm{sec}$$

SAMPLE PROBLEMS

(3) An 8-inch diameter water main is flowing full at a velocity of 2 feet per second. What is the flow rate of the water in the pipe in cubic feet per second? in gallons per minute?

Answer _____ cfs Answer ____ gpm

(4) If the same main was flowing at 1 fps, what would the flow rate be?

Answer _____ cfs Answer _____ gpm

(5) What diameter main should be installed to provide 500 gpm at a velocity of 1.4 fps?

Answer _____ inches

ANSWERS TO CHAPTER 8 SAMPLE PROBLEMS

(1) $\frac{150\ \cancel{\text{ft}}}{1} \times \frac{1\ \text{psi}}{2.31\ \cancel{\text{ft}}} = 65\ \text{psi}$

(2) $\frac{16\ \cancel{\text{psi}}}{1} \times \frac{2.31\ \text{ft}}{1\ \cancel{\text{psi}}} = 37\ \text{ft}$

(3) $\text{Q} = \text{V} \times \text{A}$

$$\text{A} = 0.785\ \text{d}^2 \quad \text{V} = 2\ \frac{\text{ft}}{\text{sec}}$$

$$\text{A} = 0.785(0.67^2) = 0.35\ \text{ft}^2$$

$$\text{Q} = 2\frac{\text{ft}}{\text{sec}} \times 0.35\text{ft}^2 = 0.7\ \text{cfs}$$

$$\frac{0.7\ \cancel{\text{ft}^3}}{1\ \cancel{\text{sec}}} \times \frac{7.48\ \text{gal}}{1\ \cancel{\text{ft}^3}} \times \frac{60\ \cancel{\text{sec}}}{1\ \text{min}} = 314\ \text{gpm}$$

(4) $\mathrm{Q = V \times A}$

$$\mathrm{A = 0.35\ ft^2} \qquad \mathrm{V = \frac{1\ ft}{sec}}$$

$$\frac{0.35\ \cancel{\mathrm{ft^3}}}{1\ \cancel{\mathrm{sec}}} \times \frac{7.48\ \mathrm{gal}}{1\ \cancel{\mathrm{ft^3}}} \times \frac{60\ \cancel{\mathrm{sec}}}{1\ \mathrm{min}} = 157\ \mathrm{gpm}$$

(5) $\frac{\mathrm{Q}}{\mathrm{A}} = \mathrm{V} \qquad \mathrm{V = \frac{1.4\ ft}{sec}} \qquad \mathrm{Q = \frac{500\ gal}{min}}$

$$\frac{500\ \cancel{\mathrm{gal}}}{1\ \cancel{\mathrm{min}}} \times \frac{1\ \cancel{\mathrm{min}}}{60\ \mathrm{sec}} \times \frac{1\ \mathrm{ft^3}}{7.48\ \cancel{\mathrm{gal}}} = 1.11\,\frac{\cancel{\mathrm{ft^3}}}{sec}$$

$$\frac{1.11\ \mathrm{ft^3}}{1\ \cancel{\mathrm{sec}}} \times \frac{1\ \cancel{\mathrm{sec}}}{1.4\ \cancel{\mathrm{ft}}} = 0.79\ \mathrm{ft^2}$$

$$\mathrm{A = 0.785(d^2) = 0.79\ ft^2} \qquad \frac{0.785(\mathrm{d^2})}{0.785} = \frac{0.79\ \mathrm{ft^2}}{0.785}$$

$$\mathrm{d^2 = \sqrt{1}\ ft^2} \qquad \mathrm{d = 1\ ft} \qquad \mathrm{1\ ft = 12\ in}$$

CHAPTER 9 – Water Distribution System

Water distribution systems are comprised of transmission and distribution mains, valves, hydrants, water storage tanks, service leads, and meters in many types and sizes. Other specialized appurtenances may include pressure reducing/sustaining valves, air relief valves, or automatic flushers. It is the engineer's responsibility to assure the system is designed to provide optimum domestic service and fire protection. It is the water system operator's responsibility to assure the distribution system is adequately maintained and a safe, continuous supply of water is available to the public. These responsibilities overlap. Both the engineer and the system operator need a working knowledge of engineering design considerations and practical aspects of operating and maintaining a water supply distribution system. In this Chapter, distribution system considerations will be covered including features, performance, and types of water main, plus water main installation.

Basic Engineering Design Considerations

Water supply distribution systems can generally be classified as grid systems, branching systems, or combinations thereof. The grid or looped system, although requiring more water main, is preferred because water can be provided from two directions and the water is usually circulated throughout the system. This helps reduce the number of dead ends in the system, as well as reduce the service area that is without pressure during repairs.

In designing a water distribution system, the engineer must consider hydraulic constraints such as the source and location of supply, available storage volumes and locations, anticipated peak demand and fire flow needs throughout the system, elevation differences, service areas, and potential expansion of the system.

Consideration must also be given to the design for any proximity of the water system to potential sources of contamination (sewers, underground fuel storage tanks, etc.).

Cost considerations for the design include initial construction costs, operational and maintenance expenses, and system longevity. The cost of constructing, operating, and maintaining a distribution system depends primarily on the size and type of water main utilized.

The completed plans and specifications for a distribution system construction project should follow the recommendations for sewer separation, valve and hydrant spacing, etc., as referenced in the distribution portion of *"Recommended Standards for Water Works"*, prepared by the Great Lakes – Upper Mississippi River Board of State and Provincial Public Health and Environmental Managers.

WATER MAIN MATERIALS

The types of water main generally in use today include cast iron, ductile iron, asbestos cement, plastic, steel, and concrete. These types of pipes have characteristics which make them either acceptable or unacceptable for specific applications. Factors which favor the use of one pipe material over another include pipe strength, performance characteristics, corrosion resistance, and material and installation costs.

The strength of a pipe is based on its ability to withstand applied internal and external forces. Internal forces include normal working system pressures and pressure surges due to water demand fluctuations. Perhaps the most devastating internal force, water hammer, is usually attributable to control problems such as closing valves and hydrants too quickly or starting pumps too rapidly. The *bursting strength* refers to the pipe's ability to withstand these internal forces.

External forces imposed upon a pipe include traffic loads and shifting earth forces. These forces can be increased appreciably by poor pipe bedding and improper installation. The external strengths of a pipe are referred to as its *crushing strength*.

The pressure rating of a particular pipe refers to its maximum working pressure. Pressure ratings take into account the internal or bursting strength with a safety factor of 2.0 to 3.5. Common pressure ratings include 100, 150, 200, and 250 psi.

When selecting pipe material, some important considerations are its weight with regard to installation costs, compatibility with the existing system and equipment, types of joints available, availability of pipe and its various sizes, depth of bury required to prevent freezing, the ability of its lining or coating to withstand corrosion and not react with the water, corrosion resistance to prevent electrolytic decomposition, longevity of the pipe, and repair costs.

Table 9.1 Pipe Types and Classifications

Type of Pipe	Common Size Range (inches)	Common Classes ANSI/AWWA	Description of Classification Method
Cast iron (CI)	3-48	20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30	Classification is based upon wall thickness. The required wall thickness is calculated by considering several factors, including iron strength, wearing factors, external loading, internal loadings.
Ductile Iron (DI)	3-54	50, 51, 52, 53, 54, 55, 56	Classification is based upon wall thickness. The wall thickness is calculated by considering several factors including wearing factors, external loadings, internal loadings.
Asbestos Cement (AC)	4-16, 18-42	100, 150, 200, 30, 35, 40, 45, 60, 70, 80, 90	Classification is based upon pressure ratings and external loading factors.
Concrete	24-144	Not applicable	Pipe is specially manufactured for each project according to designer's specifications. Many manufacturers have their own standard classes.
Steel	6-30	A, B, C, D, E, 42, 45, 50, 52 (For steel quality)	Pipe is specially manufactured for each project according to designer's steel thickness and quality specifications. Many manufacturers have their own standard classes.
Plastic (PVC) (CPVC) (PE)	1.5-12	80-200	Based upon pressure ratings. Other factors that must be considered are the type of materials used and the standard dimension ration. (SDR)
Copper	1.5-2.5	L, K	Classification is based upon wall thickness.

The following outline lists pipe material types and inherent advantages and disadvantages of each.

Figure 9.2 Advantages and Disadvantages of Pipe Material Types

A.	Grey Cast Iron Pipe 1. Manufactured by centrifugal casting process using either sand-lined or metal molds. 2. Interior linings available include bituminous materials, cement mortar, epoxy. 3. Exterior linings consist of bituminous, coal tar or fiberglass materials. 4. Joints available are: flanged with rubber gaskets, mechanical, flexible (ball and socket), push on, bell and spigot. 5. Advantages - high bursting and crushing strength; long life; taps easily. 6. Disadvantages - higher installation costs; reacts with aggressive soils and water
B.	Ductile Iron Pipe 1. Cast centrifugally in metal molds. 2. Linings or coatings usually not necessary. 3. Advantages - conductive; easy to install and tap; corrosion resistant; high smoothness or "C" factor. 4. Disadvantages - not as strong as cast iron; higher installation costs.
C.	Plastic Pipe 1. Polyvinyl chloride (PVC) and chlorinated polyvinyl chloride (CPVC) thermoplastic pressure pipe is acceptable for water main construction in PWSs subject to the following criteria: a) Class 150 to 200 or greater (do not confuse with pressure rating). b) Standard dimension ratio (SDR) 18 to 13.5 or less (criteria based on a safety factor of 2.5 plus 35 psi surge allowance). c) Meets AWWA Specification C900. d) Compound designation class No. 12454. e) Pipe and fittings must bear the National Sanitation Seal of Approval (NSF-pw) for potable water. Pipe should also carry appropriate identification code. f) Joints must be ball and spigot with elastomeric rubber gasket. g) Acceptance of thermo plastic pressure pipe is optional with water utility. 2. Advantages - Smooth interior surface (high "C" factor); lightweight, flexible to a degree, corrosion resistant; should provide long service life. 3. Disadvantages - nonconductive, requires a tracing wire, requires careful bedding and backfilling.
D.	Steel Pipe 1. Pipe fabricated of steel plates either riveted or electronically welded together. 2. Requires protective coatings and linings usually of bituminous material, cement mortar or epoxy. 3. Advantages - Strong, rigid construction ideal for above ground installations. 4. Disadvantages - does not readily resist high external pressures; corrodes readily; must be handled carefully to prevent cracking of liner; lower service life.
E.	Asbestos Cement Pipe 1. Made of asbestos for strength, silica sand as a filler, and cement as a binder. Heat applied by water (water cured) or steam (autoclaved) to develop strength of cement. 2. Linings or coatings usually not necessary. 3. Advantages - lightweight; easy to install and tap; corrosion resistant; high smoothness or "C" factor. 4. Disadvantages - not as strong as cast iron; requires careful handling and bedding; nonconductive; deteriorates with aggressive water, requires a tracing wire.

F.	Concrete Pipe 1. Types classified by method of reinforcement. a) cylinder b) prestressed c) pretensioned 2. Advantages - strong; durable; easily installed; provides sustained carrying capacity. 3. Disadvantages - heavy; difficult to tap.
G.	Service Piping Materials 1. Copper - strong; electrically conductive. 2. Plastic - inexpensive; easy to work with; nonconductive. 3. Galvanized - strong; corrodes readily. 4. Lead - no longer allowed on new installation or replacements.

WATER MAIN INSTALLATION

Installing water main involves a number of phases during construction, each of which is an integral part of a properly constructed and easily maintainable water supply distribution system. Trench excavation and backfilling, pipe handling and laying, valve and hydrant installation, and thrust or reaction blocking must all be done correctly to assure a reliable water distribution system.

Pressure testing, flushing, disinfection, and sampling of newly installed water mains are important procedures to follow to assure a water main has been correctly installed and does not pose a problem when connected to the existing distribution system. Excessive leakage and poorly installed water mains create a headache for the operator and unnecessary maintenance and water production costs for the utility. Contaminated water from a new section of water main can affect the entire distribution system and pose a public health hazard to all customers.

Hydrostatic or pressure testing is done to ensure that the water main has been installed correctly. The pressure test is usually followed by the leakage test. The pressure and leakage tests are conducted at a minimum of 150 psi. The allowable leakage is noted in the project's engineering specifications.

When ductile iron water main is specified for a project, an electrical continuity check is sometimes performed to assure continuity and repair of breaks. This test is conducted prior to backfilling over the exposed joints.

The cleaning or flushing and disinfection of water main should follow State of Michigan guidelines. The water main should be flushed in approximately 1,000-foot intervals at a minimum velocity of 2.5 feet per second until the water runs clear. Sufficient chlorine should be applied for a 25-ppm chlorine residual and allowed to remain in the water main for 24 hours.

Methods of chlorinating a water main include the universally accepted continuous flow method, the slug flow method, and the tablet method. In the continuous flow method, water from an approved source is channeled to flow into the new line at a constant rate, while chlorine is applied at a measured rate. The chlorine is usually applied with a chemical feed pump. Slug chlorination is used for large transmission mains of appreciable length and involves pumping a slug of highly chlorinated water (100 ppm free chlorine) through the water main. For the tablet method, solid calcium hypochlorite tablets are affixed to the interior of water main during installation. This method is only suitable for short sections of small diameter water main and is generally discouraged because the main cannot be flushed prior to chlorination.

After the chlorine has been applied, a chlorine residual analysis should be conducted to make certain an adequate chlorine residual exists. After 24 hours the chlorine should be flushed from the new main and two consecutive bacteriological samples collected, 24 hours apart.

Since chlorine is a strong chemical oxidizing agent, care must be taken to make sure the chlorine flushed from the new main is not discharged directly to a surface water where it could endanger aquatic life. The preferred methods for disposing of a high strength chlorine solution are chemical reduction prior to discharge, discharge to a ditch a sufficient distance from a surface water course to allow the chlorine to dissipate, or dike and contain the solution until the chlorine dissipates.

Water Main Installation Procedures

Engineering Considerations

Minimum diameter should be 6 inches. Water main should be separated from storm and sanitary sewers by 10 feet in parallel installations and 18 inches in crossings (water main should be higher). Maintaining local positioning protocol should be followed whenever possible.

Excavation and Preparation of Trench

General: Before digging, call MISS DIG 811 or 800-482-7171 to make sure all underground utilities are marked. The trench should be excavated to the required alignment and depth as called for in the plans. Trenches should not be opened too far in advance of the pipe laying. All trenches five feet deep or greater should be shored unless cut back at an appropriate angle. Excavated materials must be stored a safe distance from trench.

Width: The trench width at the surface will depend on the type of soil encountered and trench depth. The minimum clearance should be 18 inches from the centerline of the pipe or 1 foot greater than the outside diameter of the barrel, whichever is greater.

Foundation: The pipe should be laid on stable soil. If stable soil conditions are not encountered, an additional depth should be excavated and backfilled with crushed stone or other suitable material.

Rock Excavation: When rock is encountered, trenches should be excavated an extra 6 inches and tamped to grade with a good bedding material such as sand or good soil.

Dewatering: Water should be kept out of the trench to make for safer working conditions and to keep the pipe as clean as possible when installing.

Handling and Laying Pipe

Inspection: All pipe should be inspected for damage and defects upon receiving the shipment from the supplier and before being lowered into the trench.

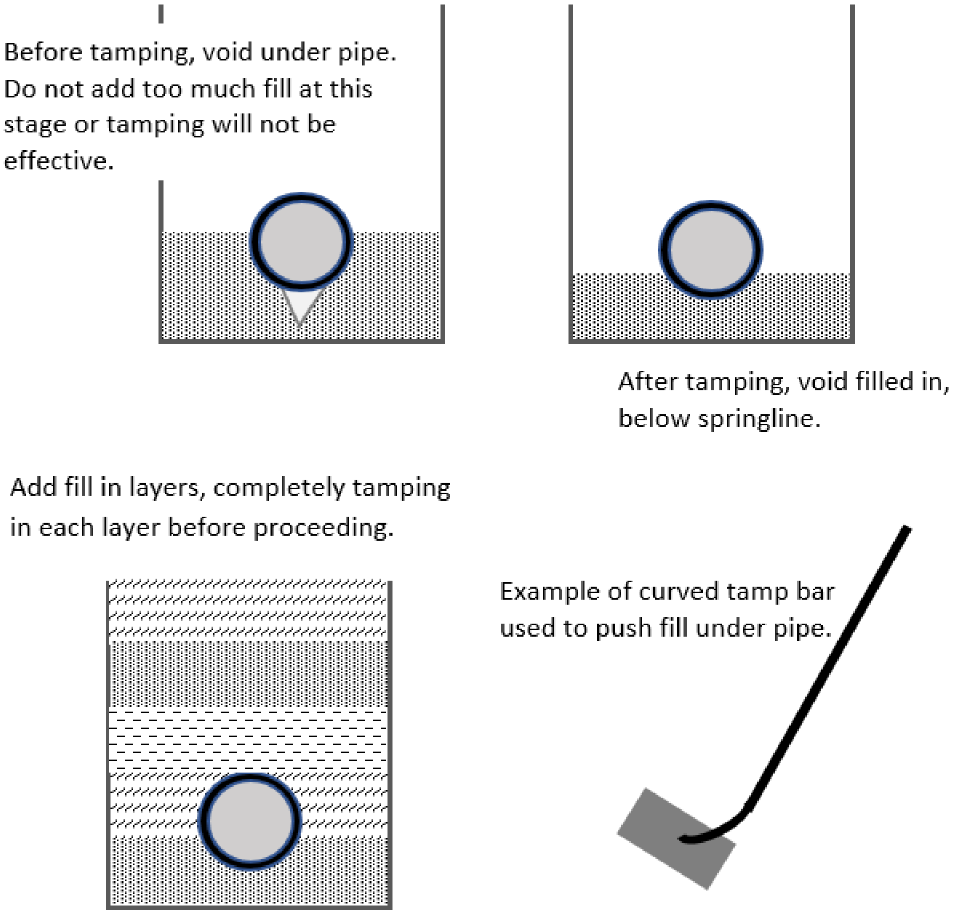
Handling: Care must be taken when unloading, storing, and handling pipe to assure it does not become damaged prior to installation. Cold weather and sunlight can also affect certain pipe materials, thus certain storage and handling precautions should be taken.

Cleaning: Each end of the pipe should be brushed and cleaned, and the pipe swabbed with a hypochlorite solution prior to being lowered into place.

Laying: Make sure that debris does not accumulate in the ends to be joined. As the pipe is laid in the trench, the bell end should face in the direction of laying except on downhill slopes where the bell faces uphill. Here, the spigot should be centered in the bell and the pipe forced home. The barrel of the pipe should lie directly on the bottom of the trench and the trench excavated a few additional inches in depth at the joints of the pipe. The pipe should then be aligned and secured in place with approved backfill material tamped under it as soon as possible. Pipe ends should be plugged when working in ground water and at the end of each working day. Be sure that the pipe gaskets are not rolled while installing.

Initial Backfilling: Backfilling should be accomplished in stages. The soil should first be tamped tightly around the bottom and up to the springline (halfway up the side of the pipe) with a curved tamping bar. Continue adding fill in approximately 4-inch layers until compacted dirt covers the pipe by at least 12 inches of well compacted material, except at joints and fittings, which should be left clear.

Figure 9.3 Backfilling



Before tamping, void under pipe. Do not add too much fill at this stage or tamping will not be effective.

After tamping, void filled in, below springline.

Add fill in layers, completely tamping in each layer before proceeding.

Example of curved tamp bar used to push fill under pipe.

Fire Hydrant and Valve Installation

Fire hydrant leads must be a minimum of 6 inches in diameter with an auxiliary valve installed. Weep holes or hydrant drains must be plugged in high-water table conditions. A combination thrust block and foundation anchor the hydrant against frost heave and the forces generated by moving water during the hydrant's use. Mega-lug systems may also be used if specified and appropriate for conditions. Hydrant spacing is recommended at 350 to 600 feet depending upon the area being served.

Valves should be located from 500 to 800 feet apart depending on the service area. Transmission main valves can be set at greater distances. The valves should be anchored in place in high pressure areas and can be operated either through a valve box or valve well for larger valves.

Thrust Blocking

General: Thrust blocking is required to resist static pressure forces and dynamic forces generated by moving water as it changes direction and/or speed.

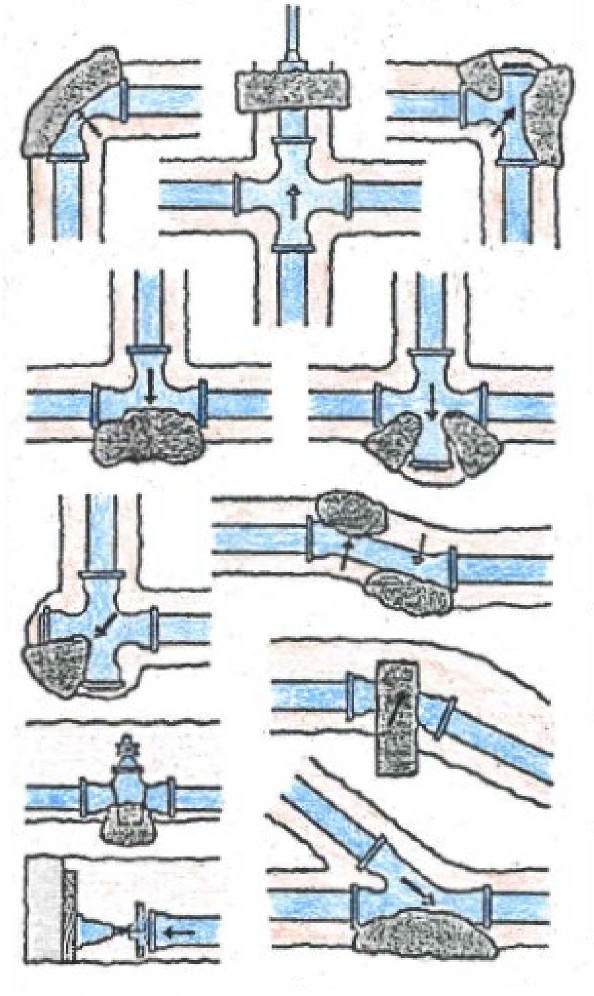
Where Required: Blocking is required at all tees, elbows, wyes, caps, valves, hydrants, bends, and reducers.

Size: In most cases the size will be specified by an engineer, but it will depend on pipe size, maximum flow and line pressure, type of fitting, degree of bend, and type of soil.

Material: Concrete to have a 28-day compressive strength of 2,000 psi.

Construction: Thrust blocks should be poured against undisturbed earth and placed so the bearing surface is in direct line with the major force created. Do not encase joints in concrete. Steel straps may be necessary to hold the pipe or valve to the thrust block.

Figure 9.4 Thrust Blocking Illustrations



Hydrostatic Testing

General: Ideally, tests will be made in 1,000-foot sections or less. This is especially important at the start of a job to give all concerned a check on the initial installations and to allow for early corrections of faulty installation procedures. At least 24 hours should be allowed for curing of thrust blocks. End caps should be temporarily blocked to undisturbed soil.

Pressure Test

Filling and Air Venting: Filling is normally done through the connection at the existing system. The new main must be filled slowly to prevent damage. Air vents should be provided at high points in the new main and left open during filling. Corporation stops or automatic air relief valves can be used for this purpose. When all air is expelled the air vents should be closed; line pressure be brought up to normal operating pressure by an auxiliary pump and allowed to stand for 24 hours. This will cause remaining air to be absorbed by the water.

Test: The pressure in the main should be brought up to a pressure 1.5 times the normal operating pressure or 150 psi, whichever is greater, and held from 1 to 2 hours during which time the main and appurtenances will be inspected for visible leaks. Defects should be corrected.

Leakage Test

General: The leakage test should be run at the normal operating pressure to be expected at the particular location. Leakage allowance and testing methods are usually specified by the engineer or the community. A 55-gallon drum is a convenient calibration tank to pump from to determine leakage.

Test: The duration of each test should be two hours and amount of leakage is defined as the quantity of water that must be supplied to maintain the specified pressure once all air is expelled from the main and test pressure is originally obtained.

Allowable Leakage: (18-foot lengths)

Mechanical and push on joints

Old AWWA Standard (C600-77):

$$L = \frac{ND\sqrt{P}}{7{,}400}$$

New AWWA Standard (C600-17):

$$L = \frac{SD\sqrt{P}}{148{,}000}$$

Where: L = Allowable leakage (gph)
N = Number of joints in length tested
D = Nominal Diameter of Pipe (inch)
P = Average test pressure (psi)
S = Length of pipe tested (feet)

Coupling/Sleeve Joints

For the allowable leakage stated in the AWWA Standards, see Table 1 of C603-778. The following equation may be used to approximate the values found in the table. The equation derived from the table is based on 13 ft pipe lengths.

$$\mathrm{L} = \frac{\mathrm{ND}\sqrt{\mathrm{P}}}{3{,}994}$$

Final Backfill

General: Backfill around exposed joints and fittings should be carried out as outlined in "Initial Backfilling." Curved tampers should be used to compact the soil under the fittings. Tamping in 4-inch layers should proceed until the compacted soil above the joints is 12 inches deep.

Fill: Fill can be placed in the trench once the compacted depth is 12 inches above pipe and joints.

Consolidating: Consolidation of fill material can be performed by mechanical means or by water. Fill should be compacted to 90 percent density under sidewalks and roads or as other specified.

In addition to the standard installation procedures, several special construction techniques are utilized for installing water main. Bore and jack is typical for placing water main beneath highways and rail crossings. This procedure involves excavating where the crossing begins and ends, and then utilizing a specially braced machine, boring and correspondingly jacking steel casing beneath the roadway. After the casing is in place, the water main is slipped through, assuring careful bedding, and cemented in place at both ends.

Special construction techniques are also warranted for river crossings where ductile iron river crossing pipe is used. This pipe, with ball and socket joints, is used due to its inherent strength and the joints deflection capabilities. It is important that valves be available to isolate the crossing and also a corporation provided between the valves for periodic pressure testing and sampling this portion of main.

Disinfection of Water Mains

Before new water mains are placed in service, they must be cleaned, disinfected, and the water passing through them must show, by test, safe bacteriological results. Approved methods for accomplishing this follow:

1. Clean the interiors of all pipes by brushing, swabbing, or washing out all dirt and other foreign matter before laying. If necessary, use a mandrel to be drawn forward as each pipe is laid. Stop up all branches and other openings with wooden plugs or heads until either capped or connected.

2. Flush out the new water mains at a velocity greater than 2.5 fps until the water runs clear. This should be done after the pressure test and before disinfection. Each valved section of the newly laid pipe should be flushed separately with potable water from the public supply.

3. Disinfect the water mains with chlorine. The preferable point of application of the chlorinating agent is at the beginning of the water main's extension, or any valved section of it, and through a corporation cock inserted in the horizontal axis of the newly laid pipe. Water from the existing distribution system should be controlled to flow very slowly into the newly laid water mains during the application of chlorine. Partially open the end-most hydrant or valve on the section of water mains under treatment to permit the flow of water through the water main. Continue treatment until the water flowing from the far end of the main contains a chlorine residual of at least 25 ppm. Stop the flow of water and chlorine by closing appropriate openings, (See Sections 6 and 7 for information on chlorine products and methods of application). Use a field test kit to determine the chlorine residual. Testing the residual may require drop dilution method depending on the test kit and reagents.

4. Permit the treated water to remain in the water main for at least 24 hours and check for a free chlorine residual of at least 10 ppm. Following this period, the main should be thoroughly flushed until all the heavily chlorinated water is removed. Test water samples to see that this has been accomplished.

5. Collect water samples in sterile bottles containing sodium thiosulfate for bacteriological analysis from the end-most outlet of the water main. If the samples show safe results on consecutive samples collected 24 hours apart, the new water main may be placed in service. The second samples are not required on chlorination supplies having a chlorine residual in the new main or if permission is obtained from EGLE to omit them. If, however, the results are unsafe, a repetition of the chlorine treatment is necessary. Samples should never be collected from hoses or fire hydrants. A suggested sampling tap is a corporation cock with copper gooseneck assembly which may be removed after use. Samples must be taken every 1,200 feet of new main, and at the end of any branch greater than one pipe length.

6. Chlorine products for disinfecting water pipes are available in several forms. The most convenient forms are as follows:

> *Liquid chlorine* is available in 1-, 5-, 30-, and 55-gallon containers, at +/- 12.5 percent available chlorine.
>
> *High Test Calcium Hypochlorite* is a powder and is available in five-pound cans and 100-pound drums. The chlorine content is approximately 65 percent to 70 percent ("Perchloron" and "HTH" are commercial products).
>
> *Liquid Laundry Bleach* is available in pint, quart, and gallon bottles at most grocery stores. The chlorine content is usually 5¼ percent ("Clorox" and "Roman Cleanser" are commercial products). Do not use any bleach with additives, such as scent.

7. Liquid chlorine should be applied to water mains by means of a solution feed chlorinating device with a power operated booster pump. High test calcium hypochlorite or liquid laundry bleach must be prepared as a water mixture for introduction into the water mains. The powder should first be made into a paste and then thinned to about a 1 percent chlorine solution (10,000 ppm). The preparation of a 1 percent chlorine solution requires the following proportions of powder to water:

Table 9.5

Product	Amount of Compound	Gals. of Water
High test calcium hypochlorite 65% to 70%	1 lb.	7.50
Liquid laundry bleach 5¼%	1 gal.	4.25

Prepare the 1 percent chlorine solution in a container and permit solids to settle. Apply the clear supernatant solution to the main by pumping through a power operated chemical feeder.

The following table indicates the amount of chlorine required for each one hundred feet of various sized pipes:

Table 9.6

Size of Pipe	Vol Gallons in 100 ft of pipe	Amount of chlorine or Chlorine solution per 100 ft of main for 50 ppm	
		Chlorine 100%	1% Chlorine Water Solution
4”	65.3	0.027 lb	1/3 gal
6”	146.5	0.061 lb	3/4 gal
8”	261.0	0.108 lb	1-1/3 gal
10”	408.0	0.169 lb	2 gals
12”	588.7	0.240 lb	3 gals

8. The application of small amounts of dry calcium hypochlorite or chlorinated lime to each length of pipe as it is laid has proven ineffective for disinfection and is not recommended.

Emergency Repairs

A water main break or leak can pose a serious problem for a water supply system. Accordingly, all such problems should be considered emergencies and acted upon based on the degree of hazard or urgency involved for each specific incident.

All utilities should have an emergency preparedness or contingency plan to deal with such emergencies. The plan should denote standby personnel, materials, and equipment available to assist in any type of emergency which could affect your water supply.

A water main break or leak could seriously jeopardize a community's fire protection capabilities, present a public health hazard, and possibly cause excessive property damage.

Once a leak or break is detected, a repair should be attempted without depressurizing the system. If the leak or break is excessive, the valves on both sides of the main should be closed to minimize any inconveniences. The trench should be dewatered if necessary and a chlorine solution should be available to disinfect the repair clamps or pipe section. If the repair is considered major, the steps of pressure testing, flushing and disinfecting, and sampling (as with a new main) should be followed. Up to date maps and valve exercising records will help with making speedy repairs.

WATER MAIN APPURTENANCES

Valves

The following discussions on valves, joints and hydrants are referenced from pages IX-l to IX-13 in the "Water Distribution Operator Training Handbook,” AWWA.

Valves have various purposes in the water works industry such as flow control, isolation of breaks, air relief, prevention of flow reversal, etc. The type of valve used depends on its function in the system. Valves can be classed either by their mode of operation or by their intended use. The general modes of operation are:

Diaphragm valve - has a flexible piece inside the body of the valve that is adjusted up and down to regulate the flow, typically controlled by water pressure.

Globe valve - has a flat or tapered disc of rubber that is adjusted onto a seal to restrict flow. Needle valves are a type of globe valve.

Rotary valves - flow is restricted by the rotation of a piece within the valve. Some types of rotary valves are: ball valves, cone valves, plug valves, and butterfly valves. The ball valve consists of a sphere with a passageway in it which can be rotated to restrict flow. The cone valve and the plug valve are basically the same except instead of a sphere there is a cone or a cylinder that is rotated. The butterfly valve has a disc that is rotated to restrict flow.

Slide valves - these valves have discs that are raised or lowered to restrict flow. Examples of these are gate valves and sluice gates. The gate valve is one of the most commonly used valves in a water distribution system.

Special purpose valves - valves that are designed for a special use. Some examples are:

a. Pressure relief valves
b. Air-vacuum relief valves
c. Check valves (several types)
d. Reduced pressure principle backflow preventers
e. Air relief valves
f. Pressure reducing valves

The spacing of the valves on the distribution system should be such that water main breaks can be isolated with a minimum of system disruption. Valves in critical locations should be located in manholes. When operating some valves, care must be taken to prevent water hammer.

Joints

Water main joints are necessary since pieces of pipe have to be connected and still maintain the ability to withstand high water pressure. Desirable features in joint compounds and materials include: non-toxicity, elasticity, strength, durability, workability, availability, economy, and do not impart taste or odor to the water. Some of the typical joints are:

Flanged joints - the flanged ends are bolted together with a gasket in between. This makes a rigid joint, which is used in above ground piping.

Mechanical joint - consists of specially fabricated ends that bolt together through a retaining ring, compressing a gasket between the bell and spigot end of the pipe.

Bell and spigot - not commonly used on new installations since it requires caulking material. Joint is made by slipping the spigot end of the pipe into the bell end of the adjacent pipe, making contact at the base of the bell. Joint has some flexibility but does not withstand high tension very well.

Sleeved coupling - collar attached to one end of the pipe and the other pipe is pushed into this collar. Pipe is grooved and gasket in collar fills the groove on completion of the joint.

Push-on joint - most widely used and newest type of joint. Joint is made by pushing the spigot end into the bell end to the home line.

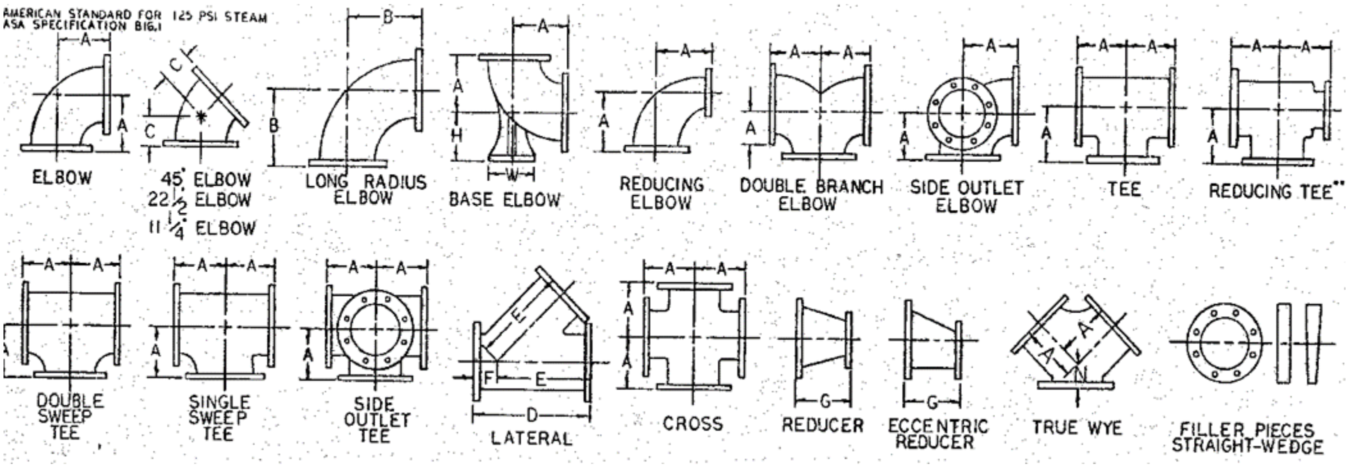
Ball and socket joint - special joint that allows some deflection. Normally used on river crossings and soil that is subject to movement.

Water Main Fittings Some typical water main fittings are:

1. Elbows (different angles)
2. Tees
3. Crosses
4. Reducers
5. Blank flanges
6. True Wye pieces
7. Etc…

Continue onto the next page for Figure 9.7 containing all water main fittings.

Figure 9.7 Examples of Water Main Fittings (Cast iron flanged)



<u>Fire Hydrants</u>

There are two basic types of fire hydrants, the dry barrel and the wet barrel. The dry barrel hydrant has a valve shut off at the base of the hydrant. The water in the hydrant can be pumped out of it or drained by gravity if there is a drain hole, after use. The wet barrel hydrant has the operating valve at the outlet of the hydrant and thus is subject to freezing. Only dry barrel hydrants are used in Michigan. All hydrants should have an isolating valve in case the hydrant is damaged, or the operating valve does not seal. The outlets on the hydrants are normally 2-1/2 and 4-1/2 inches in diameter. When ordering hydrants, the following information should be supplied:

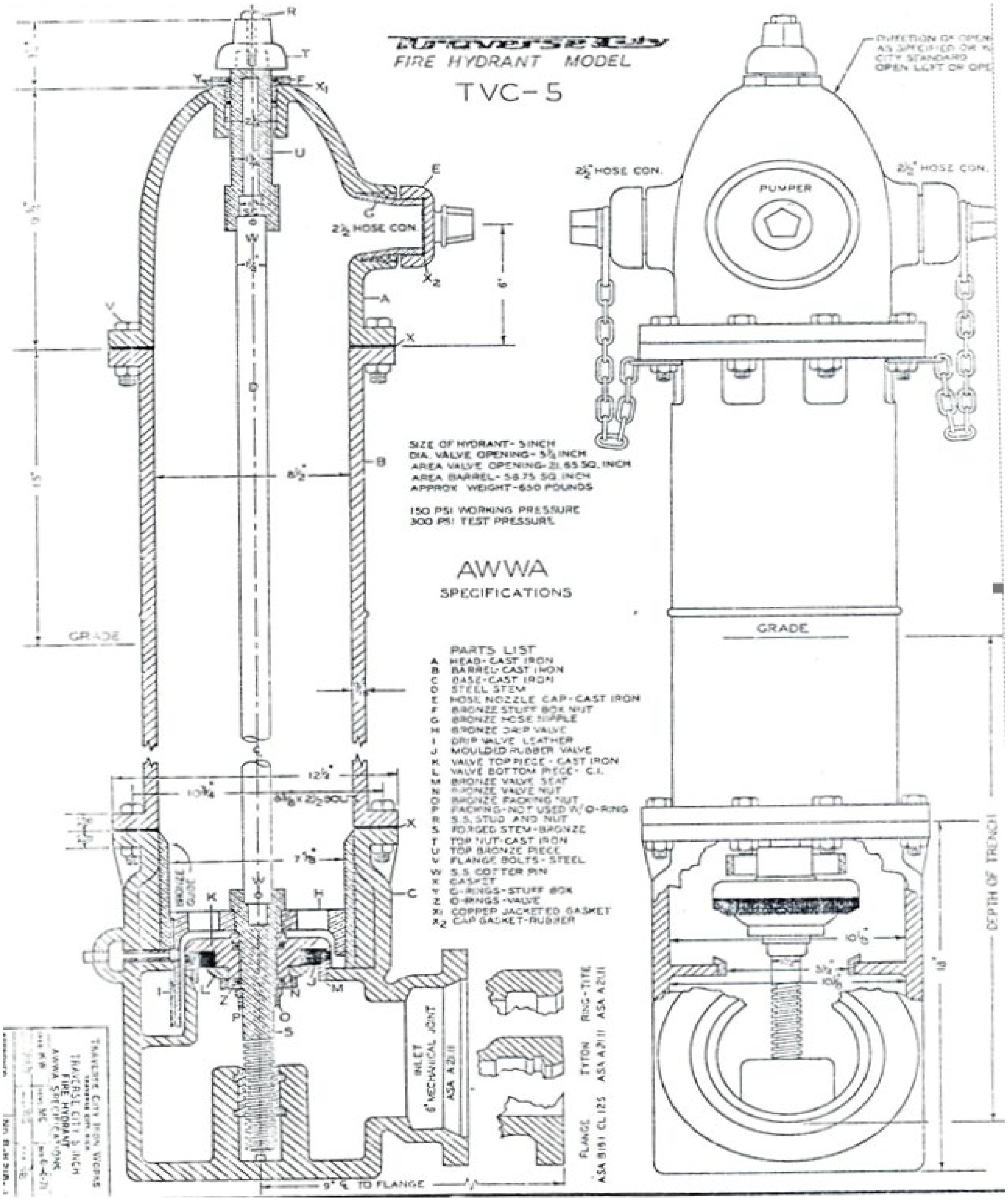
1. Size of hydrant
2. Size and style of bottom connection at inlet
3. Length in ground
4. Number and size of hose nozzles
5. Number and size of steamer nozzles
6. Size and form of nut to open hydrant
7. Gage of thread
8. Direction of opening

Vandalism of fire hydrants is common and must be guarded against. For example, an open hydrant near the base of a 100-foot-high elevated tank would discharge over 2,000 gpm. At this rate a 100,000-gallon tank could be drained in less than one hour.

<u>Blow Offs</u>

If possible, hydrants should be provided for flushing purposes instead of blow offs. A blow off serves only one purpose: flushing. It may be as expensive and more troublesome than installing the more versatile hydrant.

Figure 9.8 Typical Fire Hydrant Diagram



SIZE OF HYDRANT - 5 INCH
DIA. VALVE OPENING - 5¼ INCH
AREA VALVE OPENING - 21.65 SQ. INCH
AREA BARREL - 58.75 SQ. INCH
APPROX. WEIGHT - 650 POUNDS

150 PSI WORKING PRESSURE
300 PSI TEST PRESSURE

AWWA
SPECIFICATIONS

PARTS LIST

A	HEAD - CAST IRON
B	BARREL - CAST IRON
C	BASE - CAST IRON
D	STEEL STEM
E	HOSE NOZZLE CAP - CAST IRON
F	BRONZE STUFF BOX NUT
G	BRONZE HOSE NIPPLE
H	BRONZE DRIP VALVE
I	DRIP VALVE LEATHER
J	MOULDED RUBBER VALVE
K	VALVE TOP PIECE - CAST IRON
L	VALVE BOTTOM PIECE - C.I.
M	BRONZE VALVE SEAT
N	BRONZE VALVE NUT
O	BRONZE PACKING NUT
P	PACKING - NOT USED W/O-RING
R	S.S. STUD AND NUT
S	FORGED STEM - BRONZE
T	TOP NUT - CAST IRON
U	TOP BRONZE PIECE
V	FLANGE BOLTS - STEEL
W	S.S. COTTER PIN
X	GASKET
Y	O-RINGS - STUFF BOX
Z	O-RINGS - VALVE
X_1	COPPER JACKETED GASKET
X_2	CAP GASKET - RUBBER

TAPPING, SERVICE LINES, AND METERS

Service Taps

Dry tapping can be done with or without a service clamp (saddle). If a service clamp is used, attach it securely to the main after cleaning the section to be tapped. Thread the corporation into the service clamp (usually before tapping). Open the corporation valve, thread the drilling device onto the outlet side of the corporation valve, and drill out the hole.

Without a service clamp, the hole is drilled into the main. The threads are then tapped into the hole and the corporation stop is threaded into the main. Care must be taken when making the threads using this method or leaks could develop through the threads.

For wet tapping, the tap is made with pressure still on the main and a tapping machine is necessary. A tapping machine drills out the hole, taps it, and inserts the corporation into it. The tapping machine is strapped to the pipe, making sure the proper gaskets have been placed between the machine and the saddle, and the saddle and the main. Usually, a combination drill and tap are used. First the hole is drilled, then tapped. The tool is then removed from the pipe and the corporation stop is connected to the machine and threaded into the hole.

Large Wet Taps

Large size connections can be made to mains while under pressure using a tapping sleeve, valve, and tapping machine. The tapping sleeve usually has a flanged opening and is clamped to the main. When clamped to the main, it has the appearance of a tee. The tapping valve is then attached to the sleeve and the tapping machine is then attached to the valve. With the valve open, the drill is extended through it and a hole is drilled in the main while under pressure. When completed, the drill is pulled back through the valve, the valve is shut, and the tapping machine is removed from the system.

When making any of the taps, good sanitary procedures should be followed. When making dry taps, it is especially important to be careful since there is no pressure on the main to prevent contamination.

Service Lines

The two most commonly used materials for service lines are copper and plastic. Plastic is usually cheaper to use. They are much harder to trace underground. A trace wire is typically installed at the time of installation to make locating it easier. The service line must be installed at the proper depth to prevent freezing, especially under driveways, roads, and sidewalks where the snow is routinely removed. When connecting the service line to the corporation, a slight bend should be provided to allow for contraction of the service line. If not, the corporation could be pulled out of the main as it contracts due to the cold. When making this bend, care should be taken to not get it too high where it could be subject to freezing. Normally, try to keep it below or close to the top of the main. Try to avoid tapping the main at the top since the service line would then be much higher than the main.

Good safety practices should be followed when trenching and installing the service line, just as for water mains.

METERS

Types of Meters

Meters are necessary on water systems in order to distribute the charge for water. In systems that charge a "flat rate," water is often times wasted or the small user pays a disproportionate amount. Meters are also necessary to determine dosage rates when injecting chemicals into a water system and necessary for efficient water plant operation.

The most common meter is the water service meter, which is usually a displacement type meter. A displacement meter measures the rate of flow by recording the number of times a container of known volume is filled and emptied. The two common styles of displacement meters are the piston type and the nutating disc.

Oscillating piston meters measure water flow by filling and emptying a measuring chamber during each oscillation of the piston. Water inflow and water outflow occur simultaneously at each position of the piston.

Almost all of the home service meters are the *nutating disc type*. In this meter, a nutating disc revolves in a circular chamber. The water in the chamber is displaced once for each rotation and a spindle, which extends from the top of the disc, registers each rotation.

Turbine meters and propeller meters are velocity meters. The flow of water turns a rotor at a speed proportional to the water velocity. With the cross-section flow area of the meter known, the velocity can be related directly to the quantity of flow. These meters have small frictional loss and are used for measuring high flows. The multi-jet meters are small, velocity type meters which have been adapted for residential use.

Compound meters are a combination of high and low flow meters. The low flow meter is normally a nutating disc meter and the high flow meter is usually a turbine meter. These meters are necessary for situations that have highly fluctuating flows. The flow goes through the low flow meter until a transition point is reached when a valve opens, allowing flow through the high flow meter.

Mag meters direct flow through a magnetic field and induce a current proportional to the water flow. These meters are used for both large and small consumers. They are becoming more and more common. These types of meters offer no flow restrictions.

There are other flow measuring devices that work on flow restriction and head loss principles. Some of these include: venturi meters, orifice plates, flow nozzles, etc. Parshall flumes and weirs are used to measure open channel flow.

Meter Installation Practices

The choice of meter installed is dependent on several factors. These include the accuracy desired, durability, ease of repair, availability of spare parts, water quality/mineral content, reputation of the manufacturers, and cost. The most important factor, however, is usually the customer's expected demand and the size of service connection.

Some requirements that must be considered when installing a meter are:

- a) Upstream isolating valve must be provided.
- b) Meter must be installed in a horizontal position.
- c) The meter must be reasonably accessible for service.
- d) An easy method for reading the meter must be provided, either direct read or remote.
- e) Must be protected from freezing.
- f) Does not interfere with the customer's safety.
- g) Should be set to remain filled with water when operating.
- h) Some meters require runs of straight pipe before and after the meter.

Special fittings are available to make meter installations easier and to allow, in some cases, for vertical alignment. These fittings are called yokes. Meters may be installed either indoors or outside. If they are installed outside, provisions to prevent freezing must be provided, usually through placement in a meter pit. Outside remote readers, with the meter located within the building, have proven very efficient.

Meter testing and maintenance is discussed on pages X-14 to X-22 of "Water Distribution Operator Training Handbook," AWWA.

CHAPTER 10 – System Operation, Maintenance, and Special Problems

A water supply's distribution system represents a considerable community investment which must be operated and maintained in a professional manner to provide the best possible protection of the public's health, safety, and welfare. Day-to-day operation of the distribution system normally involves sampling, connecting services, repairing leaks, reading meters, and addressing customer complaints. An ideally operated distribution system also involves recordkeeping and maintenance programs. Maintenance of a distribution system should include not only the routine, daily functions but also a preventative maintenance program of valve turning, hydrant inspection, and system flushing.

Records

The water utility's knowledge and record of every part of a water supply's distribution system is essential to properly maintain the system. Experience has shown that poor records result in "lost" valves, closed or partly closed valves, duplicated valves, or similar costly and detrimental effects of carelessness and forgetfulness. Good records discourage liability suits, help maintain good public relations, and, most importantly, provide the basis for sound system operation. It is important to follow update schedules contained with the documents to ensure accuracy with the current state of the system.

Records of importance include: maps of the entire distribution system depicting size, type, and perhaps installation date of water main and valve and hydrant locations. Individual valve and hydrant records should also be kept as should records of samples, flushing procedures, meters, curb stops, and system repairs.

Valve Maintenance

Valves are provided in a distribution system principally to isolate small areas for emergency repair. As a result, valves suffer from lack of operation rather than from wear. There are no hard and fast rules regarding how often to run tests on these but the corrosiveness of the water, the rate of disposition of sand or other solids, and the sizes and location of the valves all have a bearing on the desirable frequency of operation. Generally speaking, valves should be operated at least once a year. Some important procedures should be followed:

1. The location and measurements to recorded reference points should be checked.
2. Valves should be operated in both directions, fully closed and fully opened, and the number of turns and direction of operation should be noted. Identify valves that operate in the opposite direction to that which is standard for the system.
3. Valves should be left in open position and any valves required to be closed should be carefully noted.

4. Badly corroded valves should be operated several times and, if necessary, flushed to clean valve seats.
5. The condition of the valve packing, stem, stem nut, and gearing should be noted.
6. Valve boxes or vaults should be checked, cleaned out, raised, lowered, or replaced as required.

Keep a record of the location, type, size, make and time of installation and whenever possible operate the valves just before flushing and during flushing to remove any debris that may have been knocked loose.

Fire Hydrants

The advantages of periodic hydrant inspections have long been recognized by water utility officials, distribution personnel, hydrant manufacturers, and the Insurance Services Office. Planned inspections and operation of hydrants keeps them clean and operable, extends their life, and pinpoints problems, allowing time for repair or replacement. Proper inspection of a fire hydrant is critical since failure of a hydrant to operate when needed presents a severe system liability. Fire hydrant inspections can be conducted concurrently with a flushing program providing two-fold benefits. The following inspection procedure is outlined in more detail in AWWA Manual M17, Fire Hydrants - Installation, Operation and Maintenance:

1. The hydrant should be sounded for leaks.
2. It should be operated and flushed, the ease or difficulty of operation noted, and any worn or loose parts remedied.
3. The condition of the drain valve, if applicable, operating nut, nozzles, nozzle caps, chains, packing, and paint should be noted.
4. After operation and closure, the interior should be observed to see if the barrel is drained properly.
5. The setting of the hydrant and the distance of the nozzles from the ground and curb line should be noted and remedied if not acceptable.
6. The hydrant should be lubricated.
7. The accessibility of the hydrant, ground clearance, and interference from poles or other objects should be noted and corrected if necessary.

Frequent painting of fire hydrants is an excellent public relations tool, as hydrants are in sight of the general public and should, therefore, create a favorable impression.

Fire hydrants in Michigan need to be pumped down in the fall to prevent freezing during the winter months. Weep holes are to be plugged unless the hydrants have gone through an exception process with the State of Michigan. Weep holes in areas with high water tables pose a risk for cross contamination to the potable water system.

You may also wish to color-code the hydrants as to the size and quantity of fire protection water available. This can be done in conjunction with neighboring communities to assure the firefighters of a consistent practice.

Main Flushing

In most distribution systems, it is necessary to clean out sand, turbidity deposits, and similar substances that settle out in the pipes when the velocity of flow is not sufficient to keep them in suspension. A good flushing at high velocities twice a year usually removes a major part of such settlement. If flushing has not been at sufficiently close intervals, more intensive methods may become necessary and at a much greater cost.

In iron pipes, tubercles and deposits produced by the corrosive action of water on the bare metal of pipes may require another type of cleaning. These deposits may combine with the chemical compounds of the water to nearly fill the pipe.

The growth of iron bacteria or slimes may also be found and must be periodically eliminated by flushing. These may be found in stubs to fire hydrants and dead ends where chlorine residual is not present.

This is also the time to check and inspect fire hydrants. Hydrants are particularly vulnerable to damage and failure because they are exposed. Again, they should be checked and operated twice a year and should become part of the flushing program.

Flushing is usually done in spring and fall or, if only once, in the fall just before the leaves begin to drop. Leaves block storm drains and water may cause a hazard to traffic and pedestrians. After flushing you have time for necessary maintenance before cold weather. This is also a period of low water consumption leaving more water available for flushing. This should also be scheduled with the water plant staff to assure an adequate supply of water.

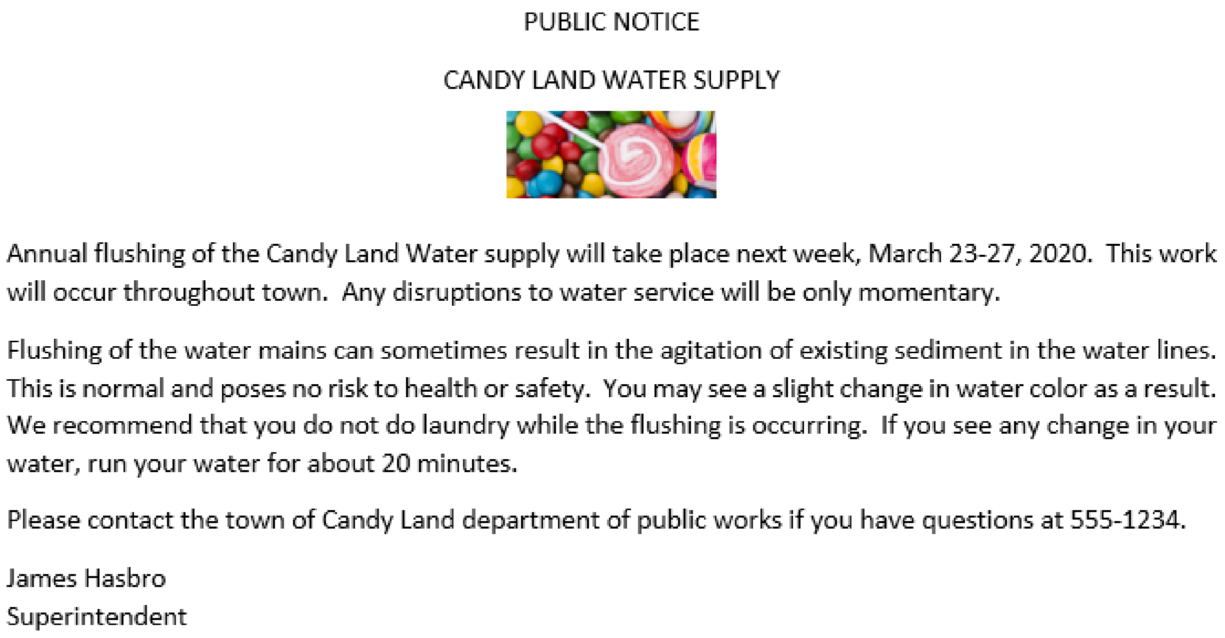
How flushing is conducted is a very important question. Each system is different, but some things to take into consideration are:

1. A map showing main sizes and hydrant and valve locations.
2. Location of source of supply (plant or reservoir), usually the plant, as you will need all the velocity to move sediment.
3. Where to start should be from source to extremities and may be determined by a careful study of the system. Determine the flow of water through the system as you flush. Being sure to isolate mains by turning off valves allows for greater directional flow scouring pipe better with high velocities.
4. Flushing crews, if more than one, have to be coordinated to keep sediment moving.

After careful thought, list the hydrants as you plan to use them and begin keeping a record of flow time from each hydrant. The next time you flush, you will have the record of the previous time. From this, determine if you may have to flush more or less often or change procedure.

Notify the consumers, by an ad in the local paper, by newsletter, by tv announcements, or other means, when you will be doing the flushing. It is good public relations and to help inform the public and prevent future problems.

Figure 10.8 Sample Flushing Notice



PUBLIC NOTICE

CANDY LAND WATER SUPPLY

Annual flushing of the Candy Land Water supply will take place next week, March 23-27, 2020. This work will occur throughout town. Any disruptions to water service will be only momentary.

Flushing of the water mains can sometimes result in the agitation of existing sediment in the water lines. This is normal and poses no risk to health or safety. You may see a slight change in water color as a result. We recommend that you do not do laundry while the flushing is occurring. If you see any change in your water, run your water for about 20 minutes.

Please contact the town of Candy Land department of public works if you have questions at 555-1234.

James Hasbro
Superintendent

Special Distribution System Problems

Problems related to operating a water supply distribution system are probably infinite in number and unique for each individual system or portions thereof. Most problems can be resolved through the efforts of effective system operation or eliminated with an ongoing maintenance program. Problems of special concern to water utility personnel involve customer water quality complaints which cannot always be readily resolved. These problems typically include red or dirty water complaints along with taste and odor problems.

Red or rusty water indicates the presence of iron in the water supply. The iron may have originated from the water source or from old cast iron mains. One can readily determine the source of iron by comparing the iron concentration of the water source with that throughout the distribution system.

Iron that is present in ground water is generally in the dissolved or ferrous state (Fe^{2+}), which will not cause discoloration. However, when exposed to air or another source of oxidation, the ferrous iron readily is oxidized to the ferric state (Fe^{3+}). It is the ferric state of iron which creates red water and stains fixtures.

Iron may impart a disagreeable metallic taste to water or a taste that is often times referred to as “old oaken bucket” or “swampy.” It also may affect the flavor of tea and coffee giving them an unappetizing, inky-black appearance. In addition, insoluble or ferric iron makes water turbid.

There are certain species of bacteria that thrive on dissolved compounds containing iron. These bacteria include Leptothrix, Crenothrix, Spirothyllum, and Gallionella. These organisms utilize dissolved iron and deposit ferric hydroxide which contributes to red water problems. These types of bacteria form grayish-black gelatinous masses in both wells and distribution mains and can decrease their capacities accordingly. They often times slough-off, appearing as a mass of slime and may impart peculiar odors as they anaerobically decompose.

Iron can also be dissolved by sulfate reducing bacteria which, under certain conditions, produce an insoluble ferric sulfate. Sulfate reducing bacteria may also cause the precipitation of iron by the production of ferric sulfide from the reduction of sulfate. In addition, these bacteria affect the aerobic corrosion of iron. These bacteria, along with iron bacteria, represent more of a nuisance than a public health concern.

The recommended limit for iron in a water supply distribution system is 0.3 milligrams per liter (mg/L) based on the above aesthetic concerns. Iron bacteria will survive, however, in iron concentrations as low as 0.1 mg/L.

Control of iron and its related problems in a water supply can be achieved by a variety of means depending on the iron’s source. If excessive iron concentrations are evident in the source of the supply, an iron removal water treatment plant could be the solution. Chlorination alone or along with phosphate treatment may resolve iron problems in the distribution system.

Manganese behaves similar to iron in water systems creating discoloration and related problems. Manganese is not as prevalent as iron; therefore, its problems are not as apparent. It is recommended for aesthetic reasons that the combined concentrations of manganese and iron be below 0.3 mg/L.

Corrosion may also be considered a cause of red water complaints for a water supply distribution system. Corrosion may not only present customer complaints, but it could also significantly affect the longevity of the system and perhaps pose problems impacting public health. Corrosion of water mains and appurtenances may be due to aggressive water, corrosive soil conditions, or bimetallic, galvanic corrosion.

Corrosive water is due to low pH and unstable chemical constituents. A softened water is typically referred to as aggressive due to an imbalance of dissolved solids, calcium, and alkalinity. Corrosion inside a water main is almost always chemical or electrochemical in nature. Hot water tends to accelerate corrosion due to the high temperature and may present problems with domestic water heaters. Aggressive waters may be treated by adjusting the pH or through the use of stabilizing compounds. Corrosion may also be prevented by utilizing inert pipe materials or interior coatings.

Corrosive soil, ground water, and stray electrical currents may corrode pipe exteriors. Galvanic action, as well as chemical reactions, may result from various types of soil and ground water when they are brought into contact or proximity with the pipes' exterior. Stray electrical currents passing back and forth between the pipe and the surrounding soil have similar detrimental effects. Corrective measures for these conditions include replacing the pipe with an inert material; coating or wrapping the pipe with a chemically inert material or with a material which will insulate electrically; or using cathodic protection or sacrificial anodes. In some areas, improper grounding of appliances on water pipe may cause the pipe to deteriorate where the current leaves the pipe. Galvanic action set up by the use of different metals attached to each other, such as a copper pipe directly threaded to a steel pipe, are inherent weak spots for a distribution system. In many instances, a useful life of 20 years for two separate metals is shortened to three or four years by a direct connection between them. An insulating gasket and insulation bolts or a fitting of dielectric material will prevent the galvanic action.

Because of the potential problems associated with corrosion, particularly the deterioration of the pipe interior and joints, the USEPA has promulgated regulations governing corrosive waters. These regulations are based on possible health implications for consumers who may ingest lead, cadmium, and similar toxic materials originating from distribution systems.

Gases originating from the source of supply or from the distribution system also pose problems for the distribution system operator. Hydrogen sulfide, methane, and our most abundant combination of gases and air can each create peculiar problems.

Hydrogen sulfide is objectionable due to its rotten egg odor which is typically detectable in concentrations above 0.1 mg/L. This gas can be removed through aeration at the source of supply or controlled at lower concentrations by chlorination.

Methane gas is produced from certain geologic formations in Michigan and is soluble in ground water. This colorless, odorless gas is released from water at atmospheric pressures; upon mixing with air, it could create an explosive atmosphere.

Air (a combination of gases, including nitrogen, oxygen, etc.) can create a variety of problems for a water supply. Air is typically introduced to the ground water supply from wells equipped with line shaft turbine pumps. An air-vacuum relief valve on the pump discharge usually bleeds off most of the air; however, air can still enter the system. Entrained air may result in cloudy water complaints which remedy themselves after letting the water set for several minutes. Corrosion within the distribution system may also be accelerated due to a higher concentration of dissolved oxygen in the water.

Excessive air in a water distribution system can accumulate in the system's higher elevations and create an air lock, prohibiting the flow of water. Air locks can be prevented with automatic or manual air relief valves.

In addition to the above-mentioned problems, operators of distribution systems whose source of supply is surface water may receive additional complaints. Surface water supplies are known to contain a variety of organic compounds and microscopic plant life. These organic compounds and plankton or algae impart taste and odor problems which can only be effectively remedied at the water treatment plant. Taste and odor problems for these types of water supplies have been known to increase with time as the water flows through the distribution system.

PART III

CHAPTER 11 – Fluoridation

In the early 1900s, it was noted that dental patients in Colorado Springs had a brown stain on their teeth and these same people also had fewer dental cavities. By 1931, it was determined that the cause of this phenomenon was excess concentrations of naturally occurring fluoride (2 to 13 mg/L) in the drinking water. It was later determined that there was an optimum fluoride concentration at which staining would not occur and yet still provide protection against cavities.

In 1945, controlled fluoridation studies were started in Grand Rapids, Michigan, and Newburgh, New York. Fluoride was added to the water supplies of these two communities and the rate of dental cavities was compared to nearby communities. Results indicated a 60 percent reduction in dental cavities in children who drank fluoridated water compared to children in the nonfluoridated control communities. These results led to the promotion and widespread use of water fluoridation as an important public health measure.

In Michigan, optimally fluoridated water must have a daily tracking range of 0.60 mg/L to 1.0 mg/L with the recommended level being 0.70 mg/L. Currently, approximately 360 community water supplies in Michigan fluoridate their water. Another 100 supplies have enough fluoride occurring naturally that adjustments are not necessary. These 460 supplies serve more than 90 percent of the total population served by PWSs and nearly 70 percent of the total state population.

The maximum contaminant level (MCL) for fluoride has been set by the USEPA at 4.0 mg/L. Exposure to fluoride concentrations above 4.0 mg/L can cause dental fluorosis, white spots, and staining (also known as mottling) on the teeth in children under six years of age. Long-term high-level exposure can lead to skeletal fluorosis and stiffness and pain in the joints in adults. Accidental ingestion of toxic overdoses generally causes vomiting, stomach cramps, and diarrhea. Fatal doses range from 4 to 5 grams, which is about 2,000 times the amount of fluoride swallowed by a person from a water supply.

Benefits

When fluoridated water is ingested, the fluoride ion seeks out and is deposited in the bone structure of the body. About 20 percent of the fluoride is incorporated onto the tooth surface while drinking the water. Most of the remaining fluoride passes through the stomach and is distributed throughout the skeletal structure, including the teeth. Incorporation of fluoride is most rapid during the time of a child's formation and growth. This time period is roughly from the fourth month of pregnancy to the tenth year. The presence of fluoride makes the tooth more resistant to acids which cause tooth decay. There is also some evidence to show that higher levels of fluoride strengthen the bones of older people, thus reducing the incidence of bone fractures.

Fluoride Chemicals

Fluorine, a gaseous halogen, is the thirteenth most abundant element found in the earth's crust. It is never found in its free state in nature but is always in combination with other elements as fluoride compounds. These compounds include fluorspar, apatite, and cryolite. Due to its abundance in nature, fluoride is found naturally in all waters. Concentrations will, of course, vary depending on the quantity of fluoride containing minerals in the area. The deeper the ground water, the greater the concentration of fluoride in the water.

The most commonly used compounds to fluoridate water are sodium fluoride, sodium fluorosilicate (formerly known as sodium silicofluoride), and fluorosilicic acid (formerly known as hydrofluosilicic acid).

Sodium Fluorosilicate (Na_2SiF_6): A white, odorless crystalline powder. A compound of pure (100 percent) sodium fluorosilicate contains 60.6 percent actual fluoride. Commercially, the compound is typically 98 percent pure and contains 59.4 percent actual fluoride.

Sodium Fluoride (NaF): A white, odorless compound available as a powder or in the form of crystals. A compound of pure (100 percent) sodium fluoride contains 45.2 percent actual fluoride. Commercially, the compound is typically 98 percent pure and contains 44.2 percent actual fluoride. It has a relatively constant solubility of 4 percent in water, which makes it especially suitable for use with a saturator feed system.

Fluorosilicic Acid (H_2SiF_6): A straw-colored, transparent, corrosive liquid having a pungent odor. A 100 percent solution of fluorosilicic acid will contain 79.1 percent actual fluoride. However, the acid is usually sold at 25-30 percent strength. Therefore, a 25 percent acid would contain 19.8 percent actual fluoride.

Example: How many gallons of 25 percent fluorosilicic acid will be required to apply 1.0 ppm of fluoride to 1 million gallons of water? Assume that 1 gallon of acid weighs 10.4 pounds.

Solution: Determine how many pounds of pure fluoride are needed.

$$\text{ppm} = \frac{\text{lbs of fluoride}}{\text{million lbs of water}}$$

$$\frac{1\text{ M-}\cancel{\text{gal}}\text{ of water}}{1} \times \frac{8.34\text{ lbs}}{1\ \cancel{\text{gal}}} = 8.34\text{ M lbs water}$$

$$1.0 \text{ ppm} = \frac{\text{x lbs of fluoride}}{\text{8.34 Mlbs water}} = 8.34 \text{ lbs fluoride}$$

Now convert from pounds of pure chemical to pounds of chemical compound (fluorosilicic acid solution):

$$8.34 \text{ lbs fluoride} \times \frac{\text{1 lb fluorosilicic acid}}{\text{0.198 fluoride}}$$

$$= 42.1 \text{ lbs gals of solution}$$

Answer needs to be in gallons, so convert:

$$42.1\ \cancel{\text{lbs}} \times \frac{\text{1 gal fluorosilicic acid}}{10.4\ \cancel{\text{lbs}}} = 4 \text{ gallons fluorosilicic acid}$$

Example: How many gallons of 25% fluorosilicic acid will be required to apply 1.0 ppm of fluoride to 1 million gallons of water if the natural fluoride concentration is 0.3 mg/L?

Solution: Determine how many pounds of pure fluoride are needed.

$$\text{ppm} = \frac{\text{lbs of fluoride}}{\text{million lbs of water}}$$

$$\text{million lbs of water} = \frac{\text{8.34 lbs}}{\text{gal}} = 8.34 \text{ Mlbs water}$$

$$\text{ppm} = 1 \text{ ppm} - 0.3 \text{ ppm} = 0.7 \text{ ppm}$$

$$0.7 \text{ ppm} = \frac{\text{x lbs fluoride}}{\text{8.34 Mlbs water}} = 5.84 \text{ lbs fluoride}$$

Now convert from pounds of pure chemical to pounds of chemical compound (fluorosilicic acid solution):

$$5.84\ \cancel{\text{lbs fluoride}} \times \frac{\text{1 lb fluorosilicic acid}}{0.198\ \cancel{\text{lbs fluoride}}} = 29.5 \text{ lbs of 25\% fluorosilicic acid}$$

Answer needs to be in gallons, so convert:

$$29.5\ \cancel{\text{lbs}} \times \frac{1\ \text{lb fluorosilicic acid}}{10.4\ \cancel{\text{lbs}}} = 2.8\ \text{gallons fluorosilicic acid}$$

SAMPLE PROBLEMS

(1) How many gallons of 25% fluorosilicic acid (10.4 lbs/gal) is required (19.8% actual fluoride), if the average pumping rate is 400 gpm for 4 hours, the natural fluoride concentration is 0.4 mg/L, and the final desired concentration is 1.0 mg/L?

(2) How many gallons of 25% fluorosilicic acid (10.4 lbs/gal) (19.8% actual fluoride) will be required for a period of 30 days if the average daily pumping rate is 700 gpm, the natural fluoride concentration of 0.45 mg/L, and the fluoride concentration desired is 0.95 mg/L?

(3) Sodium fluoride is sometimes applied by means of a saturator. In this treatment, excess sodium fluoride is added to the solution container, and is applied as a 4% solution (maximum solubility). The amount of fluoride used can be determined by measuring the number of gallons of the 4% solution used in a given period of time. If a city pumps 480,000 gallons of water per day, and 26.4 gallons of 4% sodium fluoride solution was used, what was the fluoride dose? Assume the weight of the 4% solution is 8.4 pounds per gallon. Sodium fluoride is 45.2% pure.

<u>Chemical Feed Equipment</u>

There are essentially three methods used for feeding fluoride to a water supply system.

- Volumetric or Gravimetric Dry Chemical Feeders.
- Liquid Acid Feed.
- Upflow Saturator and Liquid Chemical Feed.

Volumetric or Gravimetric Dry Chemical Feeders: The amount of dry chemical compound (usually sodium fluorosilicate) can be measured with a machine, then added to a solution tank where it is thoroughly mixed and then delivered to the main flow of water. Two types of feeders are used for this. A volumetric feeder (Figure 11.1) which delivers a certain volume of chemical over time, and a gravimetric feeder (Figure 11.2) which delivers a certain weight of chemical over time. These types of feed systems are bulky and relatively expensive and are therefore best suited for large water systems.

Figure 11.1 Volumetric Feeder

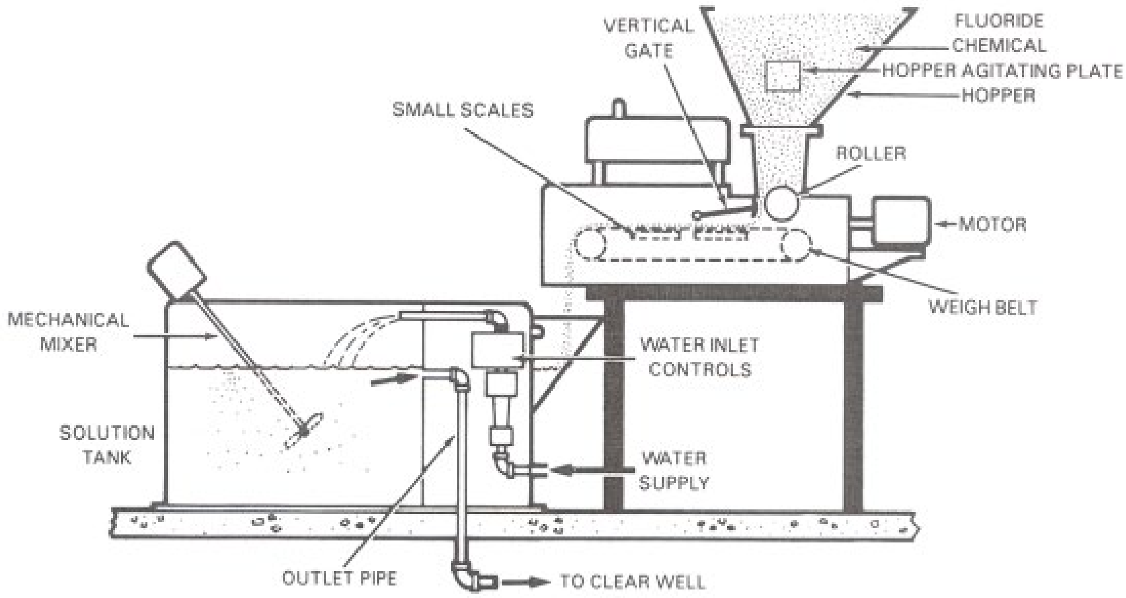
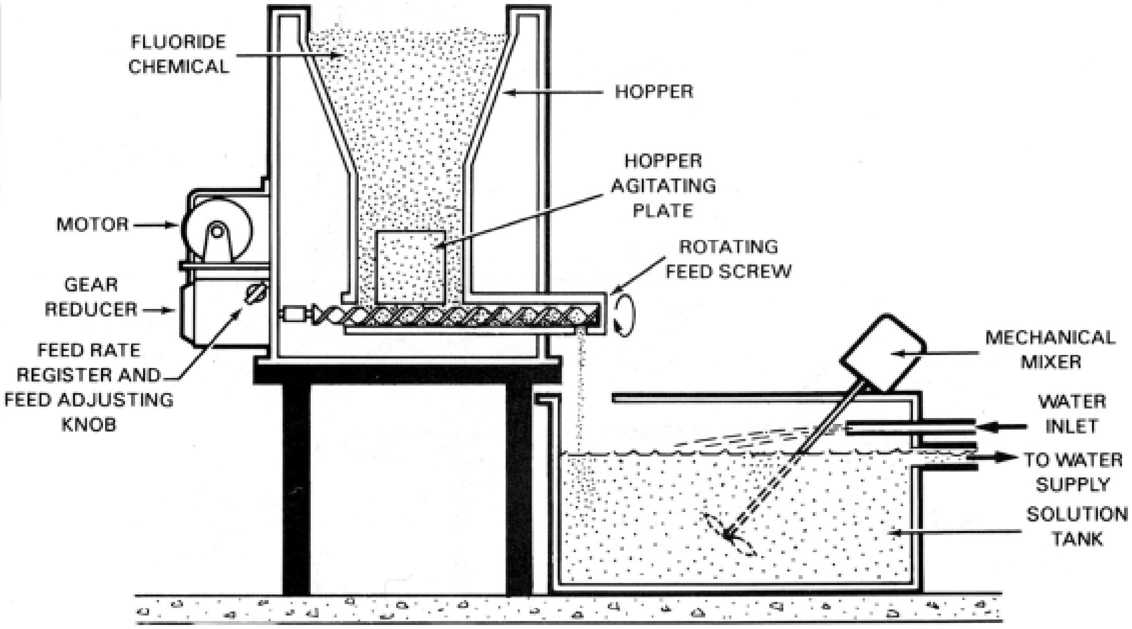


Figure 11.2 Gravimetric Feeder



Acid Feed by Positive Displacement Pump: A small pump can be used to add solutions of fluorosilicic acid directly to the water supply system. Typically, a positive displacement pump is utilized to pump the acid out of a carboy or day tank, to the water system. The carboy sets on a scale, which measures the amount of chemical used. A typical installation is illustrated in Figure 11.3. In the past, due to the size of pumps available, it was often necessary for the smaller water systems to dilute the fluorosilicic acid in order to add the small amount of fluoride desired. However, the electronic pumps available today, as shown in Figure 11.4, can accurately feed small amounts of chemical, making dilution unnecessary. Dilution should be avoided to reduce possible errors and for safety reasons.

Figure 11.3

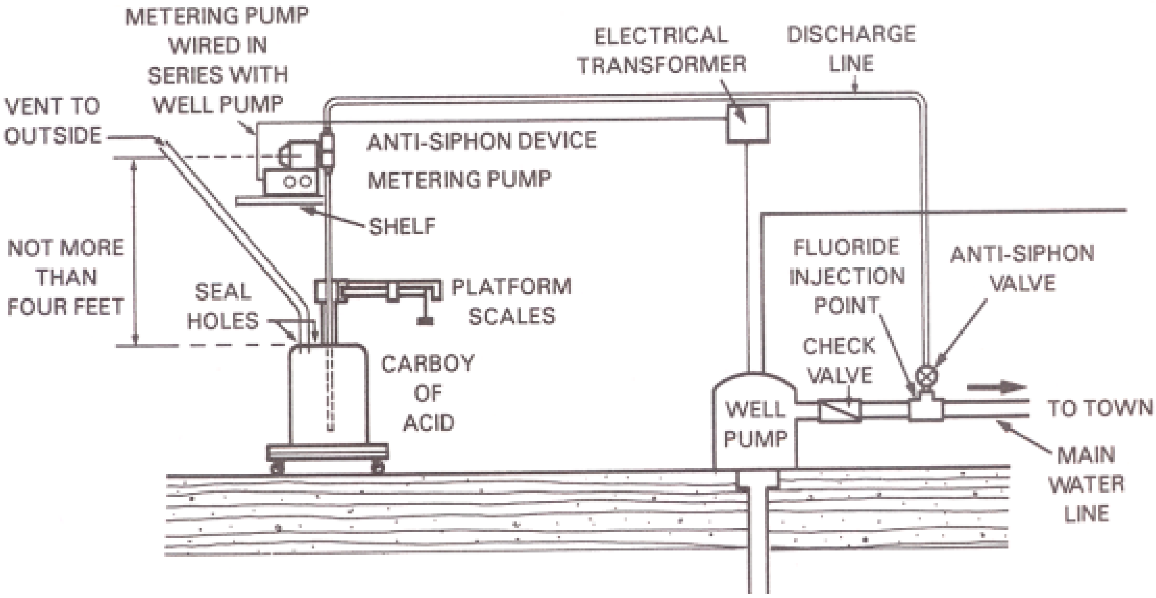
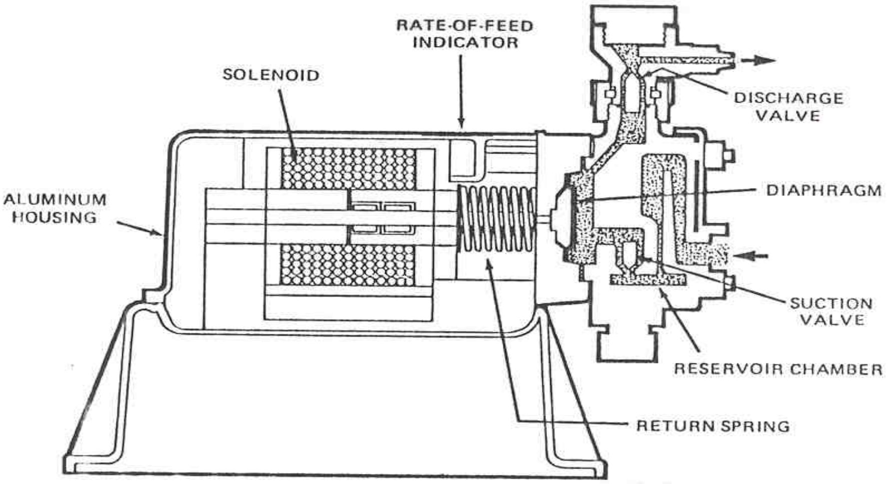


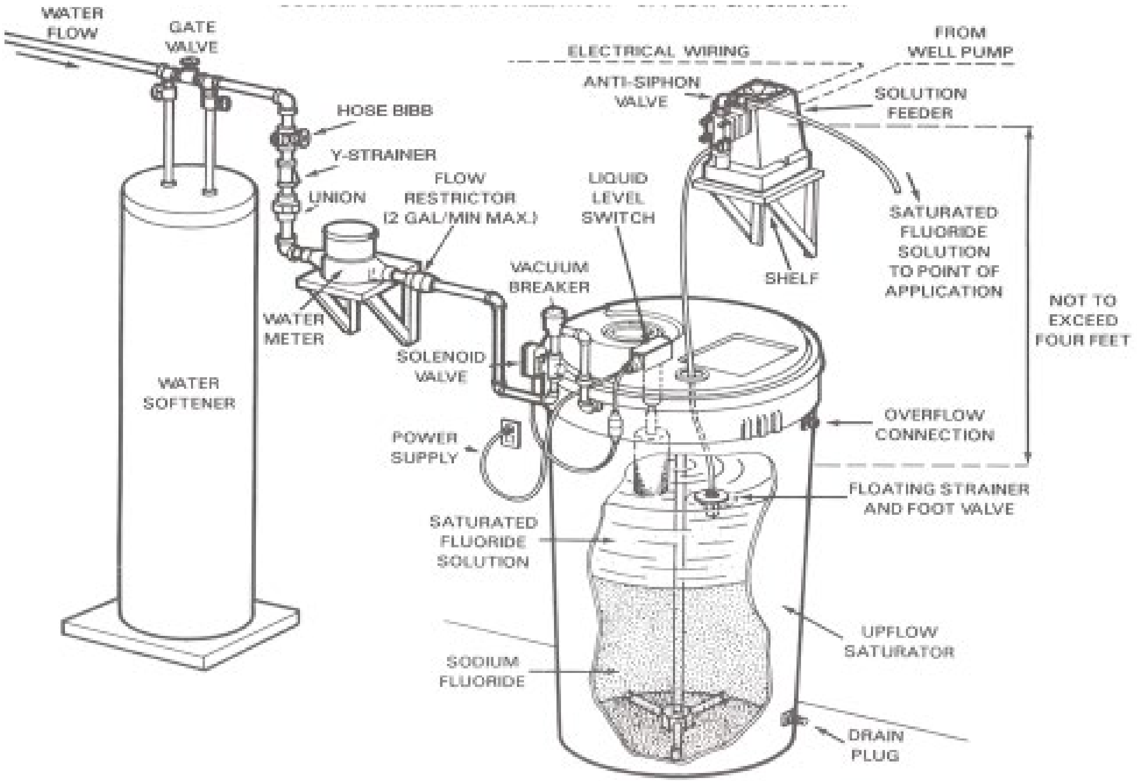
Figure 11.4



"Water Treatment Plant Operation, Volume II"
"Chapter 13, Fluoridation", page 33
California State University, Sacramento

Saturated Solution Feed by Upflow Saturator: Saturated solutions of sodium fluoride, in constant strengths of 4% (18,000 ppm of fluoride), can be produced in a saturator tank, and then pumped with a small solution feeder to the main flow of water. The saturator is essentially a tank of sodium fluoride which is allowed to dissolve in make-up water. The dissolved (saturated) solution is then fed to the water supply. The make-up water to the solution tank should be softened to minimize calcium deposition. A small meter on the make-up line is also necessary to measure the amount of solution used. This type of system is very easy to operate since it eliminates the need for weighing sodium fluoride, measuring solution water volume, and stirring to ensure dissolving. A typical upflow saturator installation is illustrated in Figure 11.5.

Figure 11.5



Fluoride Testing

There are essentially two methods available for measuring the amount of fluoride in the water: the SPADNS method and the electrode method.

In the SPADNS method, a dye is added to the water, which turns the sample red. Any fluoride present in the water decreases the intensity of the color. This color change is barely discernible by the human eye; therefore, it must be measured with a spectrophotometer. The fluoride concentration is determined from the spectrophotometer reading and a standard fluoride curve. It is very important in this test to hold the time and temperature constant for the fluoride testing and development of the standard curve. Also, there are several substances, including chloride, iron, sulfate, aluminum, color, turbidity, etc., which interfere with this test. If these interfering substances fluctuate widely, as in surface water systems, specific procedures must be followed to minimize the interfering effects.

In the electrode method, a fluoride electrode is utilized which contains a crystal doped with fluoride ions. When placed in a sample of water, a voltage potential is developed which is proportional to the difference between the fluoride concentration inside the electrode and that outside the electrode in the water sample. This voltage potential is then measured with a specific ion electrode which has been calibrated with known fluoride standards. This method is less susceptible to interfering substances than the SPADNS method. In addition, once set up, the electrode method is quicker, particularly when several measurements are necessary.

Frequent testing is necessary to adequately monitor your chemical treatment system. The primary purpose is to confirm that the correct amount of chemical is being added. For this purpose, the monitoring schedule described in Table 11.6 should be followed by groundwater supplies.

Table 11.6

LOCATION	FREQUENCY
Raw	Monthly
Plant Tap	Daily
Distribution	Weekly

Systems that add fluoride have to report level on the Monthly Operation Reports.

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"Water Fluoridation - A Manual for Engineers and Technicians," U.S. Department of Health and Human Services.

"Water Fluoridation Principles and Practices," (AWWA Manual M4), American Water Works Association.

"Water Treatment Plant Operation, Volume II," California Department of Health Services, Sanitary Engineering Branch, and U.S. EPA, Office of Drinking Water.

ANSWERS TO CHAPTER 11 SAMPLE PROBLEMS

(1) $\frac{400\text{ gal}}{1\ \cancel{\text{min}}} \times \frac{60\ \cancel{\text{min}}}{1\ \cancel{\text{hr}}} \times 4\ \cancel{\text{hrs}} = 96{,}000\text{ gal water}$

$$96{,}000\ \cancel{\text{gallons}}\text{ water} \times \frac{8.34\text{ lbs}}{\cancel{1\text{ gal}}} = 800{,}640\text{ lbs of water}$$

$$800{,}640\text{ lbs water} \div 1{,}000{,}000 = 0.80\text{ M lbs water}$$

$$1\ \text{mg/L} - 0.4\ \text{mg/L} = 0.6\ \text{mg/L of fluoride needed}$$

$$\text{ppm} = \text{mg/L so } 0.6\ \text{mg/L} = 0.6\text{ ppm}$$

$$0.6\text{ ppm} = \frac{\text{lbs of fluoride}}{0.80\text{ M lbs of water}} = 0.6 \times 0.80 = 0.48\text{ lbs fluoride}$$

$$0.48\ \cancel{\text{lbs fluoride}} \times \frac{1\text{ lb fluorosilicic acid}}{0.198\text{ lbs }\cancel{\text{fluoride}}} = 2.43\text{ lbs of acid}$$

$$2.43\ \cancel{\text{lbs}} \times \frac{1\text{ gal fluorosilicic acid}}{10.4\ \cancel{\text{lbs}}} = 0.28\text{ gal acid}$$

(2) $\frac{700\text{ gal}}{1\ \cancel{\text{min}}} \times \frac{60\ \cancel{\text{min}}}{1\ \cancel{\text{hr}}} \times \frac{24\ \cancel{\text{hrs}}}{1\ \cancel{\text{day}}} \times 30\ \cancel{\text{days}} = 30{,}240{,}000\text{ gal water}$

$$30{,}240{,}000\ \cancel{\text{gal}} \times \frac{8.34\text{ lbs}}{1\ \cancel{\text{gal}}} = 252{,}201{,}600\text{ lbs water} \div 1{,}000{,}000$$
$$= 252.2\text{ M lbs water}$$

$$0.95\ \text{mg/L} - 0.45\ \text{mg/L} = 0.5\ \text{mg/L of fluoride needed}$$

$$0.5\text{ ppm} \times \frac{\text{x lbs of fluoride}}{252.2\text{ M lbs of water}} = 126.1\text{ lbs fluoride}$$

$$126.1\ \cancel{\text{lbs fluoride}} \times \frac{1\text{ lb fluorosilicic acid}}{0.198\ \cancel{\text{lbs fluoride}}} = 637\text{ lbs of acid}$$

$$637\ \cancel{\text{lbs}}\text{ of acid}\times\frac{1\text{ gal fluorosilicic acid}}{10.4\ \cancel{\text{lbs}}}=61.25\text{ gal fluorosilicic acid}$$

(3) $\frac{480{,}000\text{ gal}}{1}\times\frac{8.34\text{ lbs}}{1\text{ gal}}=4{,}003{,}200\text{ lbs of water }\div 1{,}000{,}000=$
$4.003\text{ M Lbs of water}$

$$\frac{26.4\text{ gal of NaF solution}}{1}\times\frac{8.4\text{ lbs of NaF}}{1\text{ gal of NaF}}=221.76\text{ lbs of NaF}$$

$$\text{Lbs of fluoride}=0.04\text{ dilution factor x }.452\text{ purity x }221.76\text{ lbs of NaF}$$
$$=4.01\text{ lbs of Fluoride}$$

$$?\text{ ppm }=\frac{4.01\text{lbs of fluoride}}{4.003\text{ M lbs of water}}=1\text{ ppm of fluoride}$$

CHAPTER 12 – Phosphate/Corrosion Control

Phosphate Treatment

Orthophosphate and polyphosphate are general terms used to denote numerous types of phosphate compounds used in water treatment. In the water treatment industry, polyphosphate is mainly used for controlling iron and manganese problems, for the stabilization of lime-soda softened water, and for boiler feed water stocks. Polyphosphates are polymers made up of linked orthophosphate molecules, which can break its bonds and separate into orthophosphate molecules. Orthophosphate is mainly used for controlling lead and copper corrosion. It should be noted that phosphate is only effective with certain water characteristics and under certain conditions.

Phosphate, when used to control iron problems, has a higher polyphosphate concentration and is added at a concentration of approximately 2 to 4 ppm for each ppm of iron. However, when the iron concentration exceeds the 1.0 ppm range, polyphosphate addition will normally not effectively control iron problems.

Polyphosphate combines with or sequesters dissolved iron and keeps it in solution. It does not remove iron from solution, like ion exchange or aeration, nor does it combine with precipitated ferric iron. The sequestering action of phosphate with iron will be less effective with an increase in time or temperature.

Phosphate can be applied to water by various types of chemical feed pumps, which need to operate when the well pump operates. It should be applied ahead of aeration or chlorination since the phosphate must be introduced before oxidation of the iron occurs. As much time as possible should be allowed to ensure that the phosphate has sufficient time to react with the iron before the other treatment processes are employed. Since phosphate is a nutrient for bacteria, chlorination must also be practiced when phosphate is used.

There are many products marketed under various concentrations and trade names that contain phosphates. Some of these products were only intended to be used for industrial application and may be toxic. Only approved nontoxic solutions may be used, and only at proper dosages. The dosage for water systems should always be kept below 10 ppm.

Example: A village has an average pumpage of 120,000 gallons per day and wishes to apply 4.0 ppm of polyphosphate to the water to control an iron problem. How many pounds of polyphosphate should be added each day?

Solution: Start with the basic equation.

$$\text{ppm} = \frac{\text{lbs of phosphate}}{\text{million lbs of water}}$$

then rearrange it to find the missing variable

$$\text{lbs of phosphate} = \text{ppm} \times \text{million lbs of water}$$

$$\frac{120{,}000\ \cancel{\text{gal}}}{1} \times \frac{8.34\ \text{lbs}}{1\ \cancel{\text{gal}}} = 1{,}000{,}800\ \text{lbs} = 1.0\ \text{million lbs water}$$

$$4.0\ \text{ppm} = \frac{\text{x lbs of phosphate}}{1\ \text{Mlbs of water}} = 4.0\ \text{ppm} \times 1\text{M lbs of water}$$
$$= 4.0\ \text{lbs of phosphate}$$

Example: Water is being pumped at a rate of 200 gallons per minute, and phosphate is added to it at a rate of 10.8 pounds per day. What is the rate of application in ppm?

Solution:

$$\text{ppm} = \frac{\text{lbs of phosphate}}{\text{million lbs of water}}$$

$$\frac{200\ \text{gal}}{1\ \cancel{\text{min}}} \times \frac{60\ \cancel{\text{min}}}{1\ \cancel{\text{hr}}} \times \frac{24\ \cancel{\text{hrs}}}{\text{day}} = 288{,}000\ \text{gal/day}$$

$$\frac{288{,}000\ \cancel{\text{gal}}}{1\ \text{day}} \times \frac{8.34\ \text{lbs}}{1\ \cancel{\text{gal}}}$$
$$= 2{,}401{,}920\ \text{lbs/day} \div 1{,}000{,}000 = 2.4\ \text{M lbs/day}$$

$$\text{ppm} = \frac{10.8\ \text{lbs phosphate}}{2.4\ \text{M lbs of water}}$$
$$\text{ppm} = 4.5$$

Example: Water is pumped at a rate of 350 gallons per minute, and a 1% stock solution of phosphate is used for an application of 2.0 ppm.

A. How many pounds of phosphate are used per day?

B. How many gallons of the stock solution are used per day?

Solution: A.

$$\text{ppm} = \frac{\text{lbs of phosphate}}{\text{million lbs of water}}$$

$$\text{lbs of phosphate} = \text{ppm} \times \text{million lbs of water}$$

$$\frac{350\ \text{gal}}{1\ \cancel{\text{min}}} \times \frac{60\ \cancel{\text{min}}}{1\ \cancel{\text{hr}}} \times \frac{24\ \cancel{\text{hrs}}}{1\ \text{day}} = 504{,}000\ \text{gal/day}$$

$$\frac{288{,}00\ \cancel{\text{gal}}}{1\ \text{day}} \times \frac{8.34\ \text{lbs}}{1\ \cancel{\text{gal}}}$$

$$= 4{,}203{,}360\ \text{lbs water/day} \div 1{,}000{,}000 = 4.2\ \text{M lbs water/day}$$

$$\begin{aligned} \text{lbs phosphate/day} &= 2.0\ \text{ppm} \times 4.2\ \text{M lbs/day} \\ &= 8.4\ \text{lbs phosphate/day} \end{aligned}$$

B. If each gallon of 1% stock solution weighs 8.34 lbs, it has 8.34 x 0.01 = 0.0834 lbs of phosphate per gallon of solution

$$\text{gal of solution each day} = \frac{8.4\ \cancel{\text{lbs phosphate}}}{1} \times \frac{1\ \text{gal solution}}{0.0834\ \cancel{\text{lbs phosphate}}}$$

$$= 100.72\ \text{gals}$$

SAMPLE PROBLEMS

(1) A village pumps 150,000 gallons per day and wants to apply 3.2 ppm of phosphate to the water to control an iron problem. How many pounds of phosphate will be used per day?

(2) A pump operates at a rate of 210 gpm for 7 hours per day and phosphate is used at an application rate of 2.5 ppm. How many pounds of phosphate will be used per day?

(3) A pump operates at a rate of 300 gpm for 16 hours per day and 10 pounds of phosphate are used per day. What is the rate of application?

(4) A city uses 0.5 MGD; Compound A (PO_4^{-3}), costs $1.25/gal, and the feed rate required is 3.1 mg/L. Compound B (PO_4^{-3}), costs $1.10/gal and the feed rate required is 3.3 mg/L. Both compounds weigh 10.4 lbs/gal. Which compound do you buy?

Corrosion Control

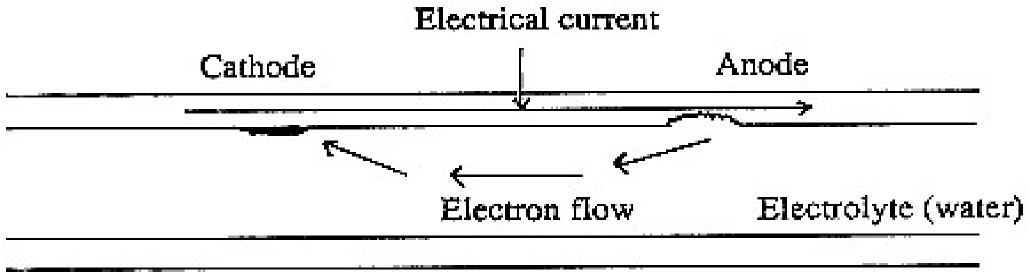
Corrosion of piping in distribution systems has long been a costly problem for many water utilities, and recent rule changes have focused attention on preventing corrosion in water systems. Fortunately, prevention or inhibition of internal corrosion in piping is often possible by chemical treatment of water.

Corrosion in water systems is defined as the electrochemical interaction between a metal pipe surface and water. Corrosion most commonly occurs in three different forms: uniform, non-uniform, and galvanic corrosion. Uniform corrosion is where an electrochemical interaction occurs along the pipe wall, resulting in a relatively uniform loss of metal across the entire surface. Non-uniform corrosion is where metal is lost from a localized point, causing pitting and mounding in some cases. Galvanic corrosion results from a coupling of dissimilar metals or internally in metallic alloys, also known as a galvanic cell.

The galvanic cell consists of four parts:

1. The *anode*--the part of the water main that corrodes by giving up electrons.
2. The *cathode*--the part of the water main that accepts the electrons from the anode.
3. The *electrolyte*--a substance that provides a path for the flow of electrons from the anode to the cathode, in this case, water.
4. The *conductor*--the material that completes the electrical circuit, in this case, the water main.

Figure 12.1 The Galvanic Cell



In galvanic corrosion, corrosion takes place in a metal pipe when a difference in electrical potential is present between two connected areas of the pipe in the presence of an electrolyte. The potential difference causes a current to flow from the anode to the cathode. This difference in potential may be caused by connecting two dissimilar metals such as copper and iron or may be caused by differences in surface features such as a scratched or gouged area. External corrosion occurs in this same way, only the electrolyte is groundwater or damp soil instead of your water supply.

The chemical reactions for corrosion of an iron water main are:

At the anode: $2Fe \rightarrow 2Fe^{2+} + 4e^-$
At the cathode: $O_2 + 4e^- + 2H_2O \rightarrow 4OH^-$

At the anode, 4 electrons enter into solution for every 2 iron ions removed. At the cathode, these electrons are accepted by dissolved oxygen. Dissolved oxygen is very important to the corrosion reaction since without its presence in water, the cathodic reaction cannot proceed and there can be no corrosion. Dissolved oxygen is known as the oxidizing agent.

Is Your Water Corrosive?

It is important to remember that all water is corrosive but can vary in aggressivity. Determining the corrosivity or aggressiveness of a water supply is not an exact science. A rough approximation of the aggressiveness of a water can be determined based on the knowledge of pH, alkalinity, hardness, temperature, and dissolved solids content of the water. In general, a water is less corrosive if it is saturated or supersaturated with calcium carbonate ($CaCO_3$). Saturated waters tend to deposit a film of $CaCO_3$ on the walls of the mains, which inhibits corrosion by reducing potential differences and making it more difficult for dissolved oxygen to reach the bare metal. Usually, very soft waters are more likely to be aggressive due to their inability to deposit this protective film.

The *Langelier Index* is used as a measure of the aggressiveness of water.
$L.I. = pH - pH_s$

Where pH_s is the pH at which the water is just saturated with $CaCO_3$. The pH_s can be approximated from a formula if the temperature, dissolved solids content, hardness, and alkalinity of the water is known. A negative Langelier Index indicates that the water is not saturated and is likely to be aggressive.

Factors Affecting the Corrosivity of Water

Several factors affect the corrosivity of water. As mentioned before, the level of dissolved oxygen is very important. Other factors include:

1. *Total dissolved solids (TDS)*--a high TDS level usually means that water is more conductive and will accelerate corrosion.
2. *Temperature*--higher temperatures increase reaction rates. This is why water heaters and boilers often have corrosion problems.
3. *Velocity*--high water velocities contribute to faster corrosion rates in aggressive waters by providing a constant dissolved oxygen supply.

Treatment to Prevent Corrosion

A number of methods are employed to inhibit corrosion in water mains. Lining mains with cement compounds is commonly done. Chemical treatment of water is often used to adjust the pH to supersaturate the water and, therefore, deposit a protective $CaCO_3$ film on the mains. Other chemicals are added to interfere with the chemical reactions causing corrosion.

The chemicals used to adjust the pH up to supersaturate water include quick lime (CaO), hydrated lime ($Ca(OH)_2$), caustic soda ($NaOH$), or soda ash (Na_2CO_3). Both types of lime are usually added only at a complete treatment plant due to the complexity of the chemical mixers and feed equipment. Soda ash is rarely used due to its high cost but is sometimes needed to treat waters with very low alkalinities. Caustic soda can be used fairly easily but is usually used only at complete treatment plants due to cost and safety concerns.

Chemicals that are more typically added on small treatment systems are zinc phosphates, orthophosphates, and silicates. These chemicals are typically sold under various brand names by chemical suppliers. They may be effective by forming their own cathodic films or by stabilizing supersaturated waters. It is important to realize that no chemical is effective for all types of water. Testing several chemicals in cooperation with the chemical supplier may be necessary to determine the most effective and least costly type of treatment.

Evaluating the Effectiveness of Chemical Treatment

Determining the effectiveness of corrosion control is not usually precise. However, there are several ways to evaluate the treatment scheme.

1. *Use of corrosion coupons*. These coupons are metal plates placed in water mains. After a period of time, they are removed and examined for evidence of corrosion.
2. *Checking flow capacity*. New sections of water main can be measured for flow carrying capacity. After a period of time, the carrying capacity is checked again. If the capacity is reduced, this is evidence that tuberculation and pitting have occurred in the main due to corrosion.
3. *Evaluation of customer complaints*. An increase in or decrease of customer complaints from red water staining may be an indication of the effectiveness of treatment. This information is more meaningful on systems where the source water has little or no iron content.
4. *Examination of abandoned sections of main*. Cutting open old sections of main or fittings will provide information on the degree of corrosion, or hopefully on the amount of protective film deposited in the mains.

LEAD/COPPER SAMPLING

A PWS system monitors the need for and the effectiveness of their corrosion control program by sampling the distribution system for lead and copper. Lead and copper are both inorganic elements found naturally in all parts of the environment around us; however, lead seldom occurs naturally in water supplies like rivers and lakes. Lead is an element, so it does not break down into less harmful substances. No level of lead in the blood is safe; it is a potent irreversible neurotoxin that causes adverse health effects with both acute and chronic exposures. Lead does not have a maximum contaminant level, or MCL, like many other substances, instead it has an “action level.” Set in 1991, the lead action level is not a health-based number but is based on feasibility of reducing lead through controlling corrosion using the treatment capabilities available at the time. New action levels for lead have been established by the USEPA at 10 ppb or 0.010mg/L, as of 2024. Copper is also a naturally occurring element, and small amounts of copper are essential for health, while high exposure can result in a variety of negative health effects.

Lead and copper leach into water through corrosion – a dissolving or wearing away of metal caused by a chemical reaction between water and the plumbing. Lead can also leach into the drinking water supply through older, corroded lead pipes, faucets, fittings, and solder. The concentration of lead and copper in drinking water is related to materials used in construction that are in contact with the water and the chemical composition of the water such as the pH, temperature, alkalinity, conductivity, and calcium content. Water usage, or non-usage, is also a factor of corrosion.

Nearly all homes built before 1982 have lead solder connecting to copper pipes, according to Plumbing Manufacturers International. Even some major U.S. cities still use lead pipes to carry water from the utilities to our homes and businesses. When the water chemistry is very carefully controlled, however, it keeps lead from leaching into the drinking water.

Lead is colorless, odorless, and tasteless in water, and the only sure way to determine if the water contains lead is to have the water tested. Some labs calculate a corrosivity index from other test results including the pH of the water, but a specific lead test is needed to determine the actual concentration of lead in drinking water.

These samples are taken at specific locations within the distribution system, based on the type of water mains and service lines in use. Each water supply system must develop a sampling plan to follow, using the tiering criteria and based on the materials in their distribution system. Also important are “water quality parameters,” which are frequent measurements of certain variables that affect the level of lead and copper that may be in the water. Tracking the water quality parameters helps an operator maintain the proper water chemistry to minimize leaching.

The number of sites that must be sampled depends on the size of the system.

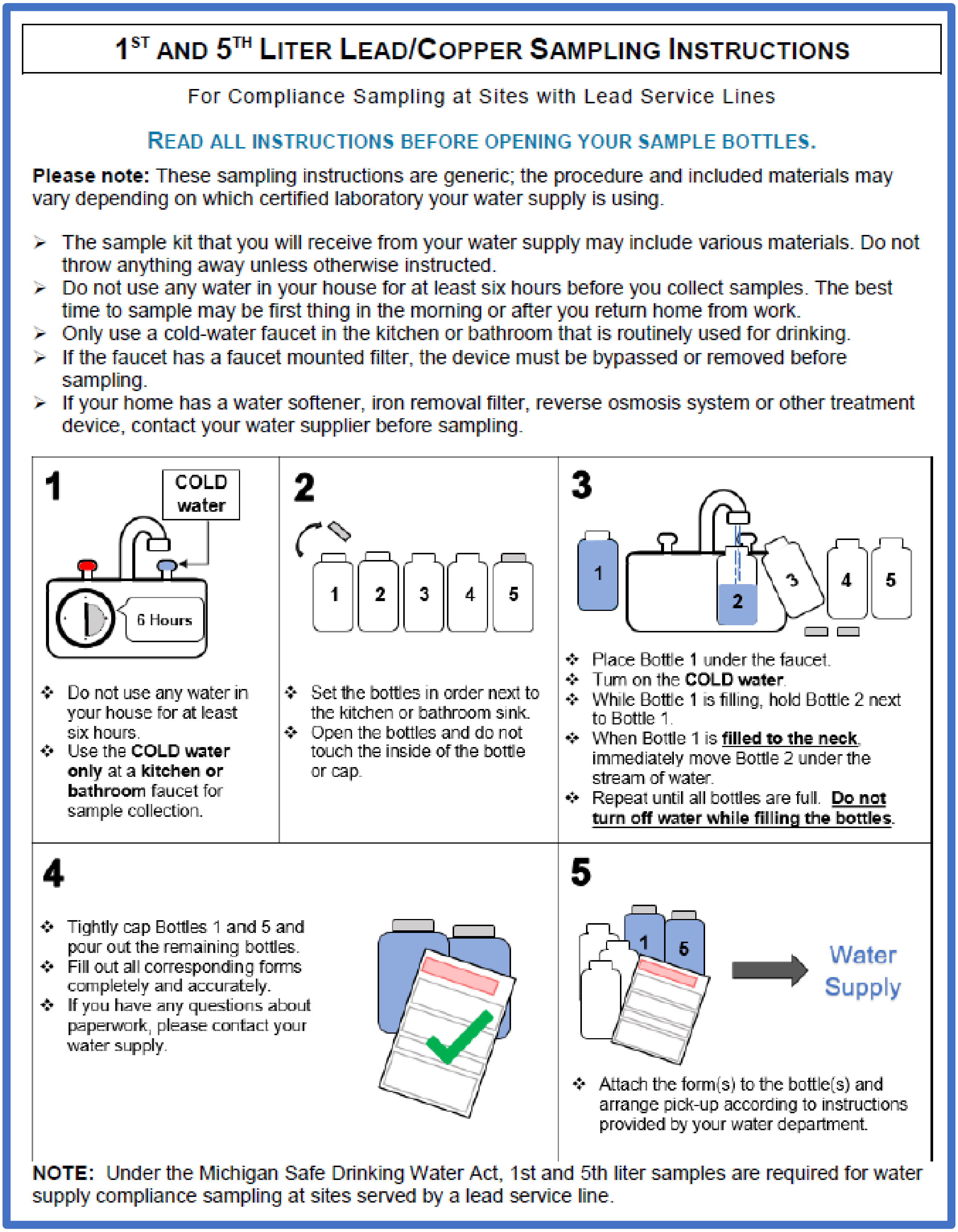
Table 12.2 Lead/copper Sampling Requirements

Supply Size (# of People Served)	Number of Sites (Standard Monitoring)	Number of Sites (Reduced Monitoring)
More than 100,000	100	50
10,001 - 100,000	60	30
3,301 – 10,000	40	20
501 – 3,300	20	10
101 - 500	10	5
Fewer than 101	5	5

Monitoring frequency depends on several factors, including sampling history, water quality and treatment, and compliance with the rules. Frequency possibilities are semi-annual, annual, and triennial. A water supply cannot reduce to triennial lead/copper monitoring unless they meet water quality parameter ranges and either have no lead service lines, or they have three annual rounds of sampling $\leq$ 0.005 mg/L for lead and $\leq$ 0.65 mg/L for copper.

Lead/copper sampling will also vary depending on whether the site being sampled is known to have a lead service line or not. If a lead service line is present, the first and fifth liter pulled from the sample point must be submitted. If a lead service line is not present, only the first liter is submitted. And since they are “first draw” samples, taken after a 6-hour period of stagnation, they are most often taken by the resident of the building being sampled. The water supply will have to develop good communications with the residents and provide information on how to do the sampling. The water supply is ultimately responsible for the results and the rule allows customers to collect lead/copper samples only after they have been provided with proper instructions. The operator must make sure the sample collection was properly completed before sending the sample to the lab. If the operator believes that the sample was not correctly taken, the sample does not have to be submitted. It is a good idea to collect more samples than required, so that the required number of samples can be submitted even if some improperly collected samples have to be discarded.

Figure 12.3 Sampling Instructions for sites with lead service lines



1ST AND 5TH LITER LEAD/COPPER SAMPLING INSTRUCTIONS

For Compliance Sampling at Sites with Lead Service Lines

READ ALL INSTRUCTIONS BEFORE OPENING YOUR SAMPLE BOTTLES.

Please note: These sampling instructions are generic; the procedure and included materials may vary depending on which certified laboratory your water supply is using.

- The sample kit that you will receive from your water supply may include various materials. Do not throw anything away unless otherwise instructed.
- Do not use any water in your house for at least six hours before you collect samples. The best time to sample may be first thing in the morning or after you return home from work.
- Only use a cold-water faucet in the kitchen or bathroom that is routinely used for drinking.
- If the faucet has a faucet mounted filter, the device must be bypassed or removed before sampling.
- If your home has a water softener, iron removal filter, reverse osmosis system or other treatment device, contact your water supplier before sampling.

1

- Do not use any water in your house for at least six hours.
- Use the **COLD water only** at a **kitchen or bathroom** faucet for sample collection.

2

- Set the bottles in order next to the kitchen or bathroom sink.
- Open the bottles and do not touch the inside of the bottle or cap.

3

- Place Bottle 1 under the faucet.
- Turn on the **COLD water**.
- While Bottle 1 is filling, hold Bottle 2 next to Bottle 1.
- When Bottle 1 is **filled to the neck**, immediately move Bottle 2 under the stream of water.
- Repeat until all bottles are full. **Do not turn off water while filling the bottles**.

4

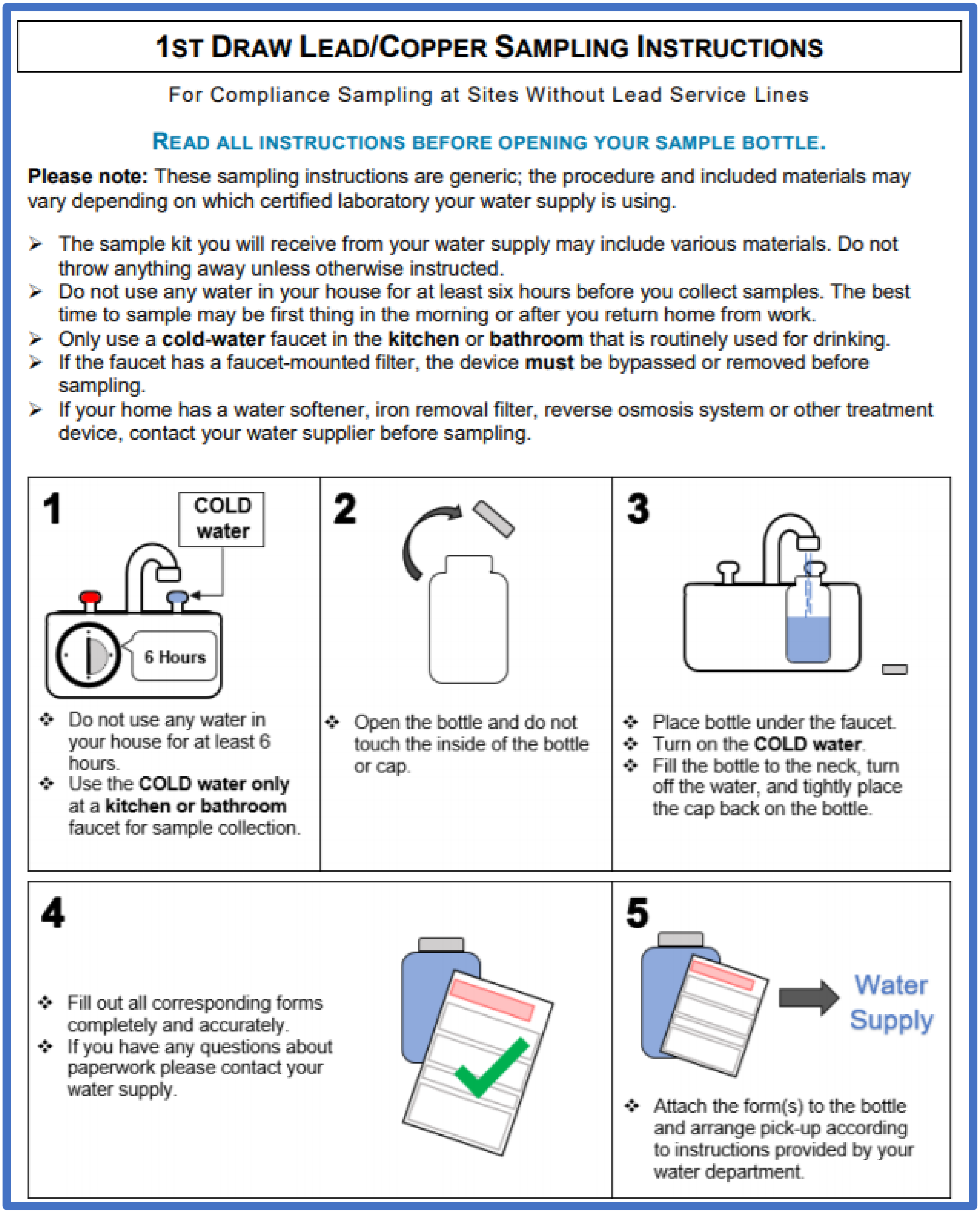
- Tightly cap Bottles 1 and 5 and pour out the remaining bottles.
- Fill out all corresponding forms completely and accurately.
- If you have any questions about paperwork, please contact your water supply.

5

- Attach the form(s) to the bottle(s) and arrange pick-up according to instructions provided by your water department.

NOTE: Under the Michigan Safe Drinking Water Act, 1st and 5th liter samples are required for water supply compliance sampling at sites served by a lead service line.

Figure 12.4 Sampling Instructions for sites without lead service lines



1ST DRAW LEAD/COPPER SAMPLING INSTRUCTIONS

For Compliance Sampling at Sites Without Lead Service Lines

READ ALL INSTRUCTIONS BEFORE OPENING YOUR SAMPLE BOTTLE.

Please note: These sampling instructions are generic; the procedure and included materials may vary depending on which certified laboratory your water supply is using.

- The sample kit you will receive from your water supply may include various materials. Do not throw anything away unless otherwise instructed.
- Do not use any water in your house for at least six hours before you collect samples. The best time to sample may be first thing in the morning or after you return home from work.
- Only use a **cold-water** faucet in the **kitchen** or **bathroom** that is routinely used for drinking.
- If the faucet has a faucet-mounted filter, the device **must** be bypassed or removed before sampling.
- If your home has a water softener, iron removal filter, reverse osmosis system or other treatment device, contact your water supplier before sampling.

1

- Do not use any water in your house for at least 6 hours.
- Use the **COLD water only** at a **kitchen or bathroom** faucet for sample collection.

2

- Open the bottle and do not touch the inside of the bottle or cap.

3

- Place bottle under the faucet.
- Turn on the **COLD water**.
- Fill the bottle to the neck, turn off the water, and tightly place the cap back on the bottle.

4

- Fill out all corresponding forms completely and accurately.
- If you have any questions about paperwork please contact your water supply.

5

- Attach the form(s) to the bottle and arrange pick-up according to instructions provided by your water department.

Lead/copper terms:

Distribution System Material Inventory (DSMI) – Identifies the materials present in the piping, storage structure, pumps, and controls used to deliver water to the public, including service lines.

Lead Service Line (LSL) – means either a service line which is made of lead or any lead pigtail, lead gooseneck, or other lead fitting that is connected to the service line, or both.

Multi-family residential (MFR).

Service Line – means the pipe from the discharge of the corporation fitting to customer site piping or to the building plumbing at the first shut-off valve inside the building, or 18 inches inside the building, whichever is shorter.

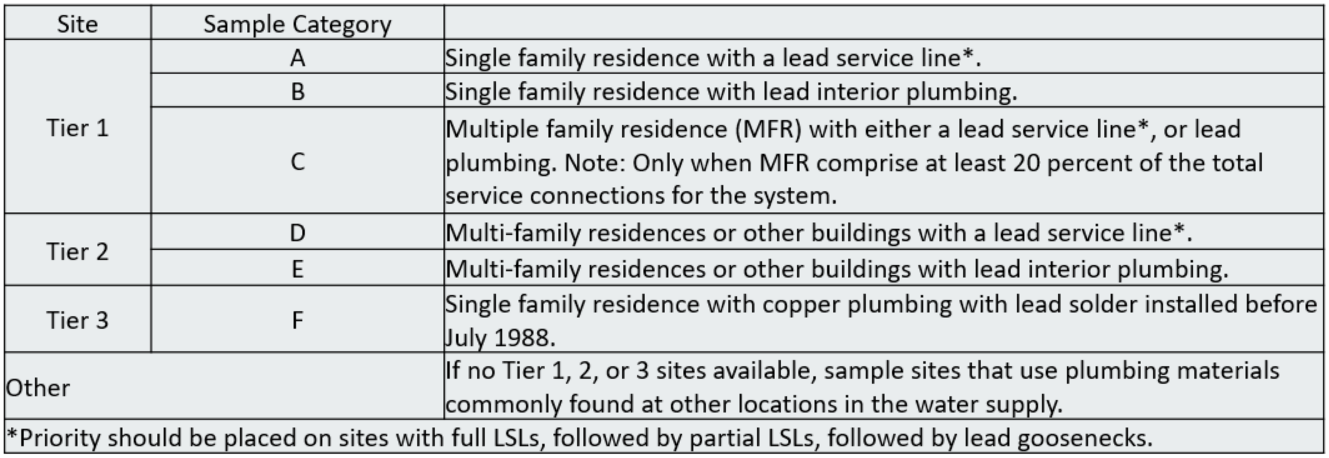
Single family residential (SFR).

90th Percentile – method of calculating and reporting the number of samples and the highest results.

Water Quality Parameters (WQP) - Measurements of pH, conductivity, temperature, alkalinity, calcium, chloride, sulfate, and, if used, orthophosphate or silica to determine water chemistry.

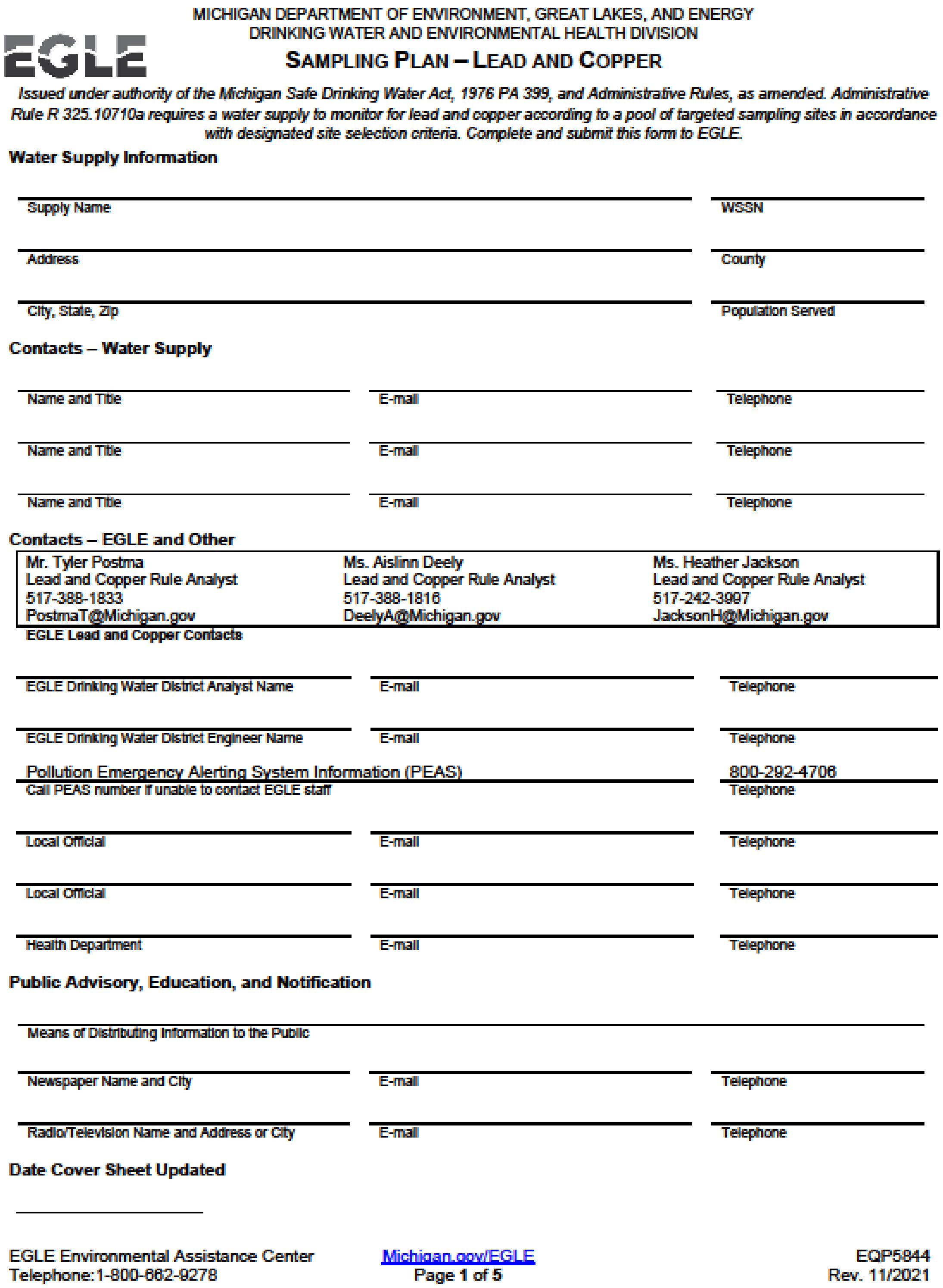
Tiering Criteria – determining sampling sites based on potential risk for lead exposure.

Figure 12.5 Michigan Tiering Chart



Site	Sample Category	
Tier 1	A	Single family residence with a lead service line*.
	B	Single family residence with lead interior plumbing.
	C	Multiple family residence (MFR) with either a lead service line*, or lead plumbing. Note: Only when MFR comprise at least 20 percent of the total service connections for the system.
Tier 2	D	Multi-family residences or other buildings with a lead service line*.
	E	Multi-family residences or other buildings with lead interior plumbing.
Tier 3	F	Single family residence with copper plumbing with lead solder installed before July 1988.
Other		If no Tier 1, 2, or 3 sites available, sample sites that use plumbing materials commonly found at other locations in the water supply.
*Priority should be placed on sites with full LSLs, followed by partial LSLs, followed by lead goosenecks.		

Figure 12.6 Lead/copper Sample Site Plan



MICHIGAN DEPARTMENT OF ENVIRONMENT, GREAT LAKES, AND ENERGY
DRINKING WATER AND ENVIRONMENTAL HEALTH DIVISION

SAMPLING PLAN – LEAD AND COPPER

Issued under authority of the Michigan Safe Drinking Water Act, 1976 PA 399, and Administrative Rules, as amended. Administrative Rule R 325.10710a requires a water supply to monitor for lead and copper according to a pool of targeted sampling sites in accordance with designated site selection criteria. Complete and submit this form to EGLE.

Water Supply Information

Supply Name	WSSN
Address	County
City, State, Zip	Population Served

Contacts – Water Supply

Name and Title	E-mail	Telephone
Name and Title	E-mail	Telephone
Name and Title	E-mail	Telephone

Contacts – EGLE and Other

Mr. Tyler Postma Lead and Copper Rule Analyst 517-388-1833 PostmaT@Michigan.gov	Ms. Aislinn Deely Lead and Copper Rule Analyst 517-388-1816 DeelyA@Michigan.gov	Ms. Heather Jackson Lead and Copper Rule Analyst 517-242-3997 JacksonH@Michigan.gov

EGLE Lead and Copper Contacts

EGLE Drinking Water District Analyst Name	E-mail	Telephone
EGLE Drinking Water District Engineer Name	E-mail	Telephone
Pollution Emergency Alerting System Information (PEAS) Call PEAS number if unable to contact EGLE staff		800-292-4706 Telephone
Local Official	E-mail	Telephone
Local Official	E-mail	Telephone
Health Department	E-mail	Telephone

Public Advisory, Education, and Notification

Means of Distributing Information to the Public

Newspaper Name and City	E-mail	Telephone
Radio/Television Name and Address or City	E-mail	Telephone

Date Cover Sheet Updated

EGLE Environmental Assistance Center
Telephone: 1-800-662-9278

Michigan.gov/EGLE
Page **1** of **5**

EQP5844
Rev. 11/2021

MICHIGAN COMMUNITY WATER SUPPLY LEAD AND COPPER TAP SAMPLING PLAN

>>> REVIEW INSTRUCTIONS ON PAGES 4 AND 5 BEFORE COMPLETING FORM BELOW <<<

WSSN: _________ Supply Name: ____ Page _____ of _____

Standard Number of Sites Required: _________ Reduced Number of Sites Required: _________

Site No.	Address	Tier Level	Category	Structure Type	Service Line Material	Interior Plumbing Material	Site Validation Method
00	*Ex: 0000 Any Street – Any Town, MI*	*1*	*A*	*SFR*	*L*	*C*	*Visual*
01							
02							
03							
04							
05							
06							
07							
08							
09							
10							
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							

Use next page to record additional sampling sites.

Plan Completed By

_____________________________ _____________________________
Name Signature

_____________________________ _____________________________
Title Date

MICHIGAN COMMUNITY WATER SUPPLY LEAD AND COPPER TAP SAMPLING PLAN (cont.)

WSSN: _________ **Supply Name:** ____ **Page** _____ **of** _____

Site No.	Address	Tier Level	Category	Structure Type	Service Line Material	Interior Plumbing Material	Site Validation Method
00	*Ex: 0000 Any Street – Any Town, MI*	*1*	*A*	*SFR*	*L*	*C*	*Visual*

Use additional pages for water supplies requiring more sampling sites.

Michigan Lead and Copper Rule
Lead and Copper Tap Sample Site Selection Criteria

Community water supplies must identify a pool of lead and copper sampling sites containing **AT LEAST** the number of sites necessary to conduct **STANDARD** monitoring (see instructions for number of required sites). It is highly recommended that the sampling pool contain more sites than required in case routine sites are unavailable at time of sampling. The sampling pool must target high risk sites using the criteria below.

- **Samples must be collected from Tier 1 sites, unless ...**
- insufficient Tier 1 sampling sites are available, then **Tier 2** sites must be used, unless ...
- insufficient Tier 1 and Tier 2 sampling sites are available, then **Tier 3** sites must be used.
- If no Tier 1, 2, or 3 sites are available, sampling sites must be representative of plumbing materials typically found throughout the water system.

TIER 1 SITES - Single family residences with either:

- Lead service lines (LSL)*
- Interior lead plumbing

Multiple family residences (MFR) with LSLs* may be used as Tier 1 sites when MFR comprise at least 20 percent of the total service connections.

TIER 2 SITES – Other buildings or multiple family residences with either:

- LSL*
- Interior lead plumbing

TIER 3 SITES - Single family residences with:

- Copper plumbing with lead solder (CLS) installed before July 1988

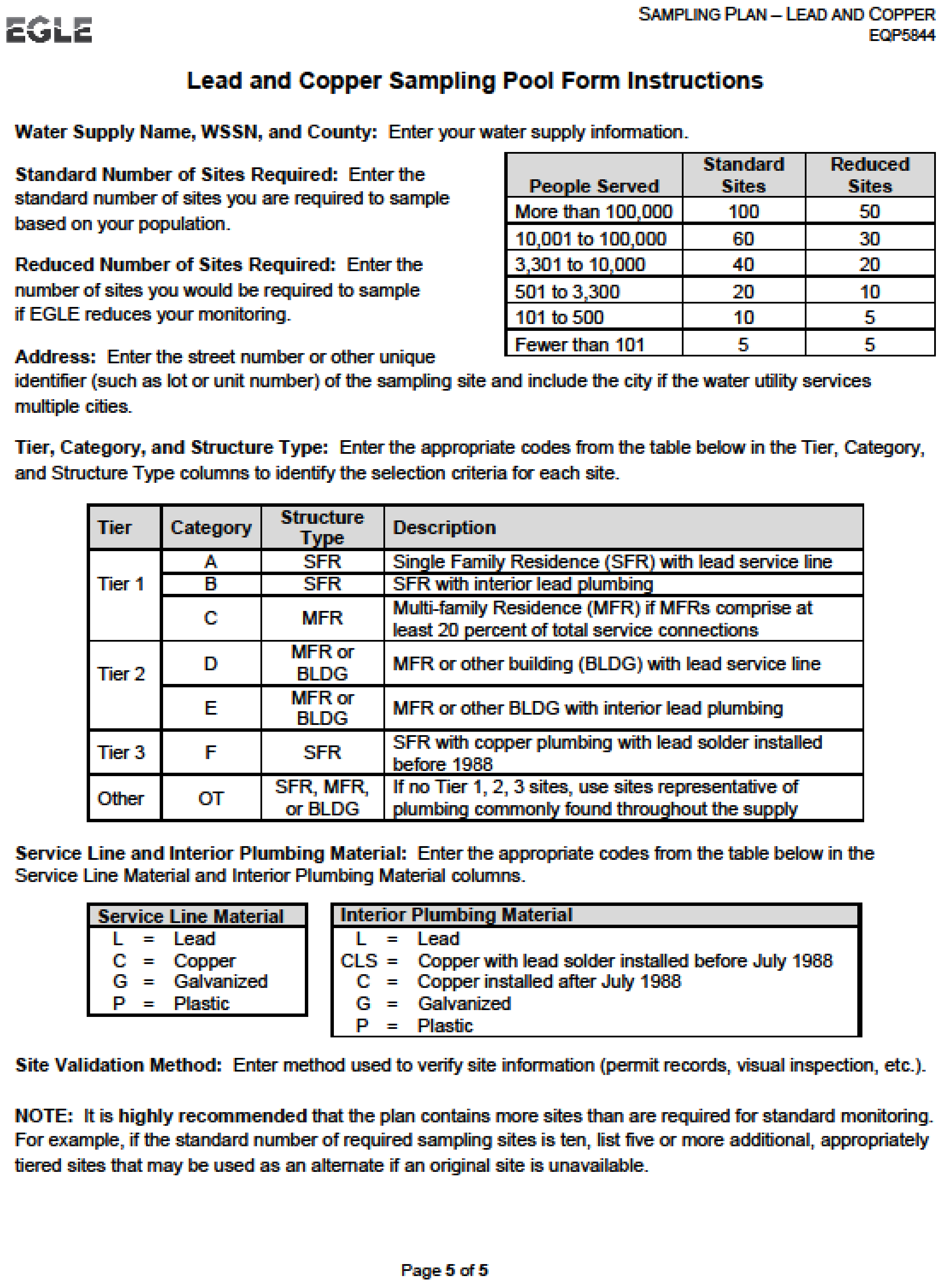
OTHER SITES

- Sites representative of plumbing materials commonly found throughout the water supply.

*** Priority should be placed on sites with full LSLs, followed by partial LSLs, followed by lead goosenecks or pigtails.**

Also Note:

- Each round of sampling should be conducted at the **SAME** sampling sites unless ...
  - a site no longer meets tiering criteria (for example, a site is no longer Tier 1 after having the lead service line replaced); or
  - a site is unavailable (for example, a site has no water service, resident refuses to participate, etc.)
- **DO NOT** sample from outside hose spigots or utility sinks.
  - For residential sites, samples **MUST BE** collected from kitchen or bathroom taps typically used for consumption. For non-residential sites, samples **MUST BE** collected from taps typically used for consumption.
- Samples **MAY NOT** be taken from taps that have point of use or point of entry treatment devices designed to remove inorganic contaminants, such as an iron removal filter, reverse osmosis system, or water softener.



EGLE

SAMPLING PLAN – LEAD AND COPPER
EQP5844

Lead and Copper Sampling Pool Form Instructions

Water Supply Name, WSSN, and County: Enter your water supply information.

Standard Number of Sites Required: Enter the standard number of sites you are required to sample based on your population.

Reduced Number of Sites Required: Enter the number of sites you would be required to sample if EGLE reduces your monitoring.

People Served	Standard Sites	Reduced Sites
More than 100,000	100	50
10,001 to 100,000	60	30
3,301 to 10,000	40	20
501 to 3,300	20	10
101 to 500	10	5
Fewer than 101	5	5

Address: Enter the street number or other unique identifier (such as lot or unit number) of the sampling site and include the city if the water utility services multiple cities.

Tier, Category, and Structure Type: Enter the appropriate codes from the table below in the Tier, Category, and Structure Type columns to identify the selection criteria for each site.

Tier	Category	Structure Type	Description
Tier 1	A	SFR	Single Family Residence (SFR) with lead service line
	B	SFR	SFR with interior lead plumbing
	C	MFR	Multi-family Residence (MFR) if MFRs comprise at least 20 percent of total service connections
Tier 2	D	MFR or BLDG	MFR or other building (BLDG) with lead service line
	E	MFR or BLDG	MFR or other BLDG with interior lead plumbing
Tier 3	F	SFR	SFR with copper plumbing with lead solder installed before 1988
Other	OT	SFR, MFR, or BLDG	If no Tier 1, 2, 3 sites, use sites representative of plumbing commonly found throughout the supply

Service Line and Interior Plumbing Material: Enter the appropriate codes from the table below in the Service Line Material and Interior Plumbing Material columns.

Service Line Material
L = Lead
C = Copper
G = Galvanized
P = Plastic

Interior Plumbing Material
L = Lead
CLS = Copper with lead solder installed before July 1988
C = Copper installed after July 1988
G = Galvanized
P = Plastic

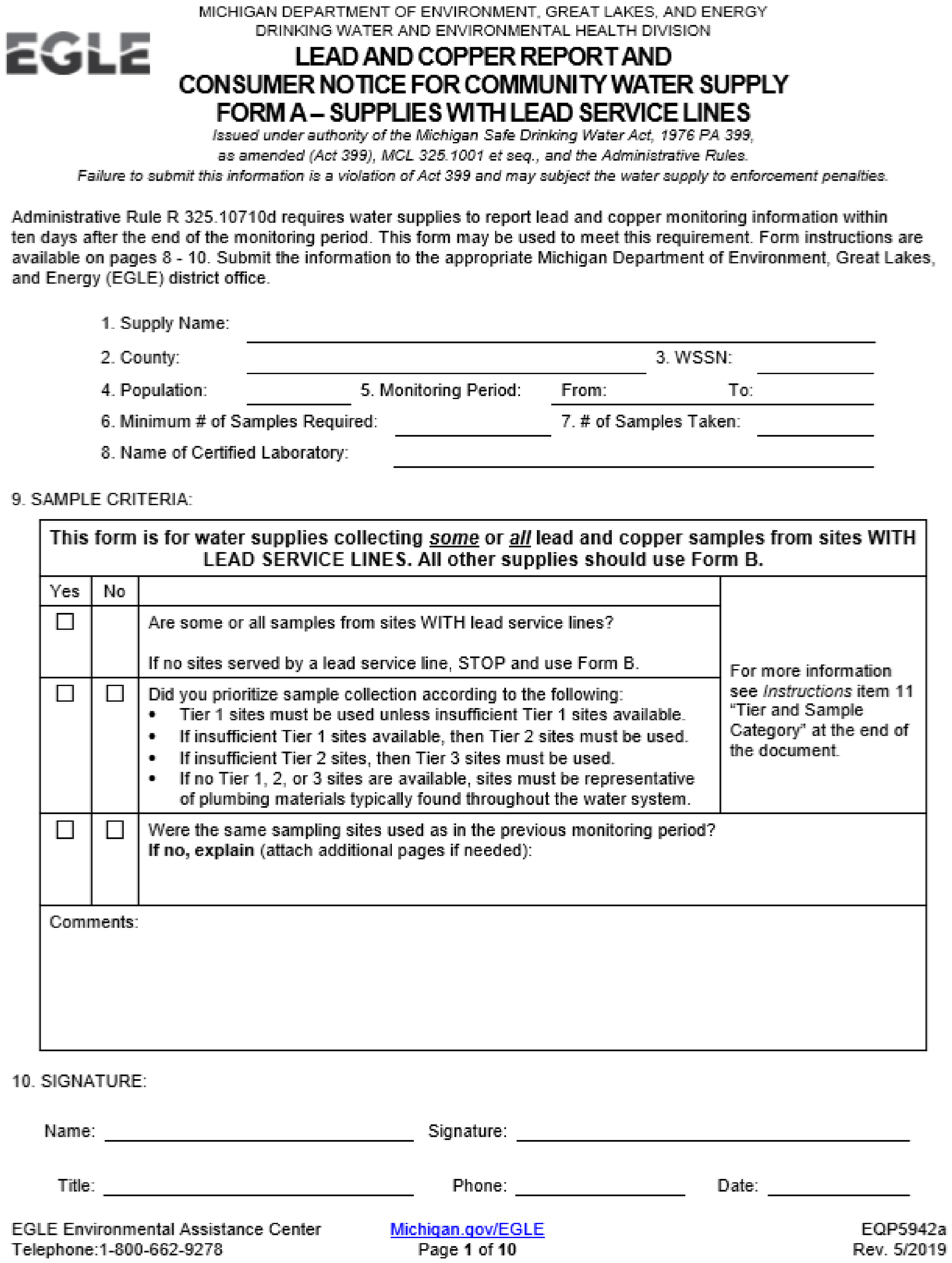
Site Validation Method: Enter method used to verify site information (permit records, visual inspection, etc.).

NOTE: It is **highly recommended** that the plan contains more sites than are required for standard monitoring. For example, if the standard number of required sampling sites is ten, list five or more additional, appropriately tiered sites that may be used as an alternate if an original site is unavailable.

Page **5** of **5**

Lead/copper results must not only be reported to EGLE, but there are additional requirements for sending the results to the property owners where the samples were taken.

Figure 12.7 Excerpt from Reporting Form



MICHIGAN DEPARTMENT OF ENVIRONMENT, GREAT LAKES, AND ENERGY
DRINKING WATER AND ENVIRONMENTAL HEALTH DIVISION

LEAD AND COPPER REPORT AND
CONSUMER NOTICE FOR COMMUNITY WATER SUPPLY
FORM A – SUPPLIES WITH LEAD SERVICE LINES

Issued under authority of the Michigan Safe Drinking Water Act, 1976 PA 399, as amended (Act 399), MCL 325.1001 et seq., and the Administrative Rules.
Failure to submit this information is a violation of Act 399 and may subject the water supply to enforcement penalties.

Administrative Rule R 325.10710d requires water supplies to report lead and copper monitoring information within ten days after the end of the monitoring period. This form may be used to meet this requirement. Form instructions are available on pages 8 - 10. Submit the information to the appropriate Michigan Department of Environment, Great Lakes, and Energy (EGLE) district office.

1. Supply Name: ____________________
2. County: ____________________ 3. WSSN: __________
4. Population: __________ 5. Monitoring Period: From: __________ To: __________
6. Minimum # of Samples Required: __________ 7. # of Samples Taken: __________
8. Name of Certified Laboratory: ____________________

9. SAMPLE CRITERIA:

This form is for water supplies collecting *some* or *all* lead and copper samples from sites WITH LEAD SERVICE LINES. All other supplies should use Form B.

Yes	No		
☐		Are some or all samples from sites WITH lead service lines? If no sites served by a lead service line, STOP and use Form B.	For more information see *Instructions* item 11 “Tier and Sample Category” at the end of the document.
☐	☐	Did you prioritize sample collection according to the following: • Tier 1 sites must be used unless insufficient Tier 1 sites available. • If insufficient Tier 1 sites available, then Tier 2 sites must be used. • If insufficient Tier 2 sites, then Tier 3 sites must be used. • If no Tier 1, 2, or 3 sites are available, sites must be representative of plumbing materials typically found throughout the water system.	
☐	☐	Were the same sampling sites used as in the previous monitoring period? **If no, explain** (attach additional pages if needed):	
Comments:			

10. SIGNATURE:

Name: ____________________ Signature: ____________________

Title: ____________________ Phone: __________ Date: __________

EGLE Environmental Assistance Center
Telephone:1-800-662-9278

Michigan.gov/EGLE
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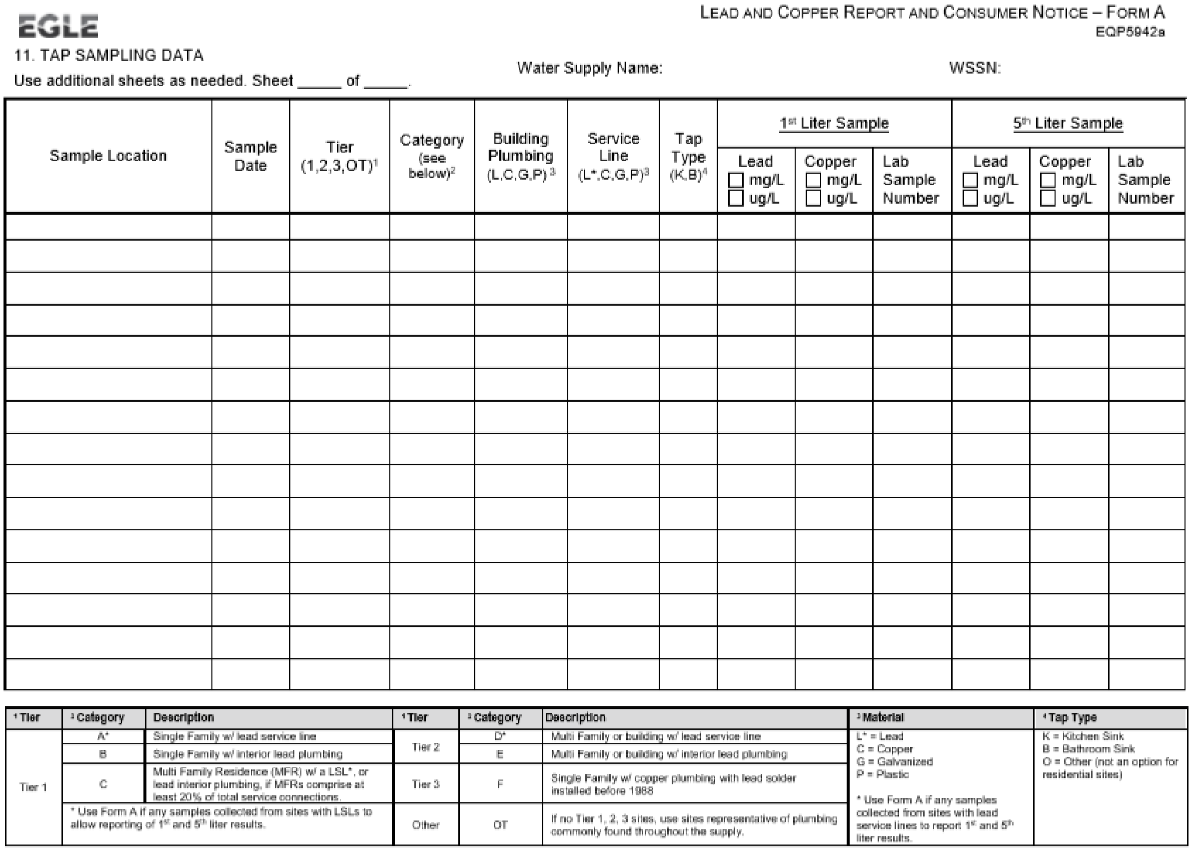
Rev. 5/2019


EGLE

LEAD AND COPPER REPORT AND CONSUMER NOTICE – FORM A
EQP5942a

11. TAP SAMPLING DATA
Use additional sheets as needed. Sheet _____ of _____.

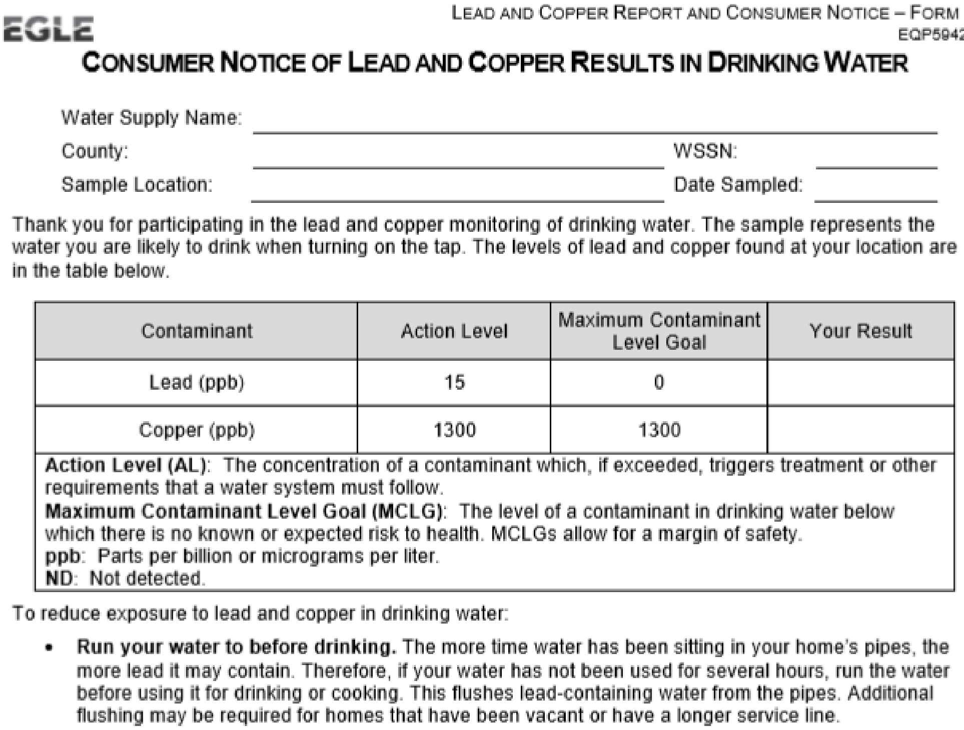
Water Supply Name:

WSSN:

Sample Location	Sample Date	Tier (1,2,3,OT)^1	Category (see below)^2	Building Plumbing (L,C,G,P)^3	Service Line (L*,C,G,P)^3	Tap Type (K,B)^4	1st Liter Sample			5th Liter Sample		
							Lead ☐ mg/L ☐ ug/L	Copper ☐ mg/L ☐ ug/L	Lab Sample Number	Lead ☐ mg/L ☐ ug/L	Copper ☐ mg/L ☐ ug/L	Lab Sample Number

^{1} Tier	^{2} Category	Description	^{1} Tier	^{2} Category	Description	^{3} Material	^{4} Tap Type
Tier 1	A*	Single Family w/ lead service line	Tier 2	D*	Multi Family or building w/ lead service line	L* = Lead C = Copper G = Galvanized P = Plastic * Use Form A if any samples collected from sites with lead service lines to report 1st and 5th liter results.	K = Kitchen Sink B = Bathroom Sink O = Other (not an option for residential sites)
	B	Single Family w/ interior lead plumbing		E	Multi Family or building w/ interior lead plumbing		
	C	Multi Family Residence (MFR) w/ a LSL*, or lead interior plumbing, if MFRs comprise at least 20% of total service connections.	Tier 3	F	Single Family w/ copper plumbing with lead solder installed before 1988		
	* Use Form A if any samples collected from sites with LSLs to allow reporting of 1st and 5th liter results.		Other	OT	If no Tier 1, 2, 3 sites, use sites representative of plumbing commonly found throughout the supply.		

Figure 12.8 Excerpt from report to owner


EGLE

LEAD AND COPPER REPORT AND CONSUMER NOTICE – FORM B
EQP5942b

CONSUMER NOTICE OF LEAD AND COPPER RESULTS IN DRINKING WATER

Water Supply Name: ______________________
County: ______________________ WSSN: __________
Sample Location: ______________________ Date Sampled: __________

Thank you for participating in the lead and copper monitoring of drinking water. The sample represents the water you are likely to drink when turning on the tap. The levels of lead and copper found at your location are in the table below.

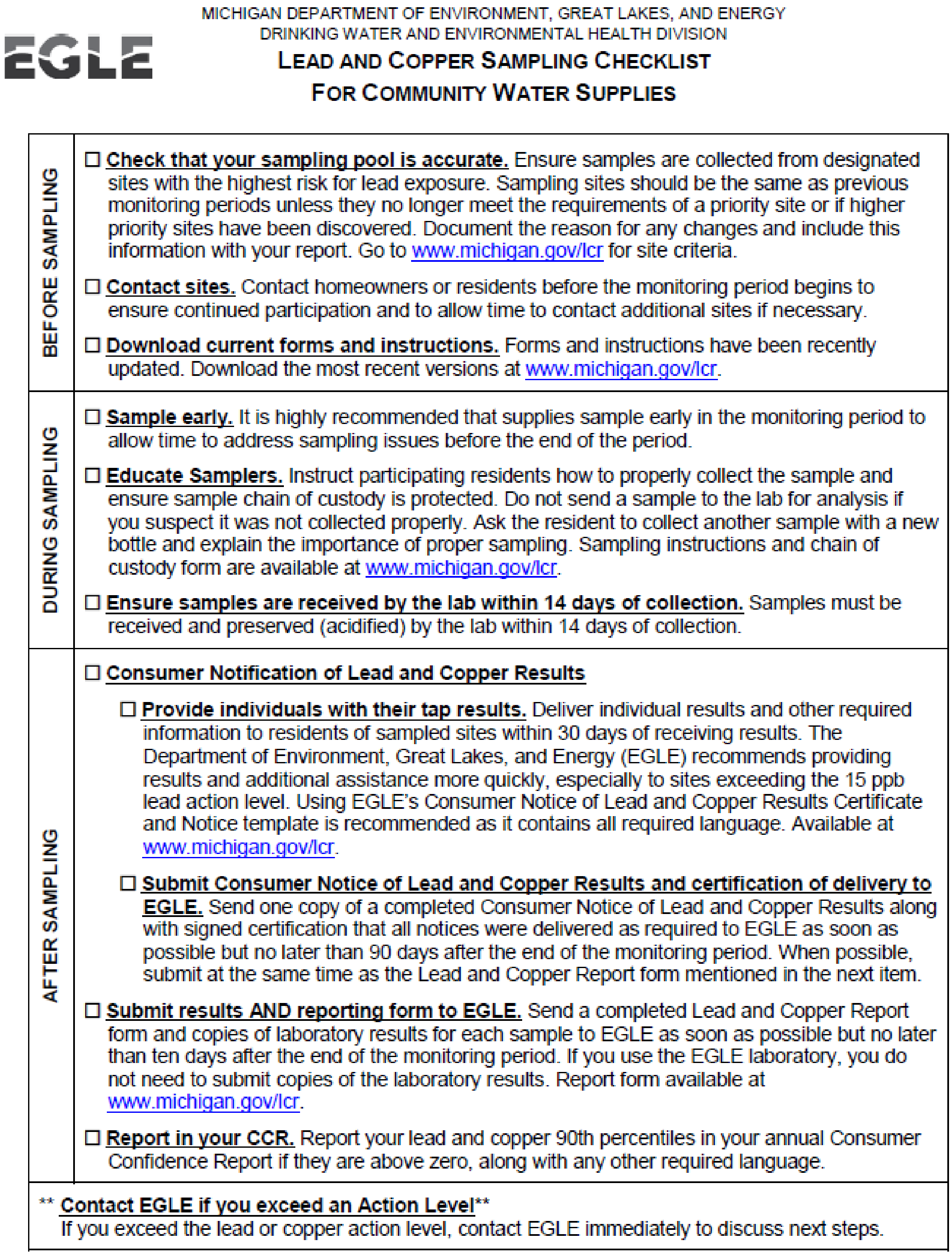
Contaminant	Action Level	Maximum Contaminant Level Goal	Your Result
Lead (ppb)	15	0	
Copper (ppb)	1300	1300	

Action Level (AL): The concentration of a contaminant which, if exceeded, triggers treatment or other requirements that a water system must follow.
Maximum Contaminant Level Goal (MCLG): The level of a contaminant in drinking water below which there is no known or expected risk to health. MCLGs allow for a margin of safety.
ppb: Parts per billion or micrograms per liter.
ND: Not detected.

To reduce exposure to lead and copper in drinking water:

- **Run your water to before drinking.** The more time water has been sitting in your home's pipes, the more lead it may contain. Therefore, if your water has not been used for several hours, run the water before using it for drinking or cooking. This flushes lead-containing water from the pipes. Additional flushing may be required for homes that have been vacant or have a longer service line.

Figure 12.9 Checklist



EGLE

MICHIGAN DEPARTMENT OF ENVIRONMENT, GREAT LAKES, AND ENERGY
DRINKING WATER AND ENVIRONMENTAL HEALTH DIVISION

LEAD AND COPPER SAMPLING CHECKLIST FOR COMMUNITY WATER SUPPLIES

BEFORE SAMPLING

☐ **Check that your sampling pool is accurate.** Ensure samples are collected from designated sites with the highest risk for lead exposure. Sampling sites should be the same as previous monitoring periods unless they no longer meet the requirements of a priority site or if higher priority sites have been discovered. Document the reason for any changes and include this information with your report. Go to www.michigan.gov/lcr for site criteria.

☐ **Contact sites.** Contact homeowners or residents before the monitoring period begins to ensure continued participation and to allow time to contact additional sites if necessary.

☐ **Download current forms and instructions.** Forms and instructions have been recently updated. Download the most recent versions at www.michigan.gov/lcr.

DURING SAMPLING

☐ **Sample early.** It is highly recommended that supplies sample early in the monitoring period to allow time to address sampling issues before the end of the period.

☐ **Educate Samplers.** Instruct participating residents how to properly collect the sample and ensure sample chain of custody is protected. Do not send a sample to the lab for analysis if you suspect it was not collected properly. Ask the resident to collect another sample with a new bottle and explain the importance of proper sampling. Sampling instructions and chain of custody form are available at www.michigan.gov/lcr.

☐ **Ensure samples are received by the lab within 14 days of collection.** Samples must be received and preserved (acidified) by the lab within 14 days of collection.

AFTER SAMPLING

☐ **Consumer Notification of Lead and Copper Results**

  ☐ **Provide individuals with their tap results.** Deliver individual results and other required information to residents of sampled sites within 30 days of receiving results. The Department of Environment, Great Lakes, and Energy (EGLE) recommends providing results and additional assistance more quickly, especially to sites exceeding the 15 ppb lead action level. Using EGLE's Consumer Notice of Lead and Copper Results Certificate and Notice template is recommended as it contains all required language. Available at www.michigan.gov/lcr.

  ☐ **Submit Consumer Notice of Lead and Copper Results and certification of delivery to EGLE.** Send one copy of a completed Consumer Notice of Lead and Copper Results along with signed certification that all notices were delivered as required to EGLE as soon as possible but no later than 90 days after the end of the monitoring period. When possible, submit at the same time as the Lead and Copper Report form mentioned in the next item.

☐ **Submit results AND reporting form to EGLE.** Send a completed Lead and Copper Report form and copies of laboratory results for each sample to EGLE as soon as possible but no later than ten days after the end of the monitoring period. If you use the EGLE laboratory, you do not need to submit copies of the laboratory results. Report form available at www.michigan.gov/lcr.

☐ **Report in your CCR.** Report your lead and copper 90th percentiles in your annual Consumer Confidence Report if they are above zero, along with any other required language.

** **Contact EGLE if you exceed an Action Level****
If you exceed the lead or copper action level, contact EGLE immediately to discuss next steps.

The Lead/Copper Rule is being revised at the time of this writing. Always go to Michigan.gov/LCR on the web to get the latest information and reporting forms.

ANSWERS TO CHAPTER 12 PROBLEMS

1. $\text{ppm} = \frac{\text{lbs chemical}}{\text{Mlbs of water}}$

$$\text{ppm} \times \text{million lbs of water} = \text{lbs of chemical}$$

$$150{,}000\ \cancel{\text{gal}}\ \text{of water} \times \frac{8.34\ \text{lbs}}{1\ \cancel{\text{gal}}} = 1{,}251{,}000\ \text{lbs} \div 1{,}000{,}000$$
$$= 1.25\ \text{M lbs water}$$
$$1.25\ \text{M lbs} \times 3.2\ \text{ppm} = 4\ \text{lbs of phosphate}$$

2. $\text{ppm} = \frac{\text{lbs chemical}}{\text{Mlbs of water}}$

$$\frac{210\ \text{gal}}{1\ \cancel{\text{min}}} \times \frac{60\ \cancel{\text{min}}}{1\ \cancel{\text{hr}}} \times 7\ \cancel{\text{hrs}} = 88{,}200\ \text{gal water}$$

$$\frac{88{,}200\ \cancel{\text{gal}}}{1\ \text{day}} \times \frac{8.34\ \text{lbs}}{1\ \cancel{\text{gal}}} = 735{,}588\ \text{lbs/day} \div 1{,}000{,}000 = 0.736\ \text{M lbs/day}$$

$$2.5\ \text{ppm} \times 0.736\ \text{M lbs/day} = 1.84\ \text{lbs phosphate/day}$$

3. $\text{ppm} = \frac{\text{lbs chemical}}{\text{Mlbs of water}}$

$$\frac{300\ \text{gal}}{1\ \cancel{\text{min}}} \times \frac{60\ \cancel{\text{min}}}{1\ \cancel{\text{hr}}} \times 16\ \cancel{\text{hrs}} = 288{,}000\ \text{gal/day}$$

$$\frac{288{,}000\ \cancel{\text{gal}}}{1\ \text{day}} \times \frac{8.34\ \text{lbs}}{1\ \cancel{\text{gal}}} = 2{,}401{,}920\ \text{lbs/day} \div 1{,}000{,}000 = 2.4\ \text{M lbs/day}$$

$$\frac{10\ \text{lbs/day}}{2.4\ \text{M lbs/day}} = 4.17\ \text{ppm}$$

4. $\text{ppm} = \frac{\text{lbs chemical}}{\text{Mlbs of water}}$

$$\text{mg/L} = \text{ppm}$$

$$\text{ppm} \times \text{million lbs of water (M lbs)} = \text{lbs of chemical}$$

$$0.5\ \text{MGD} = 500{,}000\ \text{gal/day}$$

$$\frac{500{,}000\ \cancel{\text{gal}}}{1\ \text{day}} \times \frac{8.34\ \text{lbs}}{1\ \cancel{\text{gal}}} = 4{,}170{,}000\ \text{lbs/day}\ \div 1{,}000{,}000$$

$$= 4.17\ \text{M lbs/day}$$

COMPOUND A

$$\frac{4.17\ \text{M lbs}}{1\ \text{day}} \times 3.1\ \text{ppm} = 12.93\ \text{lbs of}\ \text{PO}_4{}^{-2}/\text{day}$$

$$\frac{12.93\ \cancel{\text{lbs}}\ \ \text{PO}_4{}^{-3}}{10.4\ \cancel{\text{lbs}}/\text{gal}} = 1.24\ \text{gal/day}$$

$$1.24\ \text{gal/day} \times \$1.25/\text{gal} = \$1.55/\text{day}$$

COMPOUND B

$$\frac{4.17\ \text{Mlbs}}{\text{day}} \times 3.3\ \text{ppm} = 13.76\ \text{lbs of}\ \text{PO}_4{}^{-2}/\text{day}$$

$$\frac{13.76\ \cancel{\text{lbs}}\ \ \text{PO}_4{}^{-3}}{10.4\ \cancel{\text{lbs}}/\text{gal}} = 1.32\ \text{gal/day}$$

$$1.32\ \text{gal/day} \times \$1.10/\text{gal} = \$1.45/\text{day}$$

CHAPTER 13 – Iron and Manganese Removal

Iron and manganese are metals commonly found in the earth's crust and, as such, are routinely found in ground waters. Iron and manganese are essential nutrients in low doses. In 2004, the USEPA issued a lifetime health advisory level for manganese at concentrations above 0.3 milligrams per liter (mg/L) to protect against concerns of potential neurological effects. In addition, both metals can cause aesthetic problems if present in high enough concentrations.

The most noticeable effect of elevated levels of iron and manganese is staining. Where iron concentrations exceed 0.3 mg/L, brown stains may occur on plumbing fixtures, sinks, tubs, and laundry. Similarly, black stains may occur when manganese concentrations exceed 0.05 mg/L.

Another consequence of iron and manganese in water is that they promote the growth of bacterial slimes in the distribution system. These slimes are rust colored from iron and black from manganese. Foul tastes and odors are often associated with these slimes, and dirty water may occur if the slimes break loose.

TREATMENT

Oxidation/Detention/Filtration

Both iron and manganese can be treated in the same manner. The method most commonly used to remove these metals from the water involves oxidation, detention, and filtration. An example iron removal process utilizing aeration, detention, and filtration is illustrated in Figure 13.1.

Oxidation

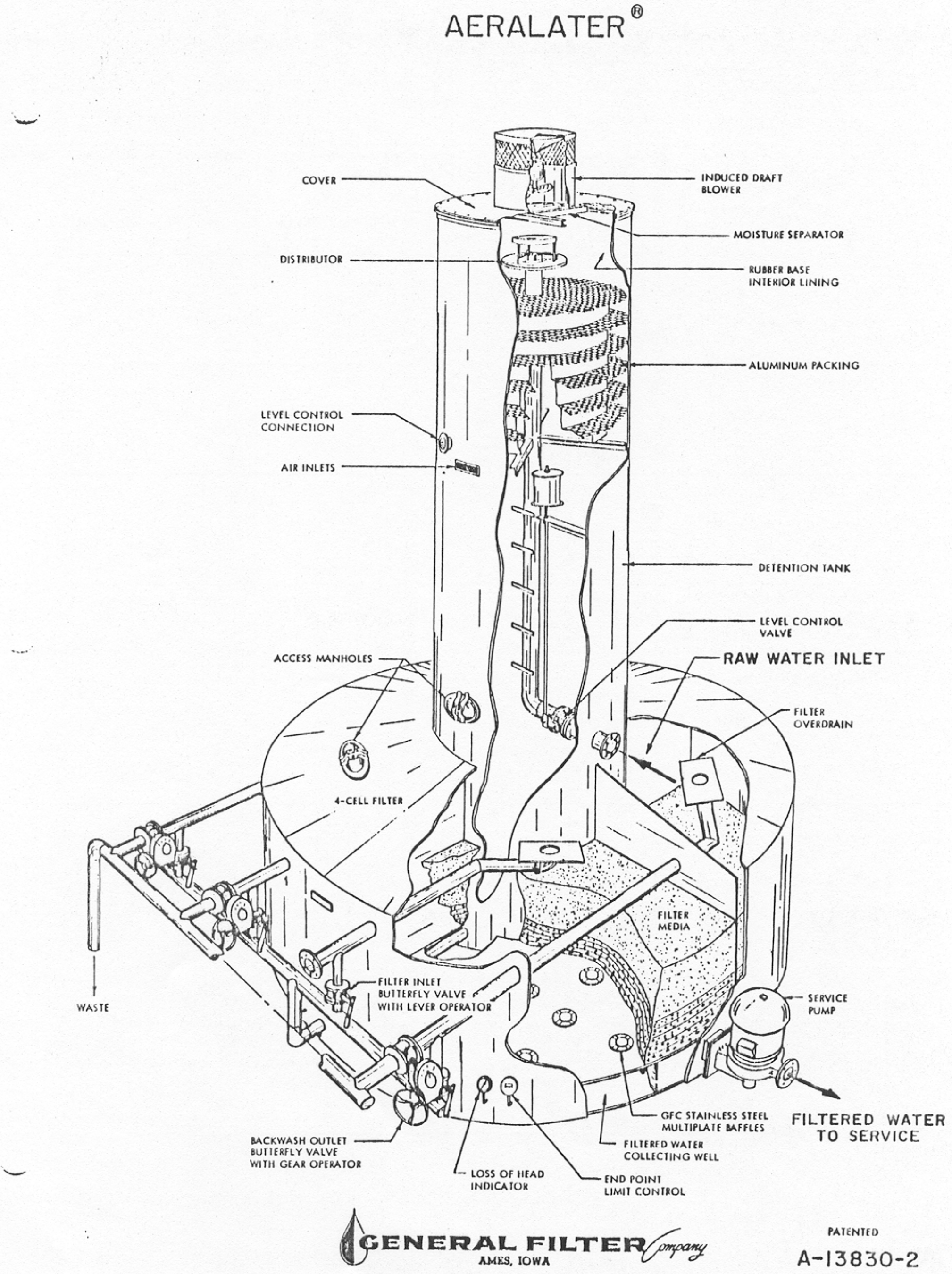
Iron and manganese that are present in groundwater are typically in the reduced state. When oxidized, iron is converted to ferric hydroxide, and manganese to manganese dioxide. Both of these compounds are insoluble and can be readily removed by filtration.

There are several methods utilized to oxidize the soluble metals to insoluble compounds – these generally include aeration and chemical oxidation with chlorine or sodium/potassium permanganate.

The aeration method of oxidation is most commonly used in the removal of iron, and simply involves adding air to the water. This can be accomplished through forced draft, multiple trays, cascades, sprays, diffusers, etc. This method is not generally utilized in the removal of manganese since the oxidation of manganese by aeration is so slow. Chlorination is required whenever aeration is employed.

Oxidation can also be accomplished through the addition of chlorine or sodium/potassium permanganate. Chlorine is a stronger oxidant than molecular oxygen, but does not efficiently oxidize manganese, nor organically bound iron and manganese. Sodium/Potassium permanganate is a very effective chemical for oxidizing iron and manganese because the reactions are complete, rapid, and require low chemical doses. Sodium/Potassium permanganate is recognized by the deep purple color that will go away once the oxidant is used up. Care must be taken to avoid overdosing as pink water can result from too large a dose.

Figure 13.1 Iron Removal Using Aeration



Detention

It is often necessary to provide a detention basin following oxidation to allow sufficient time for the oxidation reactions to take place. The detention time required for adequate oxidation is dependent on the concentration of iron and manganese, the type of oxidant being used, and the pH of the water. For example, a minimum detention time of 20 minutes should be provided for oxidation of iron with aeration, while iron oxidation with chlorine can occur in less than 10 seconds. The pH of the water influences the time for the reaction to take place (the higher the pH due to higher concentrations of hydroxide ions, the faster the reaction).

Filtration

The last step in the treatment process is to pass the water through filters where the insoluble iron and manganese are removed. These filters are generally pressurized filters containing sand and/or anthracite. Filtration may also be done using gravity or vacuum filters. The usual maximum rate of filtration is about 3 gallons per minute per square foot of filtering area. Eventually, these filters will accumulate large amounts of the iron and/or manganese precipitates which will cause a pressure loss through the filter. When the pressure loss reaches 3 to 5 psi, the unit should be backwashed. In some cases, the iron and/or manganese may break through the filter before a significant headloss has developed.

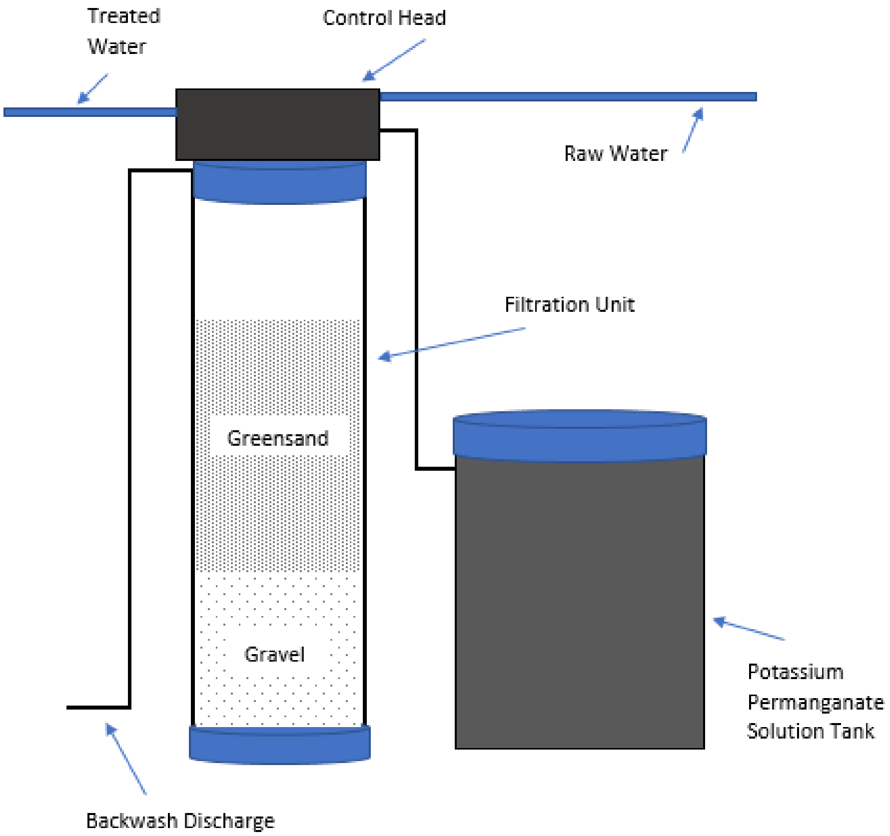
This generally indicates that there is a problem with the filter media which is allowing this to occur. The filter should be inspected for mud balls, mounding, cracking, etc., and corrected. The average backwash rate for a pressure sand filter is 12 to 15 gallons per minute per square foot of filtering area. For an anthracite filter, the rate is approximately 10 gal/min/ft^2, and for greensand (discussed below), the rate is 9 to 10 gal/min/ft^2. The backwash water is usually disposed into a sanitary sewer or an infiltration basin. A groundwater discharge permit may be necessary when discharging to an infiltration basin for disposal, but sampling of the backwash water may be conducted to maintain an exemption from permitting under Part 22 rules.

Greensand/Manganese Oxide Coated Media

Iron and manganese can also be effectively removed by filtering the water through manganese-treated greensand. Manganese greensand is a mineral, glauconite, that is often coated with manganese oxide and capable of oxidizing iron and manganese to their insoluble, filterable states. Greensand/manganese oxide coated media can be operated in a continuous regeneration or intermittent regeneration method. For the continuous regeneration, an oxidant, typically chlorine or permanganate, is fed ahead of the filter and the oxidant will aid in the removal of the iron and manganese. For the intermittent regeneration, the greensand/manganese oxide coated media will oxidize the iron and manganese to the insoluble form and filter them out. During the backwash, the media is regenerated with permanganate.

The typical process of continuous regeneration is illustrated in Figure 13.2 and involves continuously adding potassium permanganate to the raw water as it is applied to the greensand filter. The iron and manganese oxidized by the permanganate will be trapped by the filter. The greensand/manganese oxide coated media will absorb any overfed permanganate and the greensand/manganese oxide coated media will oxidize any iron and manganese remaining in solution from contact with the media surface and trap it in the filter media. If the greensand/manganese oxide coated media becomes exhausted due to underfeeding of permanganate or operated as intermittent regeneration, it can be regenerated by either increasing the permanganate dosage or by backwashing the filter with a permanganate solution. Like a conventional filter, greensand/manganese oxide coated media will need to be backwashed on occasion to clean the media of trapped particles, which includes the insoluble iron and manganese. One major advantage of this treatment method over the aeration/detention/filtration method is that double pumping is eliminated.

Figure 13.2 Greensand System



Ion Exchange

Ion exchange resins identical to those used for water softening are effective in removing small amounts of soluble iron and manganese. In this case, sodium ions are exchanged for iron and manganese ions. However, this process is extremely expensive. In addition, the resins can easily become fouled with iron and manganese hydrates. For these reasons, ion exchange is not generally utilized as an iron or manganese removal technique. However, where ion exchange is practiced for softening purposes, iron and manganese may be reduced as a side benefit. Care must be exercised to minimize fouling of the exchange resin.

Example: If a well is pumping 500 gpm and the iron content is 0.5 ppm, how many pounds of iron are removed in 24 hours if all of the iron is removed? What is the amount of wash water used if the filters are backwashed at 12 gal/min ×ft^2 for 10 minutes, if the filter diameter is 10 feet?

Solution:

$$\frac{500\ \text{gal}}{1\ \cancel{\text{min}}} \times \frac{60\ \cancel{\text{min}}\ \text{hrs}}{1\ \cancel{\text{hr}}} \times \frac{24\ \cancel{\text{hr}}}{1\ \text{day}} = 720{,}000\ \text{gal of}\ water/day$$

$$\frac{720{,}000\ \cancel{\text{gallons}}}{1\ \text{day}} \times \frac{8.34\ \text{lbs}}{1\ \cancel{\text{gal}}}$$

$$= 6{,}004{,}800\ \text{lbs water/day} \div 1{,}000{,}000$$

$$= 6\ \text{M lbs water/day}$$

$$\text{ppm} \times \text{million lbs of water} = \text{lbs of chemical}$$

$$0.5\ \text{ppm} \times 6\ \text{million lbs water/day} = \mathbf{3\ lbs\ iron/day}$$

$$\text{A} = 0.785\text{d}^2 = 0.785 \times 10\text{ft} \times 10\text{ft} = 78.5\text{ft}^2$$

$$78.5\ \text{ft}^2 \times \frac{12\ \text{gal}}{1\ \text{min}} \times \frac{1}{\text{ft}^2} = \frac{942\ \text{gal}}{\text{min}} \times 10\ \text{min} = 9{,}420\ \text{gal of water}$$

SAMPLE PROBLEMS

(1) A. How many minutes can a 15-foot diameter filter be backwashed at a rate of 9 gpm/ft^2 if a 20,000-gallon wash water tank is used?

B. If the average daily pumpage rate was 450 gpm and the raw water iron content was 0.7 ppm, how many pounds of iron would be removed in 72 hours?

(2) A city pumps at a rate of 720 gpm for 10 hrs/day into its iron removal plant. The raw water iron concentration is 3 mg/L and the effluent iron concentration is 0.2 mg/L. How many pounds of iron are removed per day?

(3) A city's filter is 10 feet in diameter. It pumped 0.7 MG over a 16-hour period.

A. What is the filtration rate in gpm/ft^2?

B. If the filter is backwashed at a rate of 15 gpm/ft^2 for 30 minutes, how much water is used?

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ANSWERS TO CHAPTER 13 PROBLEMS

1. A.

$$A = \pi \frac{d^2}{4} = 3.14 \frac{15^2}{4} = 176.7 \text{ ft}^2$$

$$176.7 \cancel{\text{ft}^2} \times \frac{9 \text{ gpm}}{1 \cancel{\text{ft}^2}} = 1{,}590 \text{ gpm} \qquad \frac{20{,}000 \text{ gallons}}{1{,}590 \text{ gal/min}} = 12.58 \text{ minutes}$$

B.

$$\frac{450\text{ gal}}{1\ \cancel{\text{min}}} \times \frac{60\ \cancel{\text{min}}}{1\ \cancel{\text{hr}}} \times 72\ \cancel{\text{hr}} = 1{,}944{,}000 \text{ gallons}$$

$$1{,}944{,}000\ \cancel{\text{gal}} \times \frac{8.34 \text{ lbs}}{1\ \cancel{\text{gal}}} = 16{,}200{,}000 \text{ lbs water} \div 1{,}000{,}000$$
$$= 16.2 \text{ M lbs water}$$

$$\text{ppm} \times \text{million lbs of water} = \text{lbs of chemical}$$

$$0.7 \text{ ppm} \times 16.2 \text{ million lbs water} = 11.34 \text{ lbs of iron}$$

2. $\frac{720\text{ gal}}{1\ \cancel{\text{min}}} \times \frac{60\ \cancel{\text{min}}}{1\ \cancel{\text{hr}}} \times \frac{24\cancel{\text{hr}}}{1\ day} = 432{,}000 \text{ gallons/day}$

$$\frac{432{,}000\ \cancel{\text{gal}}}{1 \text{ day}} \times \frac{8.34 \text{ lbs}}{1\ \cancel{\text{gal}}} = 3{,}602{,}880 \text{ lbs/day} \div 1{,}000{,}000$$
$$= 3.6 \text{ M lbs/day}$$

$$3.0 - 0.2 = 2.8 \text{ mg/L} = 2.8 \text{ ppm}$$

$$2.8 \text{ ppm} \times 3.6 \text{ Mlbs/day} = 10.1 \text{ lbs iron/day}$$

3. A.

$$0.7 \text{ MG} = 700{,}000 \text{ gallons}$$

$$700{,}000 \text{ gallons} \div 1.16 \text{ hrs} \div 60\ min/hr = 729\ gal/min$$

$$10 \text{ foot diameter} = 5 \text{ foot radius} \qquad \text{A} = \pi r^2 = 3.14(5\ ft^2) = 78.5\ ft^2$$

$$\text{rate} = \frac{729 \text{ gpm}}{78.5 \text{ ft}^2} = 9.3 \text{ gpm/ft}^2$$

B.

$$15 \text{ gpm/ft}^2 \times 78.54 \text{ ft}^2 = 1{,}178 \text{ gpm}$$
$$1{,}178 \text{ gpm} \times 30 \text{ min} = 35{,}340 \text{ gallons}$$

CHAPTER 14 – Ion Exchange Softening

INTRODUCTION TO WATER SOFTENING

Hard water is generally water that contains high amounts of dissolved minerals – divalent cations - largely calcium and magnesium (iron and manganese can also contribute to hardness but to a lesser degree). Hard water is most evident when considerable amounts of soap is required to produce a foam or lather. In addition, hard water will also produce scale in hot water pipes, water heaters, boilers, and other units in which the temperature of water is increased. The soap consuming capacity is most important because of the economic aspects and because of the difficulty encountered in obtaining suitable conditions for optimum cleansing.

The hardness of water varies considerably around the State of Michigan. In general, surface water is softer than groundwater. The hardness of water reflects the nature of the geological formations with which it has been in contact. For example, hard water can originate in areas where groundwater has been in contact with either a limestone or dolomite formation or the unconsolidated aquifer (e.g., glacial outwash) contains calcium and magnesium minerals. Conversely, soft water would be groundwater located where limestone and dolomite formations are sparse or absent and/or the unconsolidated aquifer (e.g., glacial outwash) contains very little calcium and magnesium minerals.

Table 14.1 Waters are commonly classified in terms of degree of hardness:

0 - 60 mg/L as $CaCO_3$	Soft
61 - 120 mg/L as $CaCO_3$	Moderately hard
121-180 mg/L as $CaCO_3$	Hard
180&up mg/Las $CaCO_3$	Very Hard

(Most Michigan groundwaters are considered hard.)

HARDNESS REDUCTION

There are two methods generally employed to reduce hardness: the precipitation method and the ion exchange method. In the precipitation method, lime and soda ash are added to hard water to precipitate calcium carbonate and magnesium hydroxide. This reduces the concentration of calcium and magnesium ions in the water, thus lowering the hardness. While the chemical cost for treating large amounts of water utilizing this method is relatively low, a large initial investment is necessary to construct the treatment plant. As a result, this method is not generally used for treatment of smaller ground water supplies. Also, with using lime softening it is impossible to remove all the hardness from water. Ion exchange softening will be discussed in greater detail below.

TERMS ASSOCIATED WITH ION EXCHANGE SOFTENING

Backwashing -- To wash upwardly through a bed of softening filtering material. Done to cleanse material of suspending matter or dirt.

Brine -- A solution of sodium chloride (salt) used for regenerating water softeners.

Calcium -- One of the principal elements making up the earth's crust, the compounds of which dissolved in water make the water hard. The presence of calcium in water is a factor contributing to the formation of scale and insoluble soap curds, which are means of clearly identifying hard water.

Cation -- A positively charged ion which is attached to the cathode in electrolysis.

Cation Exchange -- In water softening is principally the exchange of calcium and magnesium ions in water for sodium or potassium ion on an insoluble ion exchange material. Ferrous iron and other metals such as manganese and aluminum are sometimes present in small quantities. These metals are also exchanged but they may precipitate and foul the exchanger bed.

Collectors -- A term used to identify a system designed to collect backwash water from the surface of ion exchange beds.

Corrosion -- The attack by water of any part of a water system, causing the wasting away of metal parts. This would include the most noticeable effects of corrosion, which are: leakage, flow stoppage, valve failure, etc.

Crenothrix -- The name given to iron bacteria.

Cubic Feet -- The volumetric unit used for measuring ion exchange materials. Volume is measured on an in place, backwashed, drained, and settled condition.

Distributors -- Devices located at the top or bottom of a water softener to distribute or collect the water and to retain the cation exchange material in the units.

Downflow -- A term applied to designate the direction (down) in which water flows through the ion exchange during any phase of the operating cycle of a household water softener.

Drain -- A line used to carry backwash water, spent regenerant, and rinse water to the wastewater system.

Effluent -- The water or solution which emerges from a water softener during any phase of the operating cycle.

Flow Rate -- The quantity of water and/or brine flowing measured in gallons per minute (gpm).

Grains Per Gallon (gpg) -- A common basis of reporting water analysis in the United States (U.S.) and Canada. One grain per U.S. gallon equals 17.1 milligrams per liter or 17.1 parts per million.

Hardness -- Dissolved calcium and magnesium salts in water; compounds of these two elements are responsible for most scaling in pipes and water heaters and cause numerous problems in laundry, kitchen, and bath. Hardness is often expressed in grains per gallon as calcium carbonate equivalent.

Hardness Leakage -- Calcium and magnesium present in water after passing through a water softener.

Hard Water -- Water containing calcium and magnesium salts in concentration of 121 milligrams per liter or more (as calcium carbonate equivalent).

Ion -- An electrically charged atom, radical, or molecule formed by the loss or gain of one or more electrons.

Ion Exchange -- A process whereby ions in solution are interchanged by a reactive material (see Ion Exchanger).

Ion Exchanger -- An insoluble reactive material capable of interchanging ions combined with the material for ions in the solution.

Iron -- Iron is an element often present in ground waters in a soluble form (such as ferrous bicarbonate) in quantities usually ranging from 0.5 to 10 parts per million. It is sometimes present in larger amounts. Iron may exist in surface waters due to natural causes or pollution. Iron in solution is susceptible to oxidation, precipitating as a reddish-brown floc when contacted by air (causing staining and discoloration). Iron can be removed by aeration or chlorination followed by filtration. Iron in solution can be removed by ion exchange. Oxidizing filters such as manganese treated zeolite are used for removing large amounts of iron from household water supplies.

Magnesium -- One of the elements making up the earth's crust, the compounds of which when dissolved in water makes the water hard. The presence of magnesium in water is a factor contributing to the formation of scale and insoluble soap curds, which are a means of clearly identifying hard water.

Parts Per Million (ppm) = Milligrams Per Liter (mg/L) -- A common basis of reporting water analysis in the United States and Canada. One part per million (ppm) equals 1 pound per million pounds of water, 17.1 ppm equals one grain per U.S. gallon.

Pressure Drop -- A decrease of water pressure across a distance or media that is measured in pounds per square inch (psi).

Rated Softening Capacity -- Softening capacity rating shall be based on grains of hardness removed (as calcium carbonate) while producing soft water between successive regenerations and must be related to pounds of salt required for each regeneration.

Regeneration -- That part of the operating cycle of a water softener in which a sodium or potassium chloride solution is rinsed through the cation exchange bed to remove hardness ions and prepare it for a service run.

Resin -- The term used to designate a synthetic organic ion exchange material such as high-capacity cation exchange resin widely used in water softeners.

Rinse -- That part of the regeneration cycle of a water softener where fresh water is introduced to remove spent regenerant and excess salt prior to placing the softener into service.

Salt -- High purity sodium chloride of a granular, rock, or briquetted type used for regenerating a water softener.

Service Run -- That part of the operating cycle of a water softener in which hard water supply is passed through a regenerated and rinsed bed of ion exchange material, thereby producing soft water.

Siliceous Gel -- A manufactured granular hydrated sodium alumina silicate often called synthetic zeolite, used in water softeners.

Soft Water -- Water containing less than 1 grain per gallon of dissolved calcium and magnesium salts (as calcium carbonate equivalent).

Upflow -- A term applied to designate the direction (up) in which water flows through the ion exchange bed during any phase of the operating cycle.

Zeolite -- A name given to ion-exchange minerals.

ION EXCHANGE SOFTENING

The ion exchange treatment process for water softening involves passing water through a media bed that has the ability to exchange hardness causing divalent cations (calcium and magnesium) with non-hardness monovalent cations (mostly sodium). As water is passed over this media, often a microporous resin that is supersaturated with sodium, the loosely held non-hardness causing cations (sodium or potassium) attached to the media are exchanged with hardness causing cations (calcium and magnesium) present in the water. This exchange will continue until the media has been exhausted. The exhausted media is then regenerated with a brine and the softening process initiated again.

Several materials are available to serve as an ion exchange media. Historically, natural occurring minerals, referred to as zeolite, were used for this purpose. Today, microporous synthetic resins are most often used due to their greater exchange capacity. These resins are small porous beads which provide numerous sites where the exchange of ions can occur. Typically, these resins have a capacity to remove between 20,000 and 30,000 grains (approximately 1,300-1,950 grams) of hardness per cubic foot of resin.

(1 grain per gallon = 17.1 mg/L of hardness as $CaCO_3$).

The exchange media utilized in the softeners have a preference for multivalent cations (ions with a positive charge greater than one) because they form more stable compounds with these ions. As such, they easily give up monovalent cations (ions with a positive charge of one) such as Na^+ for divalent cations (ions with a positive charge of two) such as Ca^{++} and Mg^{++}. This reaction can be described by the following formula:

$$X^{2+} + Na_2Z \leftrightarrow XZ + 2Na^+$$

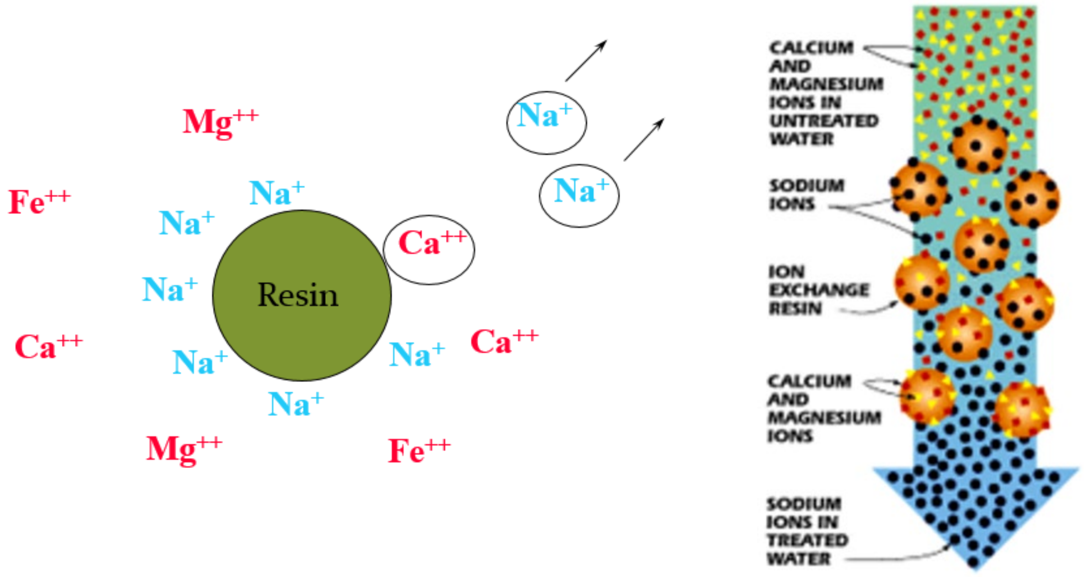
where X = hardness causing cations (Ca^{2+}, Mg^{2+}, Fe^{2+}, Mn^{2+}, Sr^{2+})

Na = sodium (Na^+)

Z = ion exchange media

From the equation above and as shown in Table 14.1, two sodium ions are needed to replace (exchange with) each hardness causing ion to maintain a balanced equation. This is because each hardness ion has a charge of two, while sodium has only a charge of one. The above reaction can also be reversed by increasing the concentration of sodium ions. This allows for regeneration of the media by passing a brine solution down through the softener.

Figure 14.2 Illustration of Ion Exchange



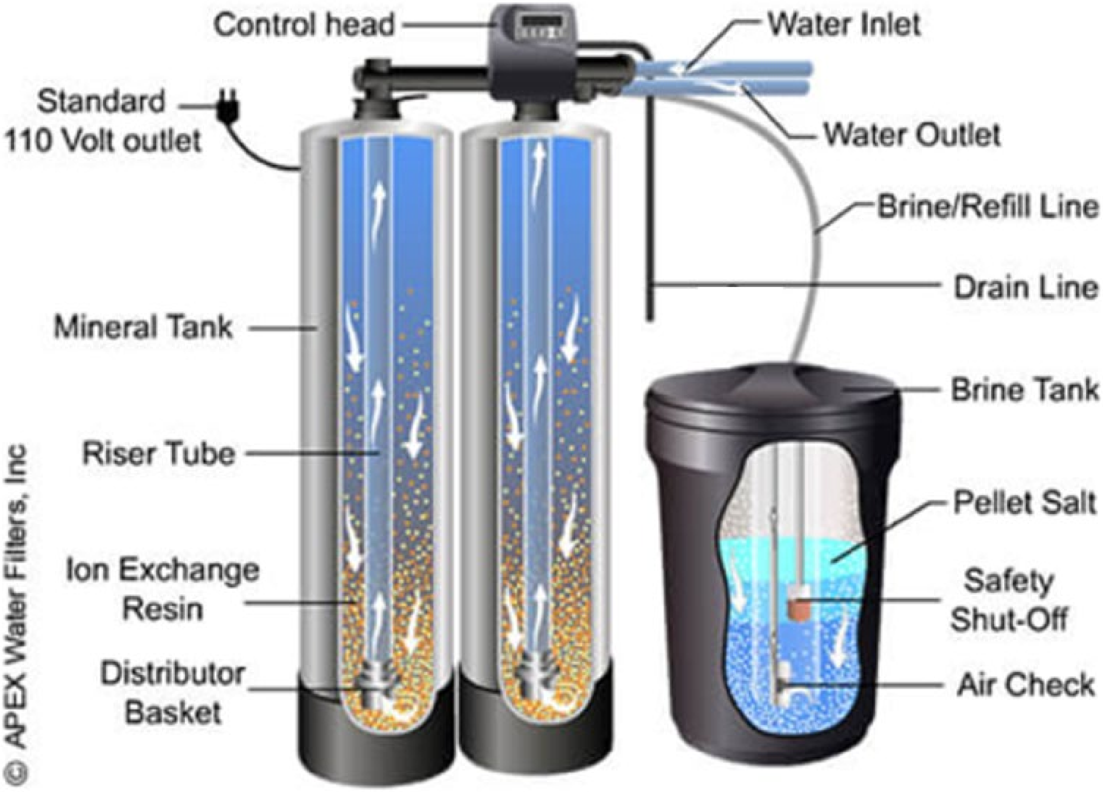
Operation

Most ion exchange softeners operate as pressurized systems with a downward flow of water through the exchange resin. The water enters the unit through an inlet distributor at the top, is forced by pressure through the exchange media where the hardness ions are exchanged for non-hardness ions, then flows into an outlet structure and into the distribution system. Refer to Figure 14.3 for a typical downflow pressure softener.

Water leaving the softener contains nearly zero hardness. Such water is corrosive and aesthetically objectionable. In general practice, a portion of the raw water is routed to bypass the softener, then added back to provide a blend of softened water and unsoftened water. The amount of water bypassed is typically adjusted so that the water entering the distribution system has a total hardness of about 80 to 100 mg/L as $CaCO_3$

The ion exchange process continues automatically until the supply of sodium ions in the exchange resin is almost depleted. When this occurs, increasing numbers of hardness ions pass through the bed, unremoved, and the softener is termed "exhausted.”

Figure 14.3 Typical Downflow Pressure Type Softener



Backwash

Once the softener has been exhausted, it is necessary to take the unit out of service to clean and regenerate the resin. This is accomplished in a three-stage process.

In the first stage, water is reversed through the unit to loosen the resin and clean it of material that may have been deposited there. These deposits can include iron and manganese particulates and other debris. To properly clean the unit, it is necessary to expand the bed 50 to 95 percent for approximately 5 to 10 minutes. This provides for the proper shearing and scrubbing action.

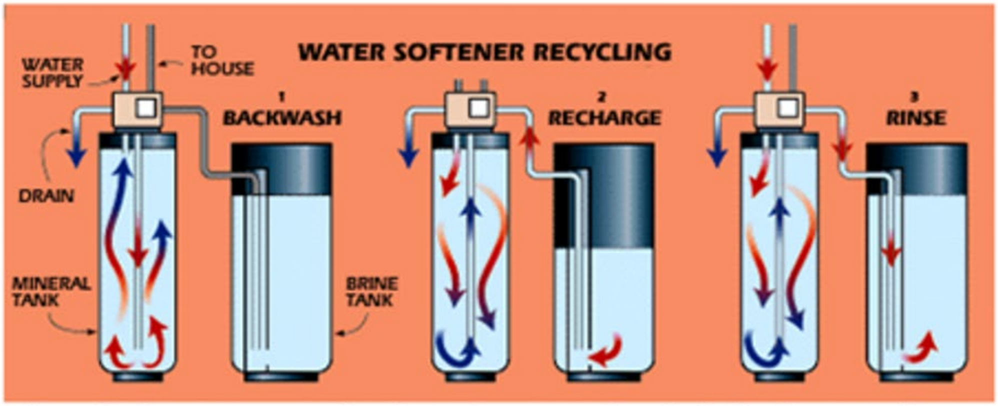
In the second stage, a brine solution is passed through the unit to regenerate the resin. The optimum brine concentration coming in contact with the resin is about 10 percent salt. A fully saturated brine solution (about 26 percent salt) is not recommended as it is less efficient and may cause the resin to eventually break up. The brine solution is passed through the resin until the water is again soft, usually at the end of 45 to 60 minutes, depending on the size and type of filter. In general, it takes about 2 to 3 mg/L of salt to displace each mg/L of hardness. If properly done, the resin should be completely recharged with sodium ions.

After the resin has been recharged, it is necessary to rinse the remaining waste products and excess brine from the softener. To accomplish this, the unit is basically placed in service except that the softener effluent goes to waste instead of to the distribution system. This rinse stage generally lasts between 20 and 40 minutes. Refer to Figure 14.4 for a description of the backwash cycles.

Upon completion of the backwash cycle, all of the calcium and magnesium ions should have been removed from the resin and replaced with sodium ions. At this point, the bed has been cleaned and recharged and is ready to produce a softened water again.

It should be noted that the method of disposing of the softener backwash water is often a major consideration. This waste discharge, consisting mostly of calcium, magnesium, and sodium chlorides, must be disposed of properly to prevent potential environmental damage. Generally, these wastes are discharged to nearby sanitary sewers. Where sewers are not available, it may be possible to obtain permits to discharge the waste to surface or ground waters in a controlled manner.

Figure 14.4 Water Softener Cycles



1. The backwash phase removes dirt from the mineral tank. 2. Recharging the mineral tank with sodium from the brine solution displaces calcium and magnesium, which is then washed down the drain. 3. The final phase rinses the mineral tank with fresh water and loads the brine tank so it's ready for the next cycle.

Meters

A meter is usually included in the effluent lines as standard equipment on all large industrial and municipal softeners. In automatic service, the meter is equipped with an electrical contact, which starts the regeneration cycle after the passage of a preset volume of water. During regeneration, the electrical component of the meter resets automatically for the next softening cycle. On manual softeners an electrical contact is made in the meter, which gives an alarm at the end of the softening cycle. These meters are reset manually as a part of the manual regeneration operation. Meters may also be used during the regeneration to measure the amount of brine and dilution water necessary. Small domestic units meter regeneration solutions through orifices on a time basis.

Brine and Salt Storage Tanks

Tanks or basins for the dissolving of salt and storage of brine can take several different forms, depending to a great degree on the size of the softener to be served. In domestic and small industrial softeners, the brine tank serves both as a salt storage and concentrated-brine storage tank. During the brining cycle, the concentrated brine is withdrawn from the bottom of the tank while freshwater is introduced at the top. An excess of undissolved salt in the tank ensures an ample supply of concentrated brine. In large installations, the salt is dissolved in a wet-storage basin or tank, and the brine is transferred to a holding tank from which it is introduced into the softener. The wet-storage basin is desirable in an installation requiring large quantities of brine. The capacity of these basins varies from several tons up to many carloads of salt.

Example: If a pumping rate is 250 gpm and the water contains 18.1 grains per gallon of hardness, how many pounds of hardness are removed in 24 hours? Assume all hardness is removed. (1 grain/gal = 17.1 ppm)

Solution:

$$\frac{18.1\ \text{grains}}{\text{gallon}} \times \frac{17.1\ \text{ppm}}{1\ \text{grain}} = 309.5\ \text{ppm}$$

$$\frac{300\ \text{gal}}{1\ \cancel{\text{min}}} \times \frac{60\ \cancel{\text{min}}}{1\ \cancel{\text{hr}}}\ \frac{24\ \cancel{\text{hrs}}}{1\ \text{day}} = 360{,}000\ \text{gal of water/day}$$

$$\frac{360{,}000\ \cancel{\text{gal}}}{1} \times \frac{8.34\ \text{lbs}}{1\ \cancel{\text{gal}}} = 3{,}002{,}400\ \text{lbs}\ \div 1{,}000{,}000$$

$$= 3.0\ \text{M lbs water}$$

$$309.5\ \text{ppm} \times 3.0\ \text{million lbs} = 928.5\ \text{lbs of hardness removed}$$

Example: If a pumping rate is 250 gpm and the water contains 18.1 grains per gallon of hardness, how many gallons of water can be softened to zero hardness without regeneration through a softener with a media capacity of 90 cubic feet and a resin capacity of 15,000 grains per cubic foot? (Assume breakthrough does not occur.)

Solution:

$$90\ \cancel{\text{ft}^3} \times \frac{15{,}000\ \text{grains}}{1\ \cancel{\text{ft}^3}} = 1{,}350{,}000\ \text{grains capacity of softener}$$

$$\frac{18.1\ \text{grains}}{1\ \cancel{\text{gallon}}} \times \frac{250\ \cancel{\text{gal}}}{1\ \text{min}} = 4{,}525\ \text{grains per minute}$$

$$1{,}350{,}000\ \text{grains} \div 4{,}525\ \text{grains/min} = 298.34\ \text{min}$$

$$\frac{250\ \text{gal}}{\text{min}} \times 298.34\ \text{min} = 74{,}585\ \text{gallons of water}$$

OR

$$90\ \cancel{\text{ft}^3} \times \frac{15{,}000\ \text{grains}}{1\ \cancel{\text{ft}^3}} = 1{,}350{,}000\ \text{grains capacity of softener}$$

$$\frac{1{,}350{,}000\ \cancel{\text{grains}}\ \text{capacity}}{18.1\ \cancel{\text{grains}}/\text{gallon}} = 74{,}585\ \text{gallons}$$

SAMPLE PROBLEMS

(1) If a pumping rate is 500 gpm and the water contains 19 grains per gallon of hardness, how many gallons of water can be softened to zero hardness without regeneration through a softener with a media capacity of 100 cubic feet and a resin capacity of 14,750 grains per cubic foot?

(2) If a pumping rate is 75 gpm and the water contains 25 grains per gallon hardness, how many pounds of hardness are removed in one day?

Limitations

Iron and Manganese: Iron in the softener feedwater, in either the precipitated or solution form, will significantly affect the exchange capacity of the resin. The problem is compounded by the fact that iron in water can take so many forms. Iron in the ferrous state will be removed from solution by ion exchange. If the iron remains in this form on the resin, it may be removed and flushed to waste with the subsequent regeneration. This appears to take place almost entirely at the surface of the particles. Some of the iron ions are exchanged deep within the structure of the resin particle. Here, the iron may be oxidized by dissolved oxygen to a stable non-exchangeable form. Hardness, chlorine, and pH of the water can intensify the problem. After this occurs, no amount of salt brine will remove the internally precipitated iron oxide. In iron-bearing waters, this one-way exchange may continue until most of the operating exchange capacity is lost.

If the iron is oxidized prior to softening and the resulting gelatinous ferrous hydroxide is not removed, it will be filtered out in the resin bed. Removal of the flocculent precipitate from the softener bed will present problems. If sufficient time elapses after the iron is precipitated until it contacts the softener, it will change from the hydroxide to an oxide form. The gelatinous property will be lost, and the iron will be filtered out by the bed. Most of this debris iron will be removed during backwashing.

The iron which precipitates on the inside of the resin beds, or which sticks to the outside, causes them to take on a dark red (rusty) appearance. If iron is present in the softener influent, a significant loss in exchange capacity may be lessened by contacting the resin with a solution of sodium bisulfate ($NaHSO_3$) or sodium hydrosulfite ($Na_2S_2O_4$). These chemicals may be mixed with the regeneration brine and the cleansing operation accomplished along with the regeneration. However, the resin supplier or manufacturer should be consulted before undertaking this chemical rejuvenation method.

Severe cases of iron fouling can be effectively handled by treating the resin with dilute hydrochloric or sulfuric acid. This method is not generally recommended unless the equipment and piping are made of corrosion-resisting materials.

Manganese in natural waters may also cause resin fouling and loss in exchange capacity. Since this is normally present in lower concentrations in most water sources, they generally pose less complications than iron.

To minimize the above problems, waters with high iron and/or manganese concentrations should not be applied directly to iron exchange softeners. Instead, these waters should be pretreated to reduce the concentration of potentially fouling contaminants. Pretreatment methods, which may be used, include: 1) aeration and filtration, 2) chemical coagulation and filtration, 3) chlorination/oxidation and filtration, or 4) use of manganese greensand filters without pretreatment. Also, because ion exchange softeners do not provide barriers against bacteria and viruses, they are not suitable for treating surface waters.

Turbidity and Bacterial Slimes: Poor operation and loss of exchange capacity in the cation exchanger can be caused by organic or inorganic turbidity in the water, which coats the resin particles. It has been shown that bacterial slime may coat resin particles when proper disinfection has not been practiced. The problem resulting from turbidity and bacterial slimes may be a loss in exchange capacity due to the coating, which mechanically blocks the surface of the particles, or it may result in excessive head loss due to deposition of foreign matter at or near the surface of the softener.

Debris which is large enough to be retained on the surface of the bed may be removed by backwashing. However, debris which will carry down through the bed can coat the resin particles and require special methods for removal. Care should be exercised where turbidity is encountered to either remove the material before passing the water to the softeners or to provide special cleaning operations along with the regeneration.

Should bacterial slimes develop within a softener, they can be eliminated by chlorination of the feedwater or by the application of liquid bleach along with the regenerant each time the unit is regenerated. Media manufactures should be consulted before any chemical is added on the resin to help avoid media degradation. Coatings of bacterial slimes may be removed by applying warm caustic solution to the resin and the softener is allowed to stand for several hours before being backwashed to remove the dead bacterial growth (slime) from the bed.

ANSWERS TO CHAPTER 15 PROBLEMS

(1) $100\ \cancel{\text{ft}^3} \times 14{,}750\ \text{grains}/1\ \cancel{\text{ft}}^3 = 1{,}475{,}000\ \text{grains}$

$$19\ \text{grains}/\cancel{\text{gal}} \times 500\ \cancel{\text{gal}}/\text{min} = 9{,}500\ \text{grains}/\text{min}$$

$$1{,}475{,}000\ \text{grains} \div 9{,}500\ \text{grains}/\text{min} = 155.26\ \text{minutes}$$

$$500\ \text{gal}/\cancel{\text{min}} \times 155.26\ \cancel{\text{min}} = 77{,}630\ \text{gallons of water}$$

OR

$$100\ \cancel{\text{ft}^3} \times 14{,}750\ \text{grains}/\cancel{\text{ft}^3} = 1{,}475{,}000\ \text{grains capacity}$$

$$1{,}475{,}000\ \cancel{\text{grains}} \div 19\ \cancel{\text{grains}}/\text{gal} = 77{,}630\ \text{gal}$$

(2) $75\ \text{gal}/\cancel{\text{min}} \times 60\ \cancel{\text{min}}/\cancel{\text{hr}} \times 24\ \cancel{\text{hr}}/\text{day} = 108{,}000\ \text{gallons}$

$$108{,}000\ \text{gal} \times 8.34\ \text{lbs}/\text{gal} = 900{,}720\ \text{lbs} \div 1{,}000{,}000 = 0.90\ \text{million lbs water}$$

$$25\ \text{grains}/1 \times \frac{17.1\text{ppm}}{1\ \cancel{\text{grain}}} = 427.5\ \text{ppm}$$

$$\text{lbs of chemical} = \text{ppm} \times \text{million lbs water}$$

$$\text{lbs of hardness removed} = 427.5\ \text{ppm} \times 0.90\ \text{M lbs of water}$$

$$\text{lbs of hardness removed} = 385\ \text{lbs}$$

CHAPTER 15 – Miscellaneous Treatment

INTRODUCTION

Water treatment plant operators often receive questions about a variety of water quality issues from their customers or other concerned citizens. Operators are expected to provide answers on subjects or topics in which they may have very little experience. It is therefore desirable for the operator to have some knowledge on many different water treatment techniques.

The intent of this chapter is to familiarize the operator with types of water treatment that other communities may use or that may be used by their customers for a special purpose.

Water treatment done at the customer's location is called "Point of Use" (POU) treatment. POU treatment systems can range from simple filters on a facet to ones that use multiple treatment techniques; the POU treatment systems with multiple treatment techniques could cost up to many thousands of dollars.

Too often customers purchase these systems without fully understanding what they will do and, in many situations, they are an unwarranted expense. Furthermore, the maintenance of the system, or the problems associated with a treatment technique, are not explained to the buyer. Ideally, the water treatment plant operator will be able to educate customers on the water quality, the capability of the POU treatment options, long-term operation and maintenance needs of the systems, and provide resources and contacts for the evaluation of additional treatment needs.

A brief description of several treatment techniques follows.

PRE-COAT FILTRATION

This treatment technique is utilized at several communities along Saginaw Bay. The treatment process is commonly called diatomaceous earth (DE) filtration and is only applicable for certain sources. The communities where it has been approved use the Saginaw-Midland raw water pipeline as a source. This filtration technique is also used extensively at large public swimming pools.

In pre-coat filtration, unclarified, turbid water is passed through a uniform layer of filtering material (filter media) that has been deposited (precoated) on a septum, a permeable material that supports the filter media. The septum is supported by a rigid structure called a filter element. As the water passes through the filter media and septum, insoluble particles of the semi colloidal size and larger are captured and removed.

Generally, precoat filtration is most cost-effective, as is granular direct filtration, when raw water turbidity is moderate to low (10 NTUs or less). Higher turbidity may be handled economically depending on the concentration of the solids to be removed and their physical characteristics.

Pre-Coat/Diatomaceous earth filters do have the advantage of being smaller with less initial cost compared to normal sand filters. Normal sand filters are designed to follow pretreatment, whereas diatomaceous earth filters are designed as the total treatment. Therefore, a diatomaceous earth system must have a relatively clean source of raw water. Due to the requirements of precoating the filters and adding the proper body feed, diatomaceous earth filters require very careful operation. The quality of water these units produce is very dependent on the quality of raw water. A fluctuating raw water quality or a poor raw water quality would be difficult to treat with this type of filtration unit. For these reasons, diatomaceous earth filtration is not commonly used for treating potable water in Michigan. The AWWA has a manual (M30) on precoat filtration for more information.

CARBON ADSORPTION

Powdered Activated Carbon

In many modern complete treatment plants, taste and odor control is conducted. The most common methods for taste and odor control are powdered activated carbon (PAC), free residual chlorination, chlorine dioxide, ozone, and aeration. PAC treatment also removes organic contaminants from water by adsorption, which is the attraction and accumulation of one substance on the surface of another. It has been estimated that one pound of activated carbon has more than 100 acres of surface area for adsorption. Excessive dosages of PAC do not harm the water as it is easily removed by filters. Besides controlling tastes and odors, PAC has been reported to stabilize sludge, improve floc formation, and reduce non-odor causing organics.

PAC is fed to water either as a dry powder or as a wet slurry by special equipment. Slurry feeding has the advantage of being cleaner to handle and assures that the carbon is thoroughly wet to increase its effectiveness. Points of application of carbon vary with local conditions and water problems. PAC may be added to the water at any point ahead of the filters. Adsorption is nearly instantaneous although a contact time is normally helpful. The amount of carbon needed will vary with the type used and water quality; however, a few milligrams per liter of carbon is the usual dosage.

Granular Activated Carbon

The use of granular activated carbon (GAC) has grown recently from the discovery of groundwater contamination by per- and polyfluoroalkyl substances (PFAS), volatile organic chemicals (VOC), total trihalomethanes (TTHM), and even chlorine in drinking water.

GAC may be installed in conventional pressure filter vessels or post filtration columns. The filtration properties of GAC are virtually the same as a comparable size sand or anthracite; therefore, the filters need backwashing provisions to remove accumulated solids with GAC. There is a required contact time for adsorption and the time will depend on the contaminants' affinity to adsorb to carbon. For example, PFAS and many VOCs will require an empty bed contact time between 10-20 minutes with GAC to have the most efficient removal.

A disadvantage to GAC is the potential colonization of the particles by bacteria. These bacteria can then enter the distribution system by sloughing off or if fine carbon particles pass through the treatment process. For application to municipal water treatment, chlorination with contact time after GAC filtration would be required.

Many POU treatment systems will include some type of carbon for the removal of chlorine, VOCs, and other contaminants. In a POU carbon filter, the problem of bacterial growth in the media or the shedding of bacteria to the effluent stream is often ignored and not mentioned in sales presentations or literature. However, some manufacturers have begun to impregnate the carbon with silver, a bacteriostat, which inhibits bacterial growth.

The other major consideration with activated carbon is the adsorption capacity (the media will have a finite adsorption capacity). The actual adsorption capacity for carbon will be dependent on the constituent and the water quality. For example, a filter can only remove a finite mass of TTHM, chlorine, PFAS, and/or benzene. Without monitoring equipment or sampling, it will be unknown when the capacity has been reached and breakthrough could occur, or the filters will be replaced without achieving max use. When a carbon filter is "spent" or has reached its adsorption capacity, regeneration or replacement is required.

DISTILLATION

Distillation is the oldest demineralization process. It consists of evaporating a part or all of the water, usually from a saline solution, and subsequent condensation of the mineral-free vapor. The products of distillation are pure water and either a concentrated salt solution or a mixture of crystalline salts. This is a process in which water is removed from the salts. The heat and power requirements are relatively independent of the amount of salt in solution. At present, most of the fresh water produced from the sea is by one of the evaporation methods.

Distillation is a process that many laboratories use to obtain mineral free water for analytical uses. POU treatment companies have residential units that are available for domestic use, but the power consumption, maintenance, and initial capital costs make this a very expensive treatment technique.

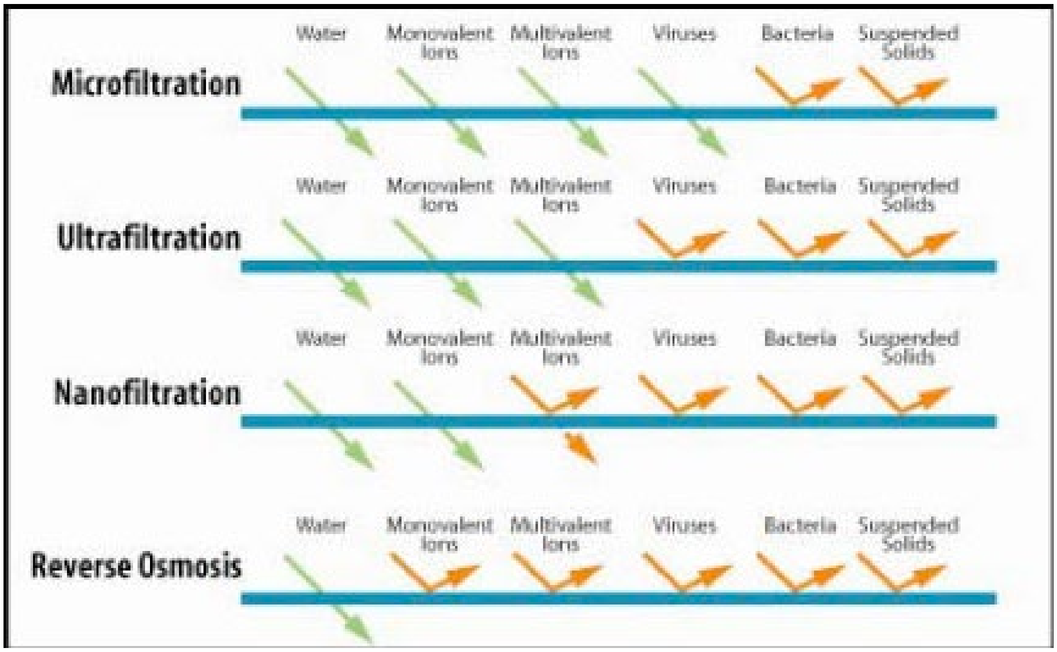
MEMBRANE FILTRATION

Membrane filtration is becoming more prevalent in the water industry. This trend is the result of more stringent regulations and recent reductions in costs that have made membrane technology competitive with other treatment. "Membrane" is the generic name for a family of treatment barriers that use **physical separation** as the primary means of achieving contaminant removal. Membranes typically used for treating drinking water may be classified as one of the following:

1. Microfiltration (MF).
2. Ultrafiltration (UF).
3. Nanofiltration (NF).
4. Reverse Osmosis (RO).

In general, pore size decreases and removal efficiency increases from Microfiltration to each subsequent classification with Reverse Osmosis having the greatest removal efficiency. Similarly, operating pressure required, and the amount of water rejected (wasted) increases as one moves in this same direction. The diagram below shows the removal capabilities by particle sizes of the different types of membranes.

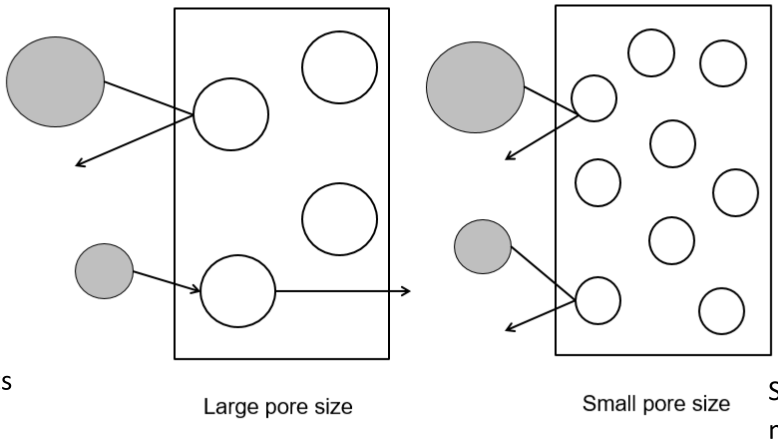
Figure 15.2 Substances Removed from Water by Membrane Filtration



(Safewater.org)

The general principle behind membrane technology is to push or draw water through a porous membrane to remove contaminants. Membranes with a relatively large pore size can operate at a lower pressure but can only remove larger sized contaminants. Membranes with a relatively small pore size can remove very small (even dissolved) contaminants but require a relatively high pressure to operate. This can be visualized in the diagram below.

Figure 15.3 Membrane Pore Sizes



Large pore size membrane-rejects only larger sized contaminants. Low operating pressure.

Small pore size membrane-rejects large and small (even dissolved) contaminants. High operating pressure

MEMBRANE TERMINOLOGY

There are several terms listed in the following table that are common definitions associated with membrane technology. The definition is given for each term and also the comparison (if any) to a treatment plant consisting of coagulation, flocculation, sedimentation, and filtration (conventional).

Table 15.3 Membrane Terminology

Term	Definition	Comparison to Conventional
Chemical Cleaning	Periodic Chemical Treatment to Remove Non Backwashable Material	None
CIP	Clean In Place	None
Module/Cassette	Individual Fibers Grouped Together to Form Filter Elements of Specified Area	Filter Area
Unit/Array/Train	Grouping of Modules/Cassettes/Units/Arrays with Common Piping	Filter Cell
Permeate	Product or Filtered Water	Filtrate
Concentrate	Material Rejected by Membrane	None
Flux	Flow Per Unit Area	Filter Loading Rate

TMP or P_m	Transmembrane Pressure	Filter Headloss
Backwash	Intermittent Reverse of Flow to Remove Solids	Backwash
Pore Size	The size (in microns) of the opening in the membrane fibers that water will pass through	Effective size, Uniformity Coefficient
MWCO	Molecular weight cut-off. The size of a protein (expressed as molecular weight) that will be removed by a membrane	Effective size, Uniformity Coefficient

The four membrane classifications previously presented are described in more detail below. In general, there is an order of magnitude difference in pore size and particle rejection between each classification. However, it is important to note that there is no regulatory or consistent industry standard regarding classification. One company may classify their product as an Ultrafiltration membrane, while a different company may classify a membrane with the same pore size as a Microfiltration membrane.

Microfiltration

Microfiltration (MF) pore sizes range from 0.1 – 1 µm, with most systems used in drinking water treatment tending toward smaller sizes. MF can reject most protozoa (Giardia and Cryptosporidium) and other contaminants as small as 0.1 µm. MF (and all other membranes discussed in this section) can replace other treatment systems that consist of coagulation, flocculation sedimentation, and filtration. MF is capable of operating under low-pressure conditions and has lower operating costs than the other membrane technologies.

Ultrafiltration

Ultrafiltration (UF) has recently gained interest because of its ability to remove smaller particles than MF while still operating at lower pressures than nanofiltration and reverse osmosis. UF is capable of rejecting contaminants as small as 0.01 µm. UF membranes can remove a significant number of viruses in addition to the protozoa removed by MF.

Nanofiltration

Nanofiltration (NF) gained more consideration in the 1980s for its water softening capabilities and removal of disinfection byproduct precursors. It is now the second largest application of membrane processes. NF is capable of rejecting contaminants as small as 0.001 µm. Thus, NF can remove some pesticides, DBP precursors, turbidity, pathogens, hardness, color, and salts. It operates at a lower pressure than RO, but at a higher pressure and operating cost than MF and UF.

Reverse Osmosis
Reverse osmosis (RO) has been used since the early 1960s as a process for desalinating seawater. RO is capable of rejecting contaminants as small as 0.0001 μm. Thus, RO can remove synthetic organic carbons, some pesticides, disinfection byproduct (DBP) precursors, turbidity, pathogens, hardness and salts. RO pushes water molecules through the membrane itself rather than through pores in the membrane. It requires a high operating pressure and is the costliest of the membranes.

RO is becoming more widely used as a commercially available system for water treatment including POU devices. Newer, better membrane materials are being developed that allow the process to be applied to other types of treatment needs.

RO does have the following considerations and maintenance issues:

1. Cellulose acetate, a common RO membrane, is an inexpensive material but is sensitive to pH changes in the water. Polyamide membranes are less sensitive to pH but more sensitive to oxidants such as chlorine. Membrane life estimates have ranged from as little as a few months to as many as three years.
2. Since the RO membrane filters water, RO is sensitive to particulate material, scale forming material, iron, manganese, turbidity, organic substances, and certain other undissolved impurities in the water. Considerable attention is needed for pretreatment requirements for RO plants, such as scale inhibitors or coagulation and settling prior to RO filtration. There may be significant differences among the various RO processes in the need for pretreatment.
3. The high pressures employed in RO equipment (generally 400 to 1,500 psi) require efficient and reliable pumping equipment and relatively costly piping, fittings, and pressure vessels.

DESIGN CONSIDERATIONS

There are several design considerations that must be addressed when evaluating a membrane plant. In general, most membrane plants operate best when using high water quality. Poor water quality such as a high total organic carbon (TOC), scale forming salts, and/or turbidity may foul the membranes and could require the installation of pretreatment (such as coagulation and settling) or the use of scale inhibitors prior to filtration.

Another consideration is the temperature of the water being treated. Colder water has a higher viscosity which can cause an increase in the operating pressure to pass the higher viscosity water through the membranes. The increased pressures result in increased electrical (pumping) costs. In extreme cases, the higher operating pressure can exceed the maximum pressure rating of the membranes causing the plant to operate at a reduced capacity.

Flow rates through membranes are typically expressed as “flux” with units of flow divided by area (Q/A, gpm/ft^2). Monitoring of the water flux at operating pressures will allow the operator to monitor the performance of the membrane over time. Reverse osmosis systems have a considerable waste flow that needs to be addressed in design and operation.

MODULE CONFIGURATIONS AND FLOW SCHEMES

Hollow fiber modules, or cassettes, consist of a bundle of thousands of hollow fibers that are parallel, self-supporting, and hair like in nature. Generally, water is pushed through the hollow fibers under pressure or pulled through via vacuum. The permeate or filtered water then exits through one or more header ports. The feed water is supplied either inside the fibers (inside-out configuration) or outside the fibers (outside-in configuration). The rejected material or concentrate also exits through the header port and consideration must be given to the disposal of the concentrate. Operating velocities in hollow fibers are low, ranging from 0 to 2.5 meters/sec, and modules or cassettes can be operated without recirculation (dead end mode). The flow of water is periodically reversed (backwashing) to clean the accumulated contaminants off the surface of the membranes. When the build-up of contaminants cannot be eliminated using a simple backwash, the membranes must be chemically cleaned with caustic soda, acid, detergent, or other proprietary solutions.

The spiral wound design is quite different from the hollow fiber tube design. It consists of an envelope of two flat-sheet membranes separated by a porous sheet called a permeate collector. It is sealed on three edges with an open edge. This open edge is connected and rolled up onto a perforated tube that carries the permeate. If one would look at the spiral wound tube, its shape would look like a cylinder. The flow of water is introduced and permeates through the membrane into the permeate collector. The permeate, once inside the membrane, is sealed off and flows into the central pipe to exit. The concentrate moves along the membranes where it can be collected and exit.

Figure 15.4 Schematic of Hollow Fiber Module

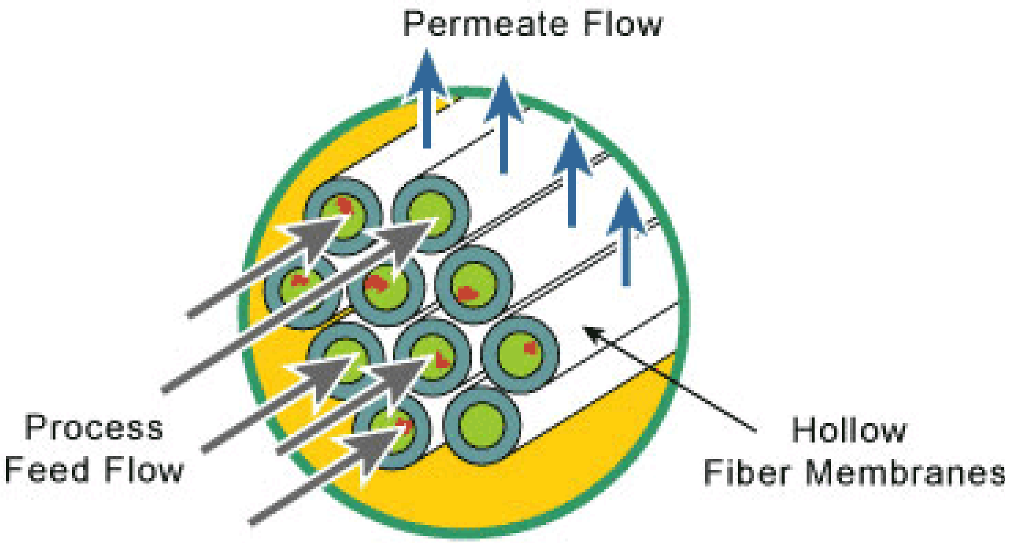
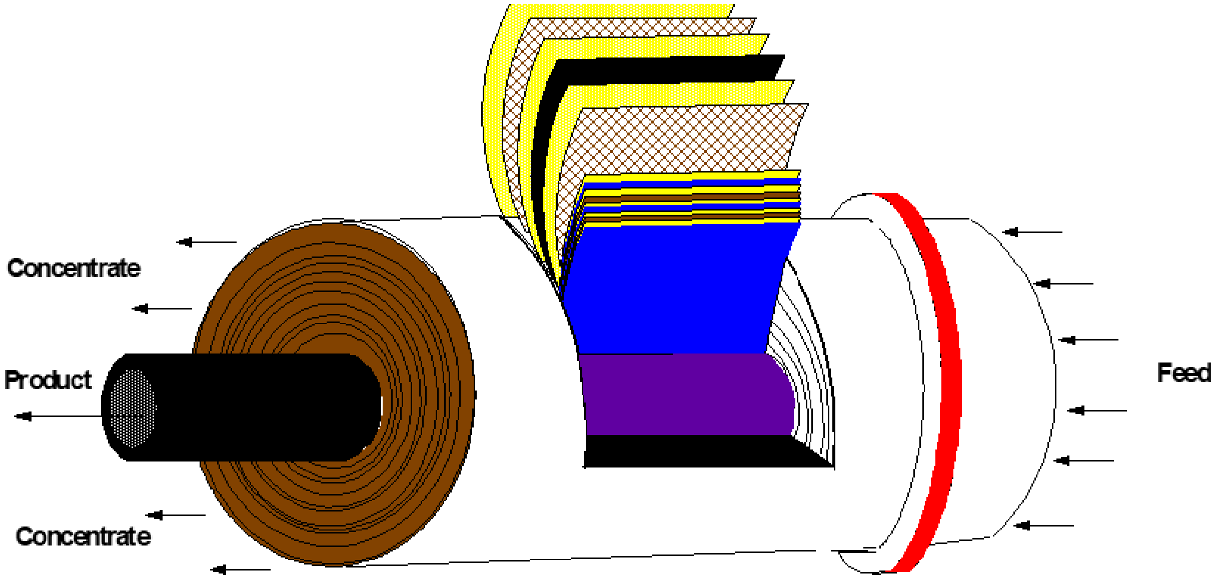


Figure 15.5 Schematic of Spiral Wound Module



PRESSURE AND FLUX

The capital and operating costs of membrane systems typically scale directly as a function of the membrane permeate flux J. The general equation for MF/UF is

$\Delta P = (R_m + R_f)\mu J$
Where:
ΔP = Pressure Drop
R_m = Membrane Resistance
R_f = Fouling Resistance
μ = Viscosity
J = Membrane flux

Flux is the rate of flow per unit area of membrane. It is a function of membrane porosity, membrane thickness, chemical composition of feed, pressure across the membrane, time of operation, and feedwater temperature. In general, the flux rates improve with higher temperatures. Over time the flux will decline due to membrane fouling (unless pressure is increased). After a certain period of time the membrane will need to be backwashed and/or cleaned. The transmembrane pressure (TMP) will indicate the need for this.

The general formula for TMP is: TMP = Feed Pressure-Filtrate Pressure

MEMBRANE INTEGRITY TESTING

As materials build up on the membrane, they reduce the permeability of the membrane by blocking or constricting pores and forming a layer of additional resistance to flow across the membrane. A reduction in the permeate flux that cannot be reversed is referred to as membrane fouling. One of the most critical aspects of using membrane technology for public health protection (e.g., pathogen or contaminant removal) is to ensure that a protective barrier exists between the feed water and the permeate or product water.

There are several methods that can be employed to monitor membrane integrity. Some of the types include:

- Turbidity monitoring
- Particle counting (multichannel counting)
- Particle monitoring (single-channel counting)
- Biological challenge testing
- Bubble point testing
- Air pressure decay testing
- Sonic testing

The first four types represent indirect methods of membrane integrity monitoring. Indirect methods measure surrogate water quality parameters to detect compromised modules, cassettes, and fibers, instead of testing the membranes themselves. The last three are all testing methods that may detect changes in the membranes directly. However, it should be noted that even the direct methods do not always assure membrane integrity.

Table 15.6 Advantage/disadvantages to the methods of integrity testing.

Monitoring Method	Advantages	Disadvantages
Particle counting	• Continuous on-line measurement • Measures several size ranges	• Indirect measurement of membrane integrity • May require several sensors for large-scale MF application
Particle monitoring	• Continuous on-line measurement	• Indirect measurement of membrane integrity • Does not count particle size ranges • May require several sensors for large-scale MF applications
Bubble point testing	• Direct measurement of membrane integrity	• Must take membrane module off-line to conduct test • Must be conducted manually • Labor intensive for large plants
Air pressure decay testing	• Automatic - Built into membrane system • Direct measurement of membrane integrity (an application of the bubble point theory)	• Not a continuous monitoring method • Not capable of detecting single broken fibers on many systems
Sonic testing	• May be a direct measurement of membrane integrity • Can conduct measurement while module in place; easy to employ • Future potential to be an on-line continuous measurement	• In most cases this is not a direct measurement of membrane integrity-merely an operator's judgment as to relative sound levels • Must be conducted manually • Labor intensive for large plants
Turbidity monitoring	• Extensive water industry experience with its use	• Not sensitive to changes in particles at low turbidities • Indirect measurement of membrane integrity
Biological challenge testing	• Most sensitive for evaluating specific microbe removal of the indirect methods of monitoring membrane integrity • Can conduct measurement while module in place • Surrogate, non-biological particles are available	• Indirect measurement of membrane integrity • Often impractical to seed a full-scale plant while serving water to consumers • Labor intensive

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CHAPTER 16 – Operation Reports

In accordance with Michigan's Safe Drinking Water Act, 1976 PA 399, as amended (Act 399), it is required that a water treatment plant submit a Monthly Operation Report (MOR) each month that treatment is employed. This is the joint responsibility of the owner, usually the municipality, and the certified water treatment plant operator in charge. Operation reports must be submitted during the month following the month for which it was prepared.

The forms provided by EGLE consist of a cover sheet and additional pages for the pumpage record, chemical application, and total coliform sampling reporting. EGLE staff will assist each community in selecting the appropriate reporting form for their system. In general, the information collected on the forms applies to the month for which the record is being prepared. Maximums and minimums will apply to that month.

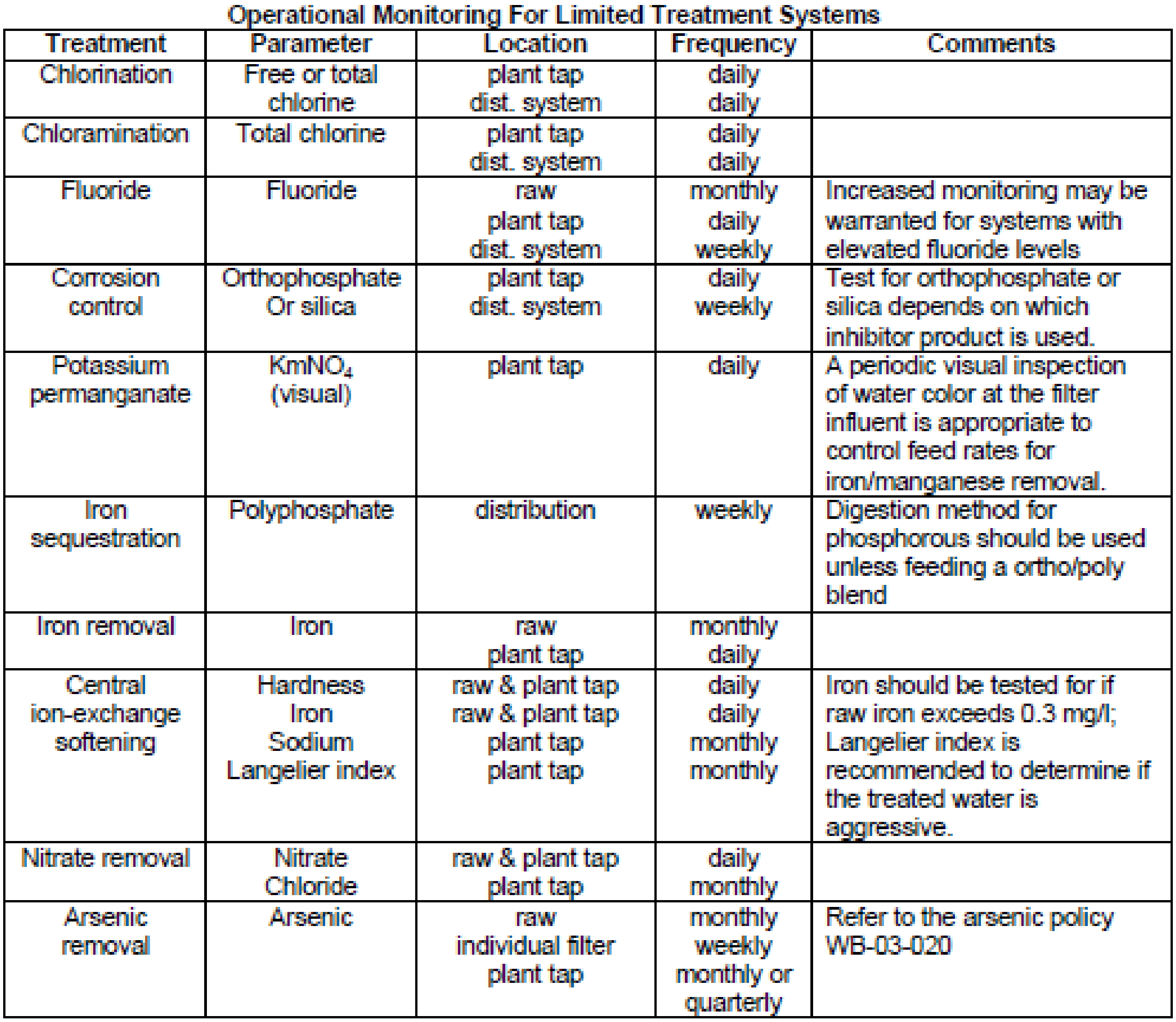
The average for a chemical applied should be computed from the known weight of the chemical applied during the month and the total pumpage for the month. It is not correct to determine the average chemical applied for a month from the daily average calculations. Averages of analytical determinations are to be calculated from the daily entries recorded. Updated spreadsheet versions of the MOR are being provided that will automatically do the calculations, though the certified operator must still be familiar with the method. The operators must also be familiar with the reporting requirements and deadlines for submission to EGLE. While total coliform sampling has to be included in the MOR, the total coliform sample results, including the chlorine residual at the time of sampling, must be submitted earlier than the MOR deadline. Total coliform results must be submitted by the tenth of the following month, yet the MOR is not due until the end of the following month. For example, total coliform results for samples taken in March must be submitted to EGLE by April 10. The MOR for March must be submitted to EGLE by April 30. If a water system choses to submit bacteriological results in the MOR it will be due on the 10th of the month following. Also, any failure to comply with water quality standards must be reported to EGLE within forty-eight hours and additional steps taken to confirm the violation and to notify the public.

The information on the MOR is an important resource for monitoring the health of the water system and, when properly completed in a timely manner, will provide staff with trends in chemical usage, daily pumpages, and provide clues to potential problems that can be addressed before they become major incidents. For example, a sudden increase in pumpage may indicate a water main break that has not yet surfaced, or an increase in chlorine usage may indicate that the water quality has been compromised.

The state law requires that records of monitoring samples for bacteriologic analyses be kept by the utility for at least five years. Drinking water samples should include labels such as a routine, check sample, etc., the date and time, chlorine residual (should be taken at same time as every bacteriological sample collection), if applicable, the laboratory, the person responsible for performing the analyses, the method of analytical technique used and the results. Persons in responsible charge of water treatment and water supply systems should refer to current Administrative Rules for Supplying Water to the Public for further details.

Operators are to take readings and track chemical usage. Figure 16.1 is an excerpt from the *Suggested Practices for Waterworks Design, Construction, and Operation*, Feb. 2008.

Figure 16.1 Operational Monitoring

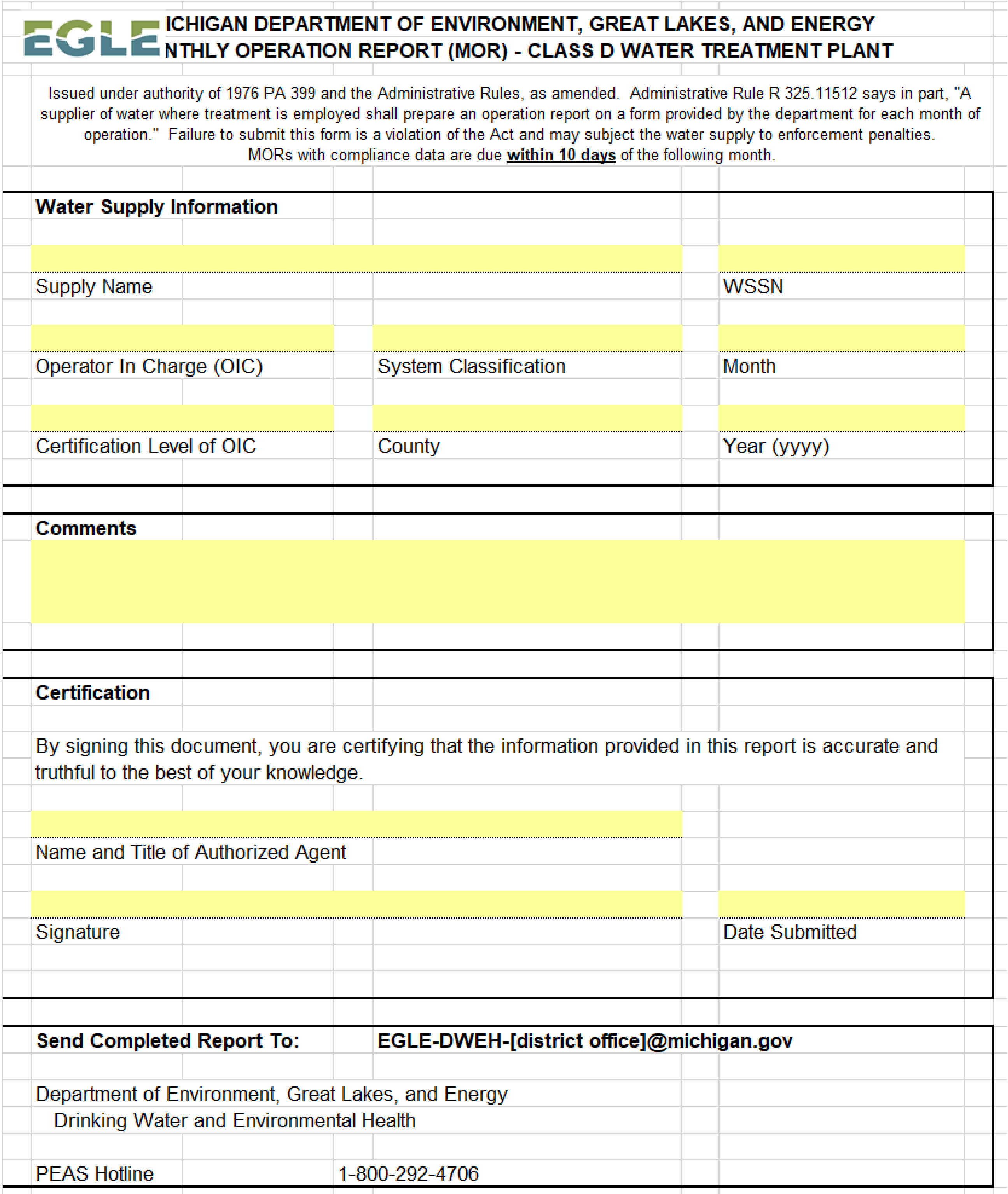


Operational Monitoring For Limited Treatment Systems

Treatment	Parameter	Location	Frequency	Comments
Chlorination	Free or total chlorine	plant tap dist. system	daily daily	
Chloramination	Total chlorine	plant tap dist. system	daily daily	
Fluoride	Fluoride	raw plant tap dist. system	monthly daily weekly	Increased monitoring may be warranted for systems with elevated fluoride levels
Corrosion control	Orthophosphate Or silica	plant tap dist. system	daily weekly	Test for orthophosphate or silica depends on which inhibitor product is used.
Potassium permanganate	$KmNO_4$ (visual)	plant tap	daily	A periodic visual inspection of water color at the filter influent is appropriate to control feed rates for iron/manganese removal.
Iron sequestration	Polyphosphate	distribution	weekly	Digestion method for phosphorous should be used unless feeding a ortho/poly blend
Iron removal	Iron	raw plant tap	monthly daily	
Central ion-exchange softening	Hardness Iron Sodium Langelier index	raw & plant tap raw & plant tap plant tap plant tap	daily daily monthly monthly	Iron should be tested for if raw iron exceeds 0.3 mg/l; Langelier index is recommended to determine if the treated water is aggressive.
Nitrate removal	Nitrate Chloride	raw & plant tap plant tap	daily monthly	
Arsenic removal	Arsenic	raw individual filter plant tap	monthly weekly monthly or quarterly	Refer to the arsenic policy WB-03-020

These readings are then recorded and reported on the MOR. The MOR format is adapted for the reporting needs of each community, but the basic layout is shown in Figure 16.2 through 16.9.

Figure 16.2 Cover Sheet



EGLE ICHIGAN DEPARTMENT OF ENVIRONMENT, GREAT LAKES, AND ENERGY
NTHLY OPERATION REPORT (MOR) - CLASS D WATER TREATMENT PLANT

Issued under authority of 1976 PA 399 and the Administrative Rules, as amended. Administrative Rule R 325.11512 says in part, "A supplier of water where treatment is employed shall prepare an operation report on a form provided by the department for each month of operation." Failure to submit this form is a violation of the Act and may subject the water supply to enforcement penalties. MORs with compliance data are due **within 10 days** of the following month.

Water Supply Information

Supply Name		WSSN
Operator In Charge (OIC)	System Classification	Month
Certification Level of OIC	County	Year (yyyy)

Comments

Certification

By signing this document, you are certifying that the information provided in this report is accurate and truthful to the best of your knowledge.

Name and Title of Authorized Agent

Signature

Date Submitted

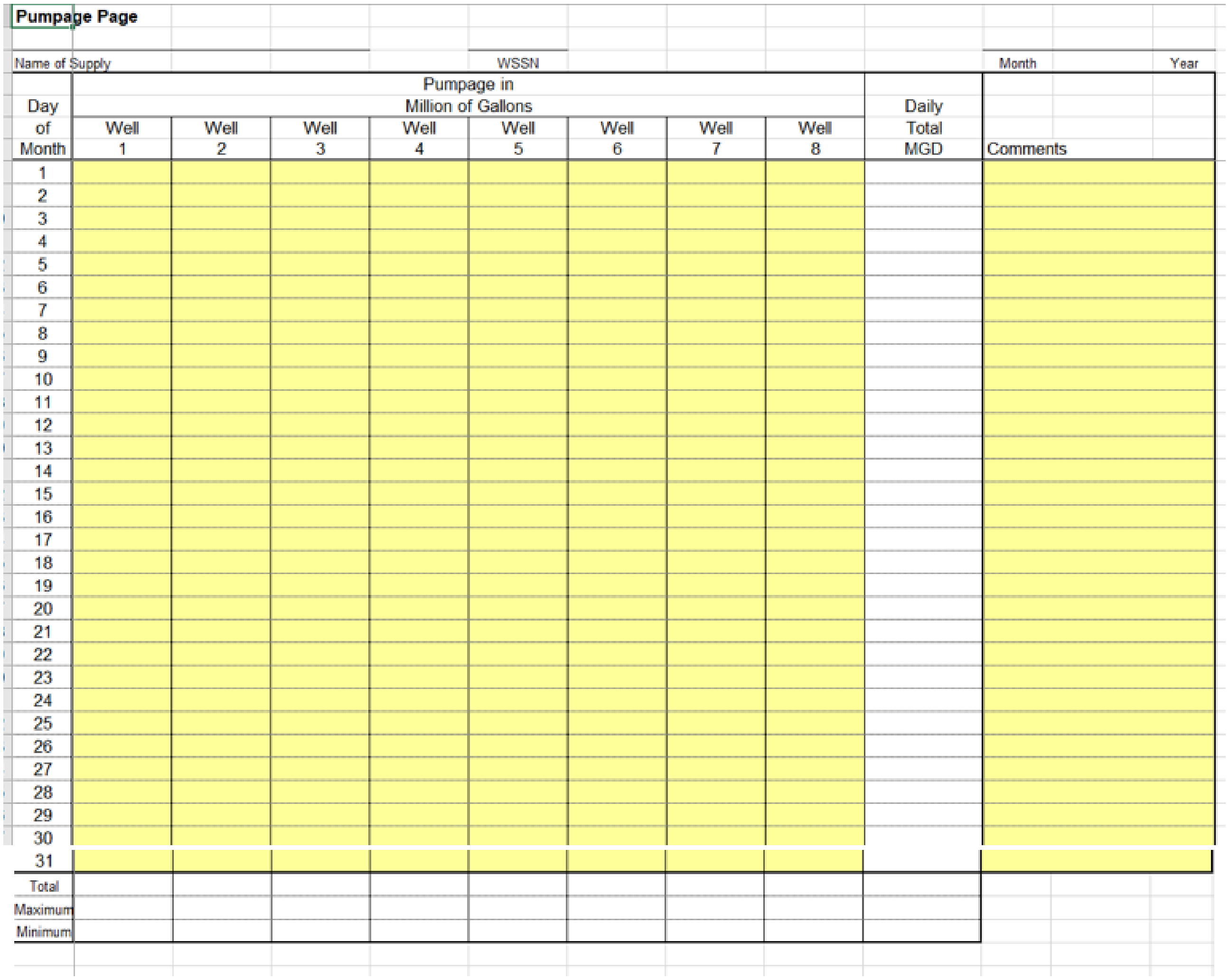
Send Completed Report To: **EGLE-DWEH-[district office]@michigan.gov**

Department of Environment, Great Lakes, and Energy
Drinking Water and Environmental Health

PEAS Hotline 1-800-292-4706

The PWSID is a Public Water Supply Identification number that has been assigned to each water system for identification purposes. The PWSID must be included on all documents for the water supply and must be entered on all pages of the MOR. The classification of the "D" treatment plant should be indicated in the space provided. The MOR must be signed by the certified operator in charge (OIC). Electronic signatures are not accepted.

Figure 16.3 Pumpage Page



Pumpage Page

Name of Supply

WSSN

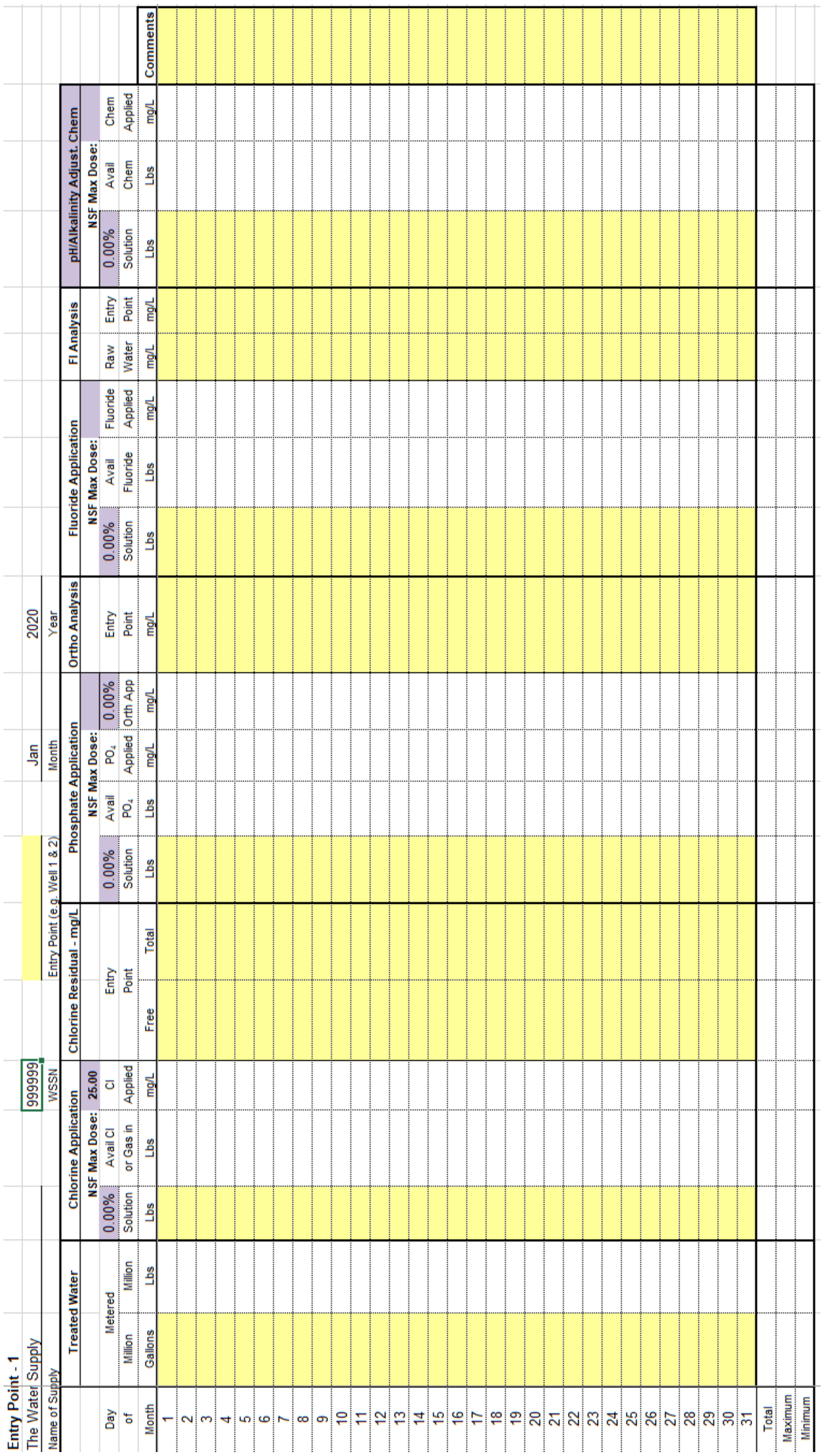
Month

Year

Day of Month	Pumpage in Million of Gallons								Daily Total MGD	Comments
	Well 1	Well 2	Well 3	Well 4	Well 5	Well 6	Well 7	Well 8		
1										
2										
3										
4										
5										
6										
7										
8										
9										
10										
11										
12										
13										
14										
15										
16										
17										
18										
19										
20										
21										
22										
23										
24										
25										
26										
27										
28										
29										
30										
31										
Total										
Maximum										
Minimum										

This page is used to track individual well pumpages and is recorded in millions of gallons. This information is taken from the meter readings. The spreadsheet will automatically calculate the total maximum and minimum readings. The operator must make sure that the month is recorded accurately on the cover page so that the spreadsheet will not enter a zero count in the calculations on the 31st. EGLE staff will work with the community to customize this page with the proper well numbers. There is a comment section on most pages of the MOR, and events affecting the water supply should be on each page as applicable. Of value would be major main breaks, control problems resulting in unusual production, extraordinary weather conditions resulting in high demands, swimming pool filling from small systems, fires, routine water main flushing, etc.

Figure 16.4 Entry Point Records



Entry Point - 1

The Water Supply
Name of Supply

999999
WSSN

Entry Point (e.g. Well 1 & 2)

Jan
Month

2020
Year

	Treated Water		Chlorine Application			Chlorine Residual - mg/L		Phosphate Application				Ortho Analysis	Fluoride Application			Fl Analysis		pH/Alkalinity Adjust. Chem			
				NSF Max Dose:	25.00				NSF Max Dose:		0.00%			NSF Max Dose:					NSF Max Dose:		
Day of Month	Metered Million Gallons	Million Lbs	0.00% Solution Lbs	Avail Cl or Gas in Lbs	Cl Applied mg/L	Entry Point Free	Total	0.00% Solution Lbs	Avail PO_4 Lbs	PO_4 Applied mg/L	Orth App mg/L	Entry Point mg/L	0.00% Solution Lbs	Avail Fluoride Lbs	Fluoride Applied mg/L	Raw Water mg/L	Entry Point mg/L	0.00% Solution Lbs	Avail Chem Lbs	Chem Applied mg/L	Comments
1																					
2																					
3																					
4																					
5																					
6																					
7																					
8																					
9																					
10																					
11																					
12																					
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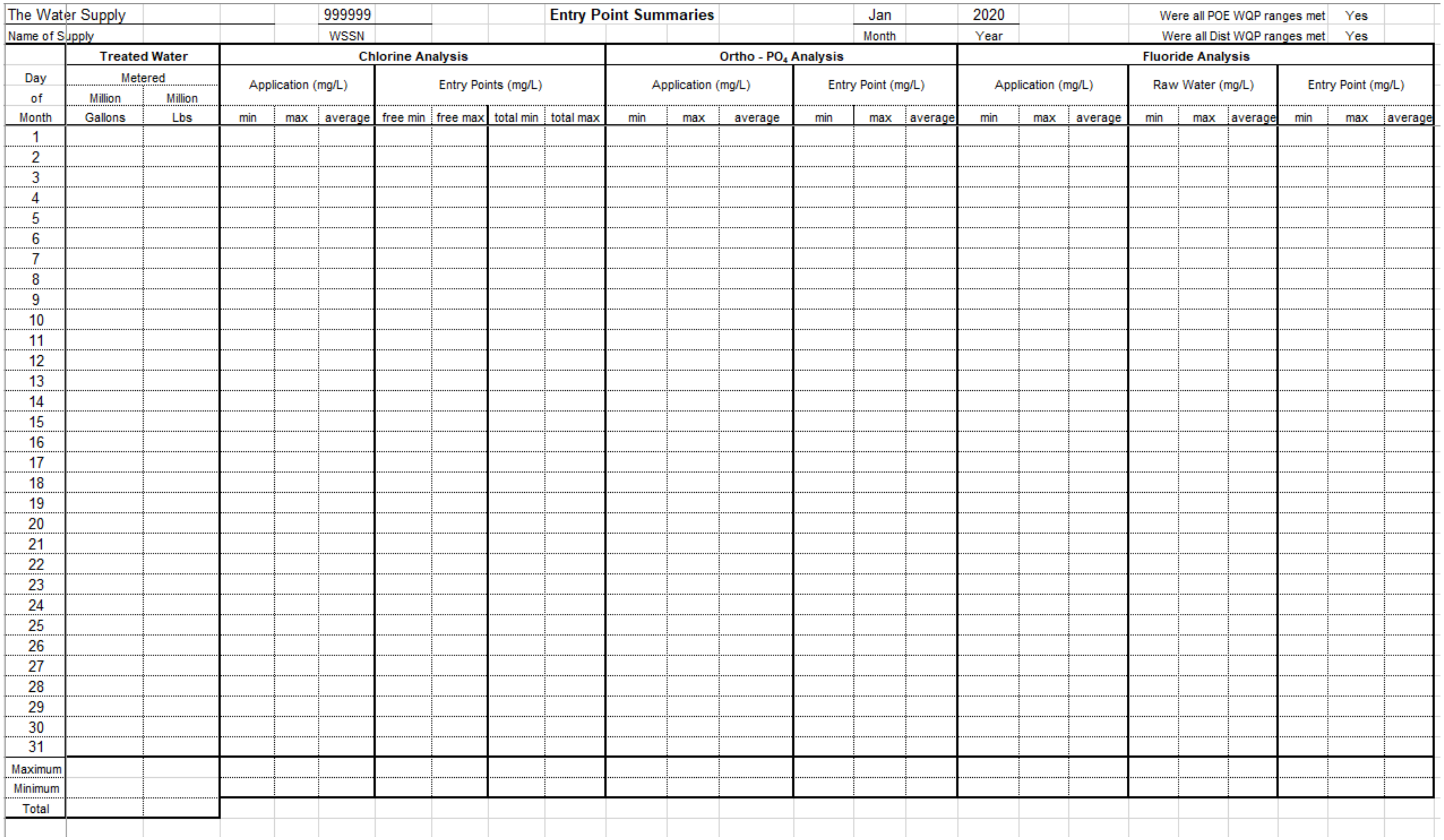
22																					
23																					
24																					
25																					
26																					
27																					
28																					
29																					
30																					
31																					
Total																					
Maximum																					
Minimum																					

This page records the total amount of water pumped and treated at an entry point to distribution. Very small systems with only one entry point will use only the one page; larger systems with multiple entry points will complete as many entry point pages as needed, and the entry point information will be collected on the summary page. Each community will have a spreadsheet customized for the treatment that they use.

Figure 16.5 Entry Point Summary Page



The Water Supply — Name of Supply

999999 — WSSN

Entry Point Summaries

Jan — Month

2020 — Year

Were all POE WQP ranges met Yes

Were all Dist WQP ranges met Yes

	Treated Water		**Chlorine Analysis**							**Ortho - PO$_4$ Analysis**						**Fluoride Analysis**								
Day	Metered		Application (mg/L)			Entry Points (mg/L)				Application (mg/L)			Entry Point (mg/L)			Application (mg/L)			Raw Water (mg/L)			Entry Point (mg/L)		
of	Million	Million																						
Month	Gallons	Lbs	min	max	average	free min	free max	total min	total max	min	max	average	min	max	average	min	max	average	min	max	average	min	max	average
1																								
2																								
3																								
4																								
5																								
6																								
7																								
8																								
9																								
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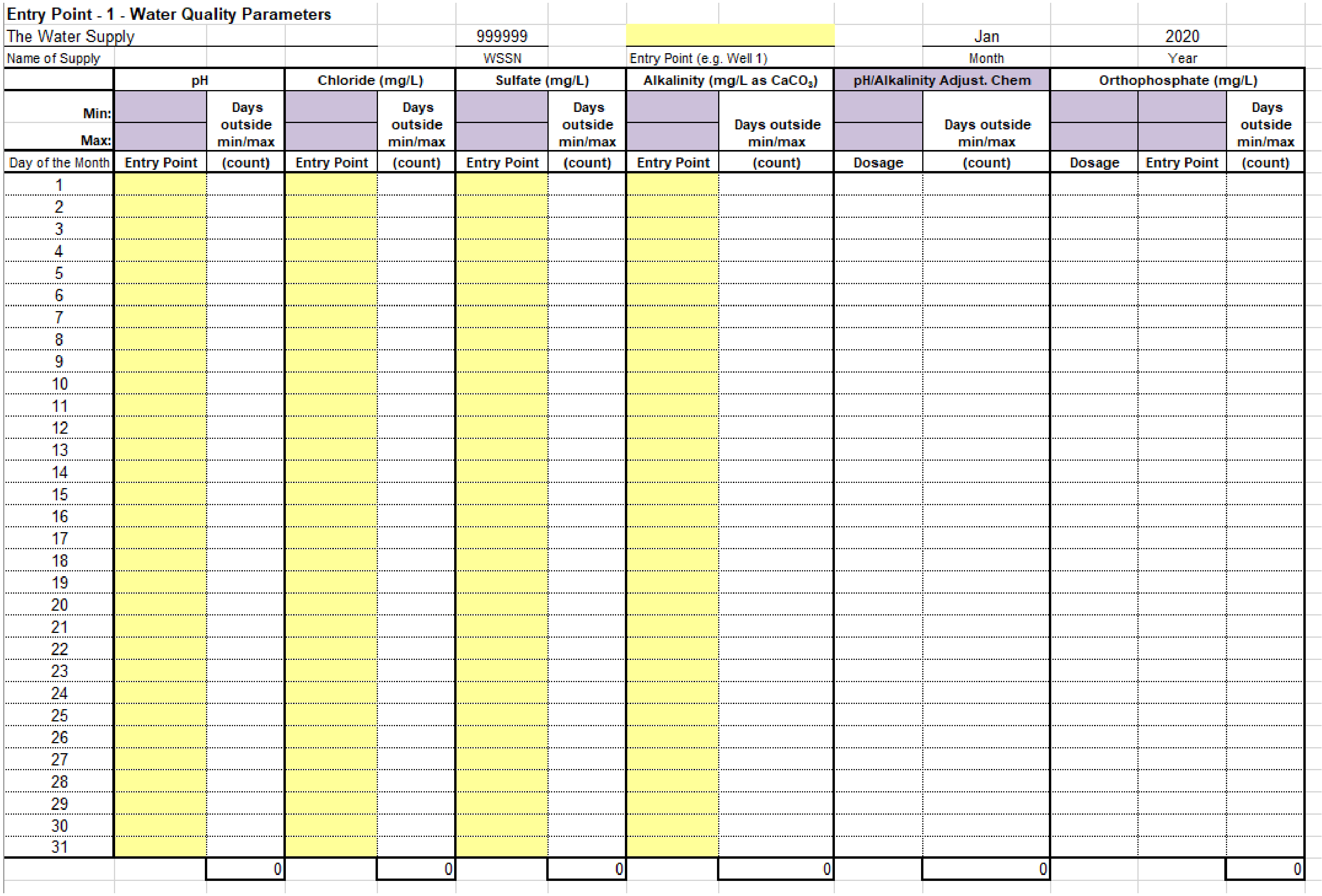
27																								
28																								
29																								
30																								
31																								
Maximum																								
Minimum																								
Total																								

Figure 16.6 Water Quality Parameters



Entry Point - 1 - Water Quality Parameters													
The Water Supply					999999					Jan		2020	
Name of Supply					WSSN		Entry Point (e.g. Well 1)			Month		Year	
	pH		**Chloride (mg/L)**		**Sulfate (mg/L)**		**Alkalinity (mg/L as $CaCO_3$)**		**pH/Alkalinity Adjust. Chem**		**Orthophosphate (mg/L)**		
Min:		**Days outside min/max**		**Days outside min/max**		**Days outside min/max**		**Days outside min/max**		**Days outside min/max**			**Days outside min/max**
Max:													
Day of the Month	**Entry Point**	**(count)**	**Entry Point**	**(count)**	**Entry Point**	**(count)**	**Entry Point**	**(count)**	**Dosage**	**(count)**	**Dosage**	**Entry Point**	**(count)**
1													
2													
3													
4													
5													
6													
7													
8													
9													
10													
11													
12													
13													
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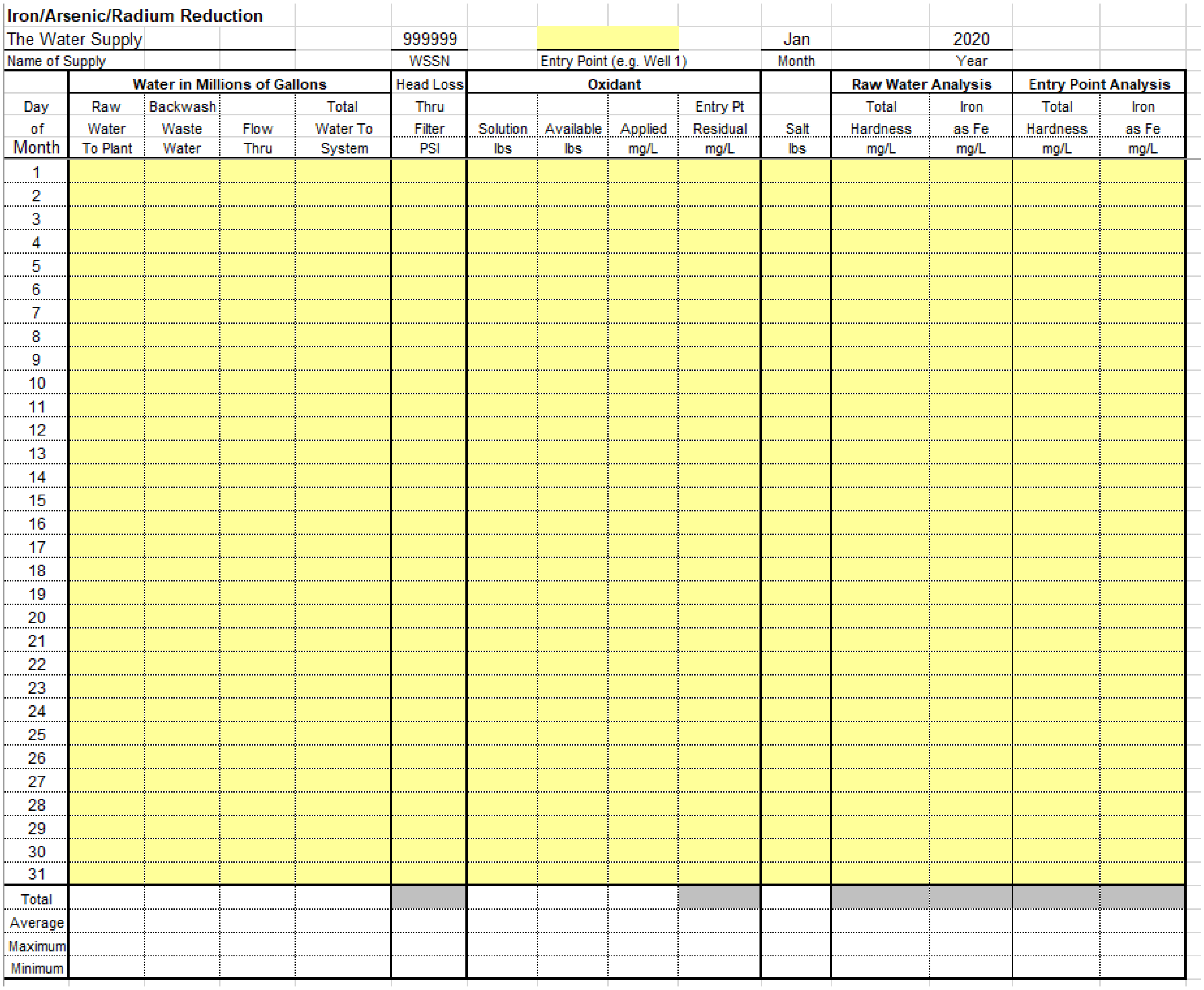
26													
27													
28													
29													
30													
31													
		0		0		0		0		0			0

This page is used when systems are required to track water quality parameters for corrosion control.

Figure 16.7 Iron/Arsenic/Radium Readings



Iron/Arsenic/Radium Reduction

The Water Supply	999999		Jan	2020
Name of Supply	WSSN	Entry Point (e.g. Well 1)	Month	Year

	Water in Millions of Gallons					Oxidant					Raw Water Analysis		Entry Point Analysis	
Day of Month	Raw Water To Plant	Backwash Waste Water	Flow Thru	Total Water To System	Head Loss Thru Filter PSI	Solution lbs	Available lbs	Applied mg/L	Entry Pt Residual mg/L	Salt lbs	Total Hardness mg/L	Iron as Fe mg/L	Total Hardness mg/L	Iron as Fe mg/L
1														
2														
3														
4														
5														
6														
7														
8														
9														
10														
11														
12														
13														
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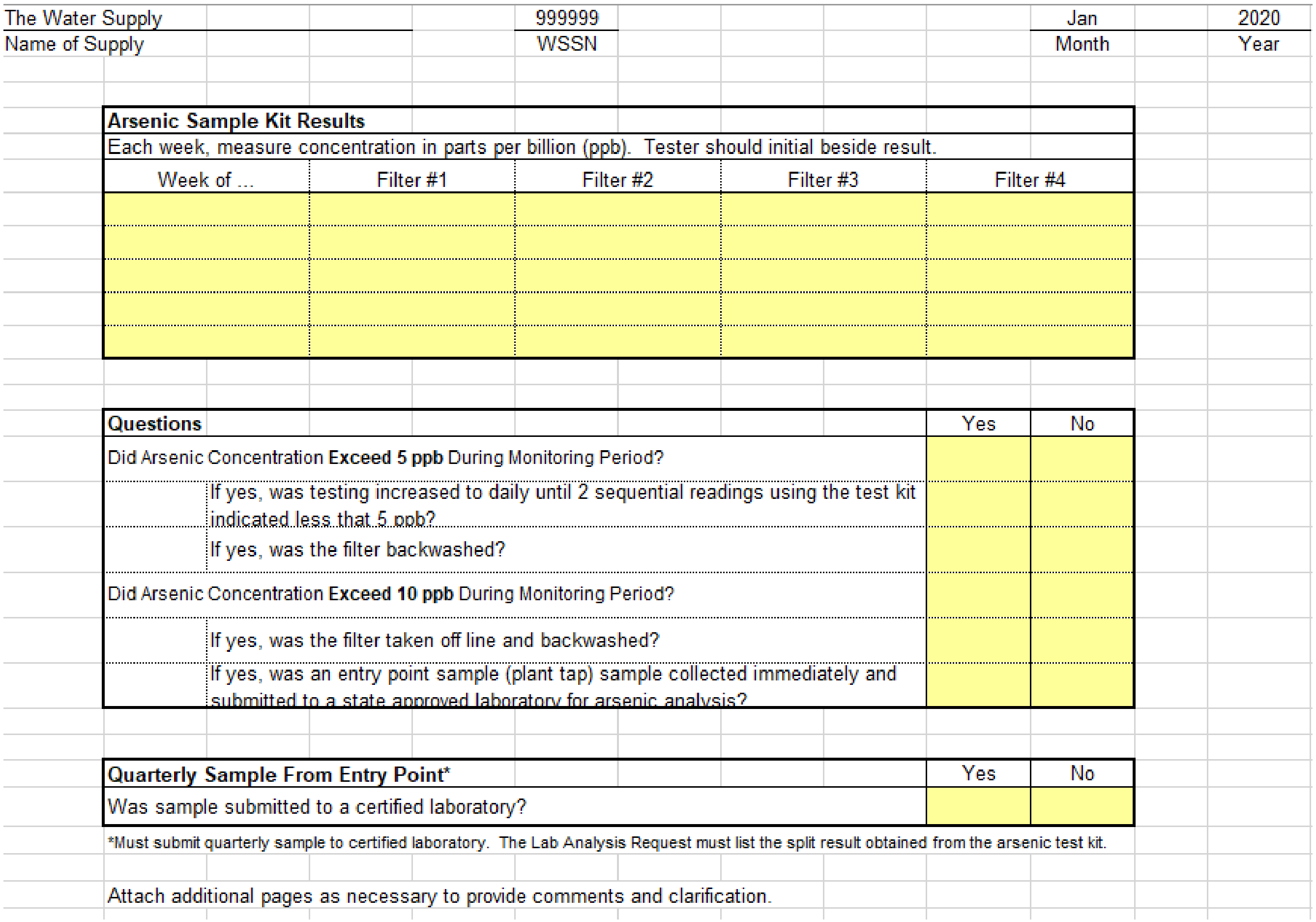
20														
21														
22														
23														
24														
25														
26														
27														
28														
29														
30														
31														
Total														
Average														
Maximum														
Minimum														

This page records information from systems treating for excess iron, arsenic, or radium. It provides columns for raw water and finished water readings, as well as tracking backwashing of filters and addition of oxidants.

Figure 16.8 Arsenic Samples



The Water Supply	999999	Jan	2020
Name of Supply	WSSN	Month	Year

Arsenic Sample Kit Results

Each week, measure concentration in parts per billion (ppb). Tester should initial beside result.

Week of ...	Filter #1	Filter #2	Filter #3	Filter #4

Questions	Yes	No
Did Arsenic Concentration **Exceed 5 ppb** During Monitoring Period?		
If yes, was testing increased to daily until 2 sequential readings using the test kit indicated less that 5 ppb?		
If yes, was the filter backwashed?		
Did Arsenic Concentration **Exceed 10 ppb** During Monitoring Period?		
If yes, was the filter taken off line and backwashed?		
If yes, was an entry point sample (plant tap) sample collected immediately and submitted to a state approved laboratory for arsenic analysis?		

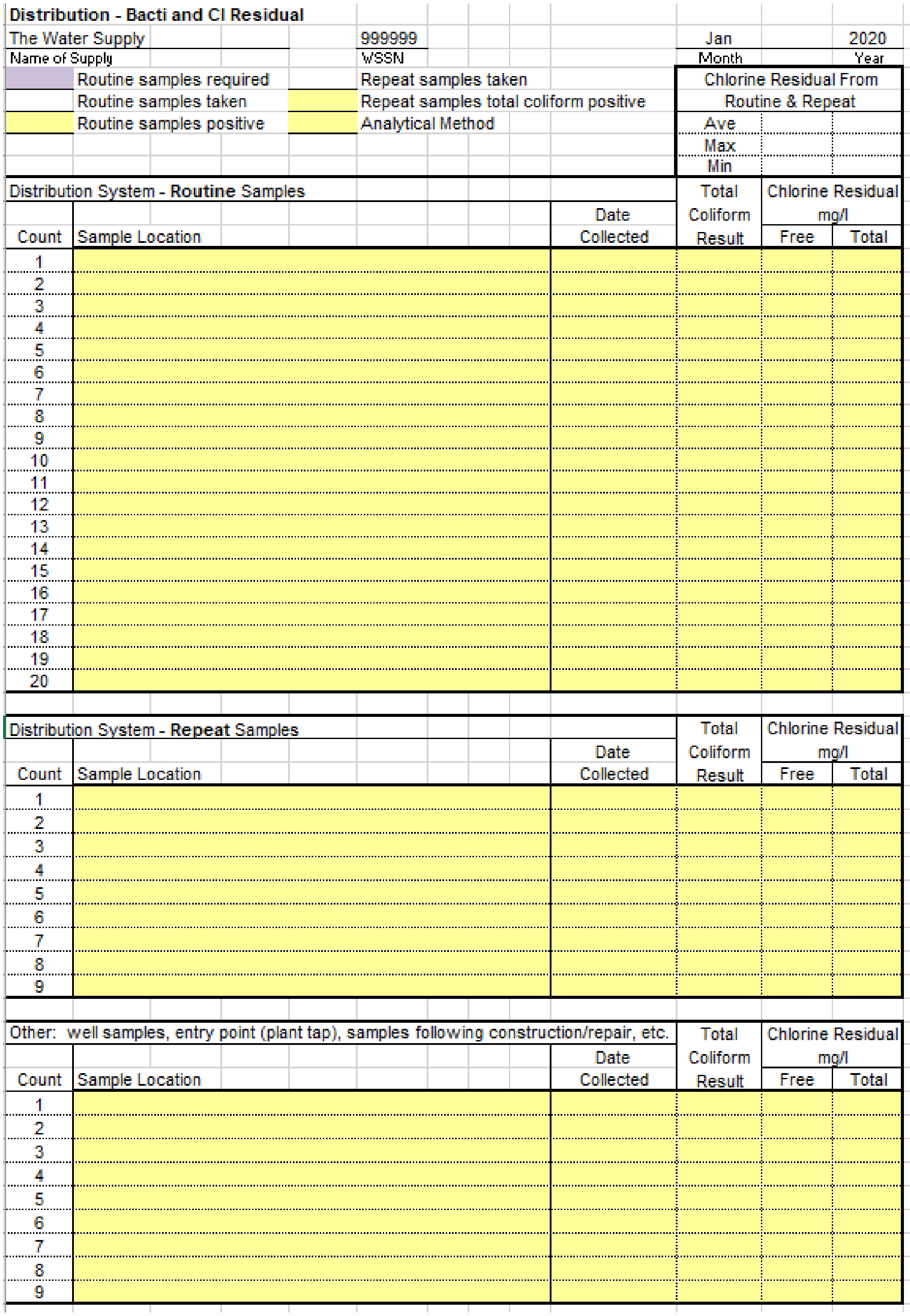
Quarterly Sample From Entry Point*	Yes	No
Was sample submitted to a certified laboratory?		

*Must submit quarterly sample to certified laboratory. The Lab Analysis Request must list the split result obtained from the arsenic test kit.

Attach additional pages as necessary to provide comments and clarification.

Those systems with high arsenic levels use this page to track weekly and monthly readings.

Figure 16.9 Total Coliform Sampling



Distribution - Bacti and Cl Residual

The Water Supply	999999	Jan	2020
Name of Supply	WSSN	Month	Year

🟪	Routine samples required		Repeat samples taken	Chlorine Residual From Routine & Repeat		
	Routine samples taken	🟨	Repeat samples total coliform positive			
🟨	Routine samples positive	🟨	Analytical Method	Ave		
				Max		
				Min		

Distribution System - **Routine** Samples

			Total Coliform Result	Chlorine Residual mg/l	
Count	Sample Location	Date Collected		Free	Total
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
18					
19					
20					

Distribution System - **Repeat** Samples

			Total Coliform Result	Chlorine Residual mg/l	
Count	Sample Location	Date Collected		Free	Total
1					
2					
3					
4					
5					
6					
7					
8					
9					

Other: well samples, entry point (plant tap), samples following construction/repair, etc.

			Total Coliform Result	Chlorine Residual mg/l	
Count	Sample Location	Date Collected		Free	Total
1					
2					
3					
4					
5					
6					
7					
8					
9					

This page is used to track the total coliform samples that the system takes each month for compliance, and any resample/special purpose samples that have been done.

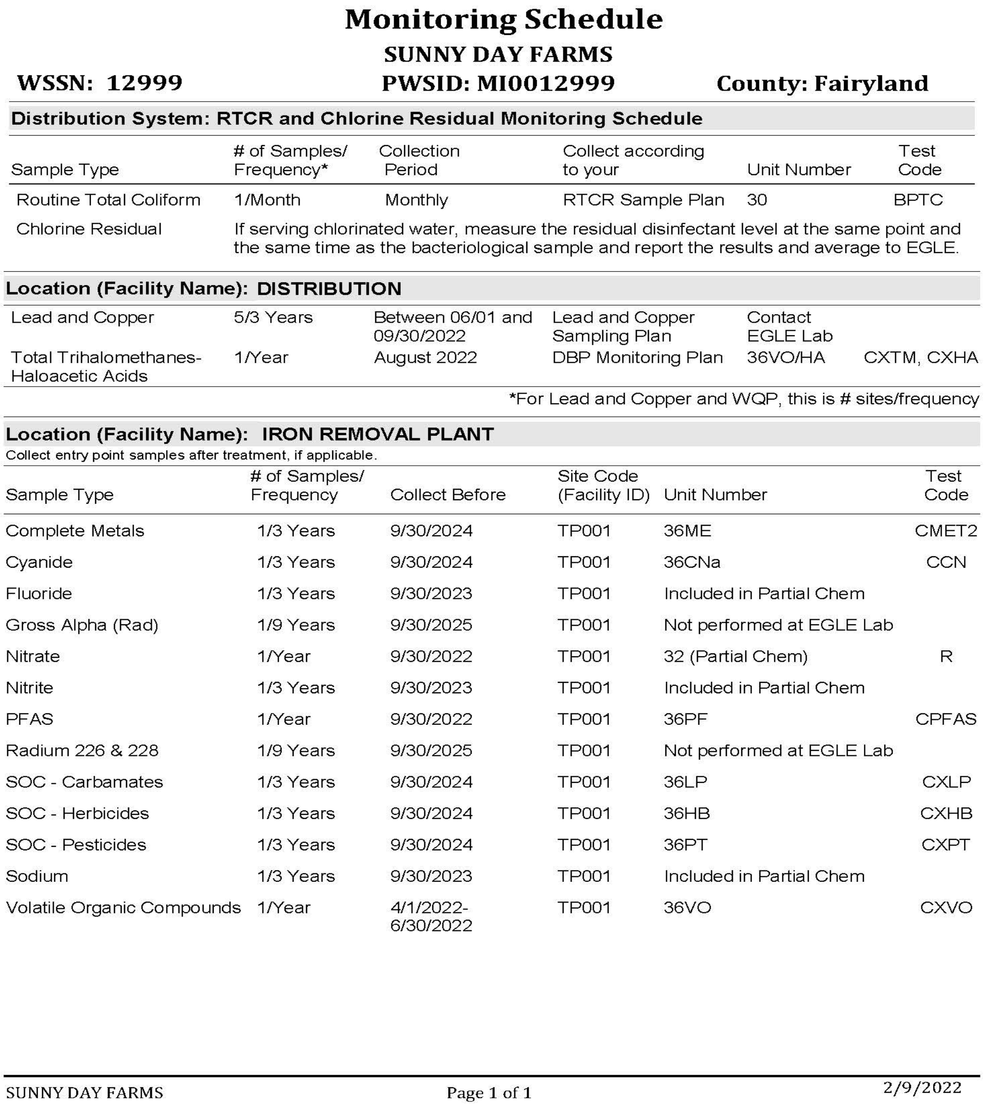
Completion and submission of the MOR is required for every system that employs any treatment. The MOR must be submitted to the EGLE district office by the end of the following month. Postmark dates are not accepted.

CHAPTER 17 – Laboratory Analyses of Water Chemistry

The Michigan Safe Drinking Water Act requires that water samples be collected from all community water supplies on a periodic basis for the purpose of determining compliance with drinking water standards. Monitoring requirements will vary somewhat based on source water type (groundwater or surface water), historical sample results (frequency of sampling may be reduced when an analyte has been non-detect) and the class of the water supply (Type I systems will have more sampling requirements than Type II systems).

Bacteriological, disinfection agents and disinfection by-products, and lead/copper samples are taken in the distributions system; other chemistry samples are taken at the plant tap, which marks the entry point of the water into distribution, after storage and any treatment. Figure 17.1 is a typical monitoring schedule for small S-4 water system.

Figure 17.1



Monitoring Schedule

SUNNY DAY FARMS

WSSN: 12999 **PWSID: MI0012999** **County: Fairyland**

Distribution System: RTCR and Chlorine Residual Monitoring Schedule

Sample Type	# of Samples/ Frequency*	Collection Period	Collect according to your	Unit Number	Test Code
Routine Total Coliform	1/Month	Monthly	RTCR Sample Plan	30	BPTC
Chlorine Residual	If serving chlorinated water, measure the residual disinfectant level at the same point and the same time as the bacteriological sample and report the results and average to EGLE.				
Location (Facility Name): DISTRIBUTION					
Lead and Copper	5/3 Years	Between 06/01 and 09/30/2022	Lead and Copper Sampling Plan	Contact EGLE Lab	
Total Trihalomethanes-Haloacetic Acids	1/Year	August 2022	DBP Monitoring Plan	36VO/HA	CXTM, CXHA

*For Lead and Copper and WQP, this is # sites/frequency

Location (Facility Name): IRON REMOVAL PLANT

Collect entry point samples after treatment, if applicable.

Sample Type	# of Samples/ Frequency	Collect Before	Site Code (Facility ID)	Unit Number	Test Code
Complete Metals	1/3 Years	9/30/2024	TP001	36ME	CMET2
Cyanide	1/3 Years	9/30/2024	TP001	36CNa	CCN
Fluoride	1/3 Years	9/30/2023	TP001	Included in Partial Chem	
Gross Alpha (Rad)	1/9 Years	9/30/2025	TP001	Not performed at EGLE Lab	
Nitrate	1/Year	9/30/2022	TP001	32 (Partial Chem)	R
Nitrite	1/3 Years	9/30/2023	TP001	Included in Partial Chem	
PFAS	1/Year	9/30/2022	TP001	36PF	CPFAS
Radium 226 & 228	1/9 Years	9/30/2025	TP001	Not performed at EGLE Lab	
SOC - Carbamates	1/3 Years	9/30/2024	TP001	36LP	CXLP
SOC - Herbicides	1/3 Years	9/30/2024	TP001	36HB	CXHB
SOC - Pesticides	1/3 Years	9/30/2024	TP001	36PT	CXPT
Sodium	1/3 Years	9/30/2023	TP001	Included in Partial Chem	
Volatile Organic Compounds	1/Year	4/1/2022-6/30/2022	TP001	36VO	CXVO

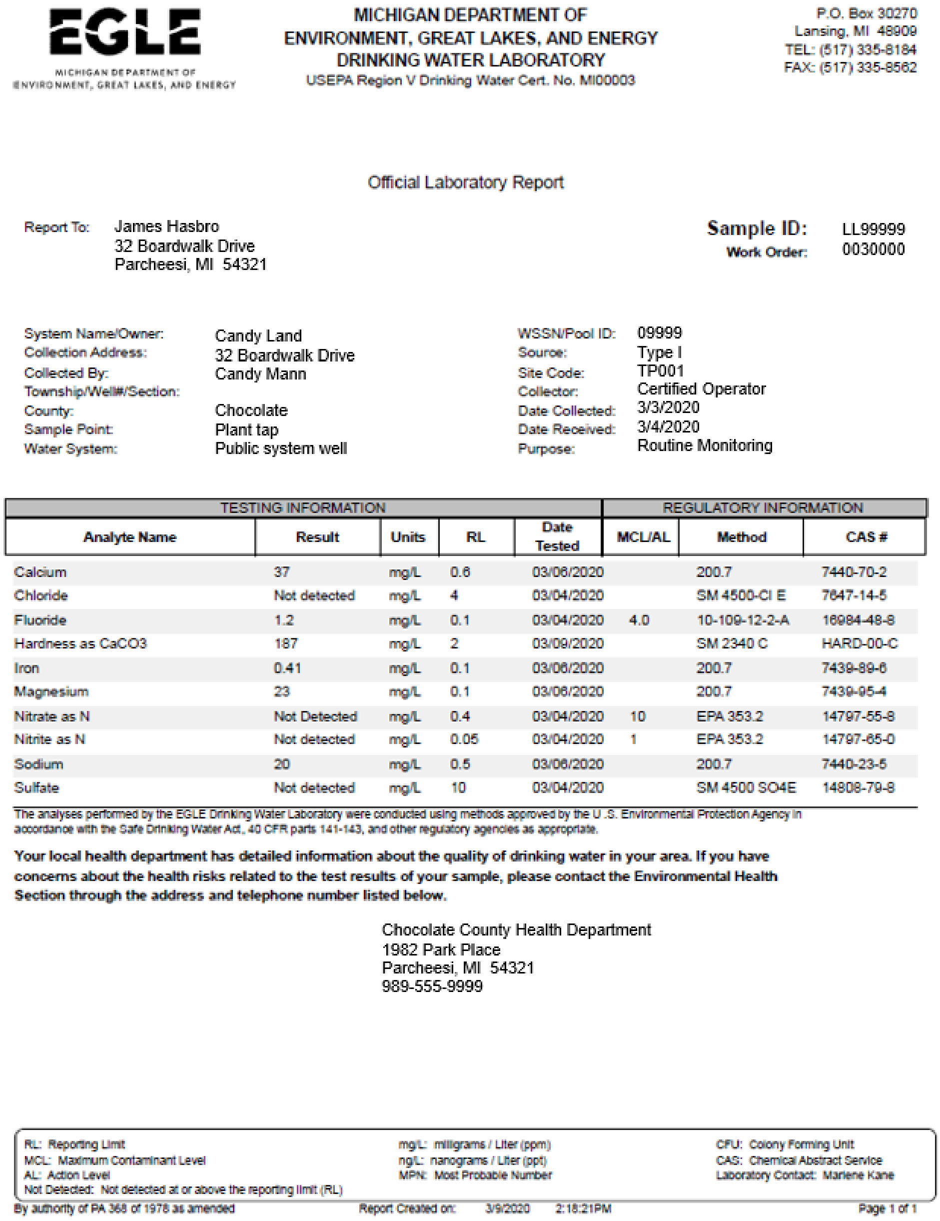
SUNNY DAY FARMS Page 1 of 1 2/9/2022

Requirements for chemistry sampling are outlined in Part 7 of the Administrative Rules. (See Chapter 1 for a description). Three years is a typical monitoring period for inorganic chemicals, volatile organic chemicals, and synthetic organic chemicals. Higher levels of chemicals that are close to the Maximum Contaminant Level (MCL), or treatment to reduce the amount of chemical present, for instance arsenic removal, will necessitate more frequent sampling.

Partial Chemical Analysis

An important basic tool for evaluating water quality and the need for further testing is the "Partial Chemistry" scan shown in Figure 17.2. This test analyzes eight commonly requested parameters.

Figure 17.2



EGLE
MICHIGAN DEPARTMENT OF ENVIRONMENT, GREAT LAKES, AND ENERGY

MICHIGAN DEPARTMENT OF
ENVIRONMENT, GREAT LAKES, AND ENERGY
DRINKING WATER LABORATORY
USEPA Region V Drinking Water Cert. No. MI00003

P.O. Box 30270
Lansing, MI 48909
TEL: (517) 335-8184
FAX: (517) 335-8562

Official Laboratory Report

Report To: James Hasbro
32 Boardwalk Drive
Parcheesi, MI 54321

Sample ID: LL99999
Work Order: 0030000

System Name/Owner: Candy Land
Collection Address: 32 Boardwalk Drive
Collected By: Candy Mann
Township/Well#/Section:
County: Chocolate
Sample Point: Plant tap
Water System: Public system well

WSSN/Pool ID: 09999
Source: Type I
Site Code: TP001
Collector: Certified Operator
Date Collected: 3/3/2020
Date Received: 3/4/2020
Purpose: Routine Monitoring

TESTING INFORMATION					REGULATORY INFORMATION		
Analyte Name	**Result**	**Units**	**RL**	**Date Tested**	**MCL/AL**	**Method**	**CAS #**
Calcium	37	mg/L	0.6	03/06/2020		200.7	7440-70-2
Chloride	Not detected	mg/L	4	03/04/2020		SM 4500-Cl E	7647-14-5
Fluoride	1.2	mg/L	0.1	03/04/2020	4.0	10-109-12-2-A	16984-48-8
Hardness as CaCO3	187	mg/L	2	03/09/2020		SM 2340 C	HARD-00-C
Iron	0.41	mg/L	0.1	03/06/2020		200.7	7439-89-6
Magnesium	23	mg/L	0.1	03/06/2020		200.7	7439-95-4
Nitrate as N	Not Detected	mg/L	0.4	03/04/2020	10	EPA 353.2	14797-55-8
Nitrite as N	Not detected	mg/L	0.05	03/04/2020	1	EPA 353.2	14797-65-0
Sodium	20	mg/L	0.5	03/06/2020		200.7	7440-23-5
Sulfate	Not detected	mg/L	10	03/04/2020		SM 4500 SO4E	14808-79-8

The analyses performed by the EGLE Drinking Water Laboratory were conducted using methods approved by the U .S. Environmental Protection Agency in accordance with the Safe Drinking Water Act, 40 CFR parts 141-143, and other regulatory agencies as appropriate.

Your local health department has detailed information about the quality of drinking water in your area. If you have concerns about the health risks related to the test results of your sample, please contact the Environmental Health Section through the address and telephone number listed below.

Chocolate County Health Department
1982 Park Place
Parcheesi, MI 54321
989-555-9999

RL: Reporting Limit
MCL: Maximum Contaminant Level
AL: Action Level
Not Detected: Not detected at or above the reporting limit (RL)
mg/L: milligrams / Liter (ppm)
ng/L: nanograms / Liter (ppt)
MPN: Most Probable Number
CFU: Colony Forming Unit
CAS: Chemical Abstract Service
Laboratory Contact: Marlene Kane

By authority of PA 368 of 1978 as amended Report Created on: 3/9/2020 2:18:21PM Page 1 of 1

Various chemical elements and compounds present in ground and surface water may be associated with either natural processes or human activities. Weathering and leaching of rock and soil are two important natural processes contributing chemicals to water. The factors controlling the release of trace elements from rock and soil materials and their solution and stability in water include solubility, pH, and absorption characteristics. Decaying vegetation can also release substances such as tannin into the water. The analytes used in the partial chemical test may indicate the possible presence of harmful or aesthetically displeasing substances and the tendency for the water to stain fixtures and clothing, or the need for softening, for example. Figure 17.3 is from the *Environmental Health Ready Reference.* Table I, has three parameters that the USEPA has assigned Maximum Contaminant Levels due to health risks. Table II lists the other parameters that are associated with aesthetic water quality problems.

Figure 17.3 Partial Chemistry Analytes

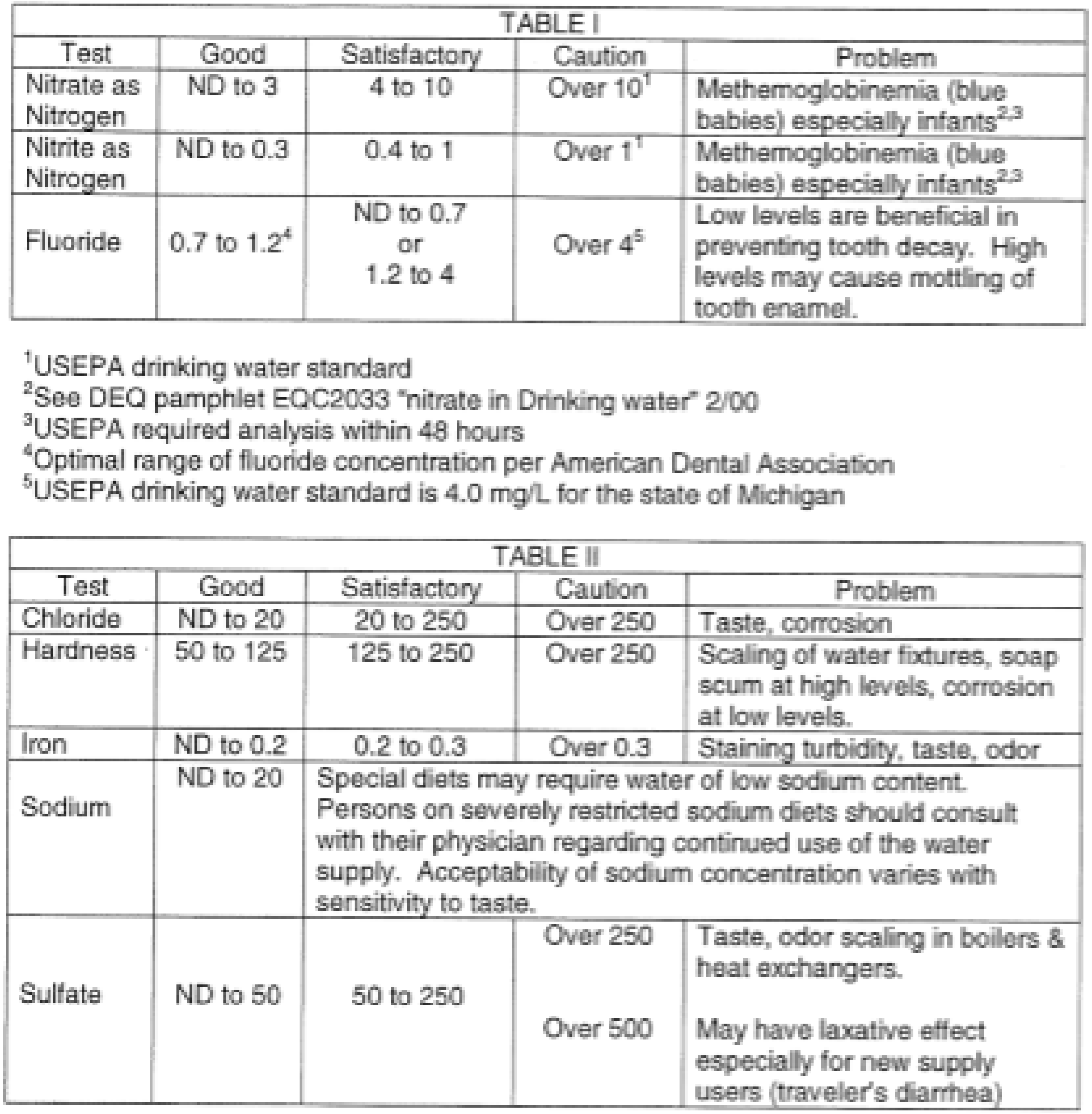


TABLE I

Test	Good	Satisfactory	Caution	Problem
Nitrate as Nitrogen	ND to 3	4 to 10	Over 10[1]	Methemoglobinemia (blue babies) especially infants[2,3]
Nitrite as Nitrogen	ND to 0.3	0.4 to 1	Over 1[1]	Methemoglobinemia (blue babies) especially infants[2,3]
Fluoride	0.7 to 1.2[4]	ND to 0.7 or 1.2 to 4	Over 4[5]	Low levels are beneficial in preventing tooth decay. High levels may cause mottling of tooth enamel.

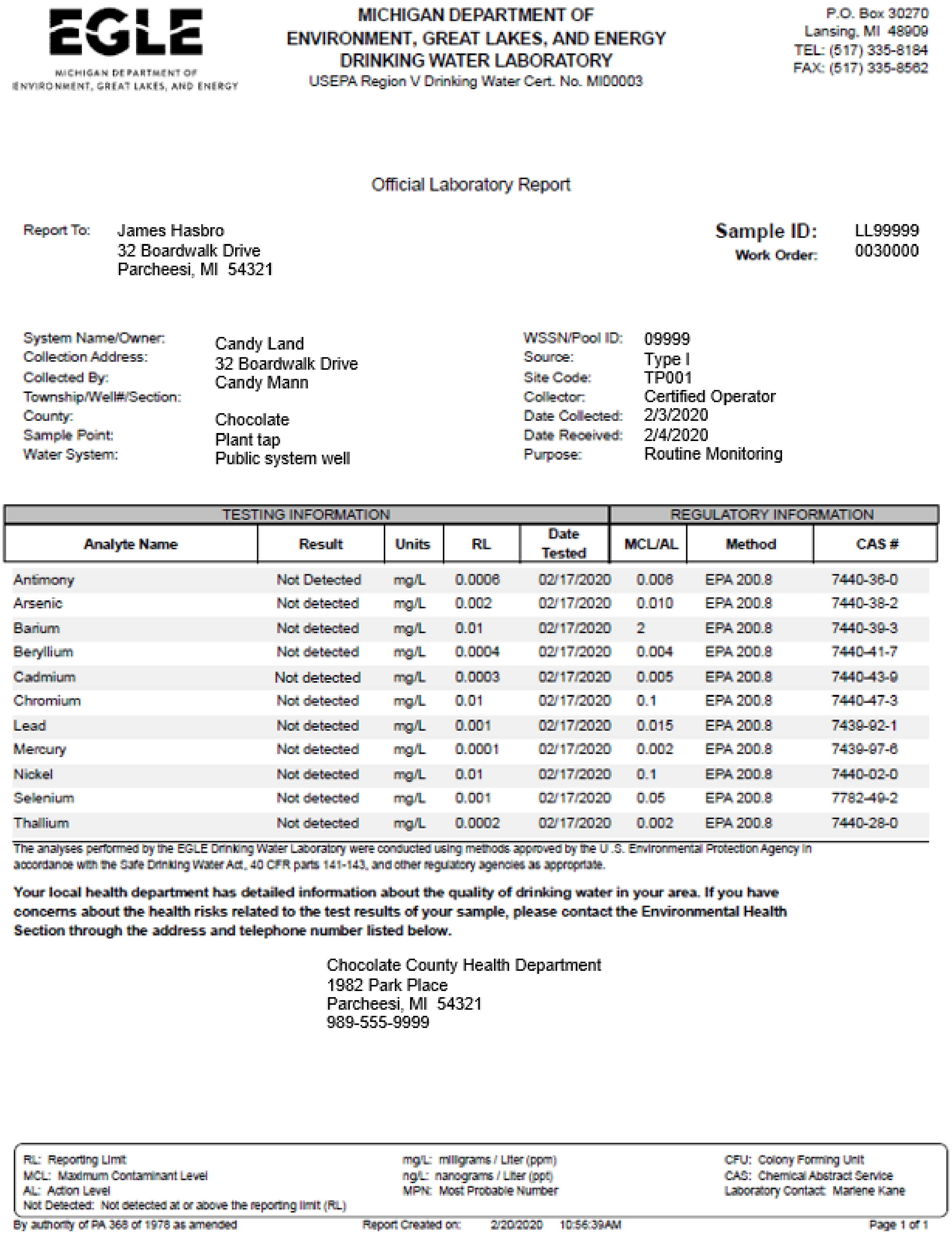
[1] USEPA drinking water standard
[2] See DEQ pamphlet EQC2033 "nitrate in Drinking water" 2/00
[3] USEPA required analysis within 48 hours
[4] Optimal range of fluoride concentration per American Dental Association
[5] USEPA drinking water standard is 4.0 mg/L for the state of Michigan

TABLE II

Test	Good	Satisfactory	Caution	Problem
Chloride	ND to 20	20 to 250	Over 250	Taste, corrosion
Hardness	50 to 125	125 to 250	Over 250	Scaling of water fixtures, soap scum at high levels, corrosion at low levels.
Iron	ND to 0.2	0.2 to 0.3	Over 0.3	Staining turbidity, taste, odor
Sodium	ND to 20	Special diets may require water of low sodium content. Persons on severely restricted sodium diets should consult with their physician regarding continued use of the water supply. Acceptability of sodium concentration varies with sensitivity to taste.		
Sulfate	ND to 50	50 to 250	Over 250 Over 500	Taste, odor scaling in boilers & heat exchangers. May have laxative effect especially for new supply users (traveler's diarrhea)

Examples of laboratory results for other chemical analysis of samples submitted to the EGLE lab are shown in Figures 17.4 through 17.6.

Figure 17.4 Complete Metals



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MICHIGAN DEPARTMENT OF
ENVIRONMENT, GREAT LAKES, AND ENERGY

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USEPA Region V Drinking Water Cert. No. MI00003

P.O. Box 30270
Lansing, MI 48909
TEL: (517) 335-8184
FAX: (517) 335-8562

Official Laboratory Report

Report To:
James Hasbro
32 Boardwalk Drive
Parcheesi, MI 54321

Sample ID: LL99999
Work Order: 0030000

System Name/Owner:	Candy Land
Collection Address:	32 Boardwalk Drive
Collected By:	Candy Mann
Township/Well#/Section:	
County:	Chocolate
Sample Point:	Plant tap
Water System:	Public system well

WSSN/Pool ID:	09999
Source:	Type I
Site Code:	TP001
Collector:	Certified Operator
Date Collected:	2/3/2020
Date Received:	2/4/2020
Purpose:	Routine Monitoring

TESTING INFORMATION					REGULATORY INFORMATION		
Analyte Name	**Result**	**Units**	**RL**	**Date Tested**	**MCL/AL**	**Method**	**CAS #**
Antimony	Not Detected	mg/L	0.0006	02/17/2020	0.006	EPA 200.8	7440-36-0
Arsenic	Not detected	mg/L	0.002	02/17/2020	0.010	EPA 200.8	7440-38-2
Barium	Not detected	mg/L	0.01	02/17/2020	2	EPA 200.8	7440-39-3
Beryllium	Not detected	mg/L	0.0004	02/17/2020	0.004	EPA 200.8	7440-41-7
Cadmium	Not detected	mg/L	0.0003	02/17/2020	0.005	EPA 200.8	7440-43-9
Chromium	Not detected	mg/L	0.01	02/17/2020	0.1	EPA 200.8	7440-47-3
Lead	Not detected	mg/L	0.001	02/17/2020	0.015	EPA 200.8	7439-92-1
Mercury	Not detected	mg/L	0.0001	02/17/2020	0.002	EPA 200.8	7439-97-6
Nickel	Not detected	mg/L	0.01	02/17/2020	0.1	EPA 200.8	7440-02-0
Selenium	Not detected	mg/L	0.001	02/17/2020	0.05	EPA 200.8	7782-49-2
Thallium	Not detected	mg/L	0.0002	02/17/2020	0.002	EPA 200.8	7440-28-0

The analyses performed by the EGLE Drinking Water Laboratory were conducted using methods approved by the U.S. Environmental Protection Agency in accordance with the Safe Drinking Water Act, 40 CFR parts 141-143, and other regulatory agencies as appropriate.

Your local health department has detailed information about the quality of drinking water in your area. If you have concerns about the health risks related to the test results of your sample, please contact the Environmental Health Section through the address and telephone number listed below.

Chocolate County Health Department
1982 Park Place
Parcheesi, MI 54321
989-555-9999

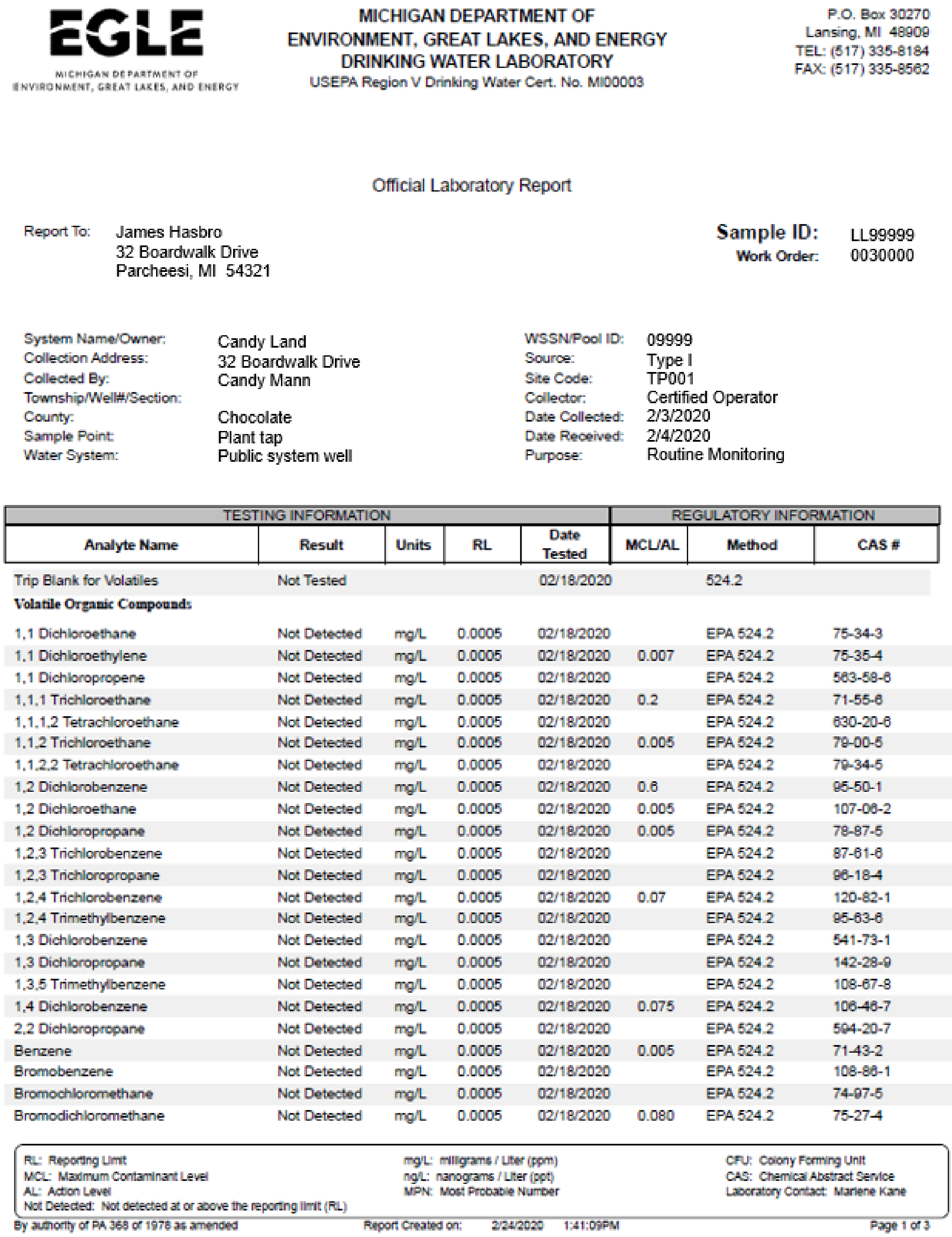
RL: Reporting Limit
MCL: Maximum Contaminant Level
AL: Action Level
Not Detected: Not detected at or above the reporting limit (RL)

mg/L: milligrams / Liter (ppm)
ng/L: nanograms / Liter (ppt)
MPN: Most Probable Number

CFU: Colony Forming Unit
CAS: Chemical Abstract Service
Laboratory Contact: Marlene Kane

By authority of PA 368 of 1978 as amended Report Created on: 2/20/2020 10:56:39AM Page 1 of 1

Figure 17.5 Volatile Organic Chemicals



EGLE
MICHIGAN DEPARTMENT OF ENVIRONMENT, GREAT LAKES, AND ENERGY

MICHIGAN DEPARTMENT OF
ENVIRONMENT, GREAT LAKES, AND ENERGY
DRINKING WATER LABORATORY
USEPA Region V Drinking Water Cert. No. MI00003

P.O. Box 30270
Lansing, MI 48909
TEL: (517) 335-8184
FAX: (517) 335-8562

Official Laboratory Report

Report To:
James Hasbro
32 Boardwalk Drive
Parcheesi, MI 54321

Sample ID: LL99999
Work Order: 0030000

System Name/Owner:	Candy Land
Collection Address:	32 Boardwalk Drive
Collected By:	Candy Mann
Township/Well#/Section:	
County:	Chocolate
Sample Point:	Plant tap
Water System:	Public system well

WSSN/Pool ID:	09999
Source:	Type I
Site Code:	TP001
Collector:	Certified Operator
Date Collected:	2/3/2020
Date Received:	2/4/2020
Purpose:	Routine Monitoring

TESTING INFORMATION					REGULATORY INFORMATION		
Analyte Name	**Result**	**Units**	**RL**	**Date Tested**	**MCL/AL**	**Method**	**CAS #**
Trip Blank for Volatiles	Not Tested			02/18/2020		524.2	
Volatile Organic Compounds							
1,1 Dichloroethane	Not Detected	mg/L	0.0005	02/18/2020		EPA 524.2	75-34-3
1,1 Dichloroethylene	Not Detected	mg/L	0.0005	02/18/2020	0.007	EPA 524.2	75-35-4
1,1 Dichloropropene	Not Detected	mg/L	0.0005	02/18/2020		EPA 524.2	563-58-6
1,1,1 Trichloroethane	Not Detected	mg/L	0.0005	02/18/2020	0.2	EPA 524.2	71-55-6
1,1,1,2 Tetrachloroethane	Not Detected	mg/L	0.0005	02/18/2020		EPA 524.2	630-20-6
1,1,2 Trichloroethane	Not Detected	mg/L	0.0005	02/18/2020	0.005	EPA 524.2	79-00-5
1,1,2,2 Tetrachloroethane	Not Detected	mg/L	0.0005	02/18/2020		EPA 524.2	79-34-5
1,2 Dichlorobenzene	Not Detected	mg/L	0.0005	02/18/2020	0.6	EPA 524.2	95-50-1
1,2 Dichloroethane	Not Detected	mg/L	0.0005	02/18/2020	0.005	EPA 524.2	107-06-2
1,2 Dichloropropane	Not Detected	mg/L	0.0005	02/18/2020	0.005	EPA 524.2	78-87-5
1,2,3 Trichlorobenzene	Not Detected	mg/L	0.0005	02/18/2020		EPA 524.2	87-61-6
1,2,3 Trichloropropane	Not Detected	mg/L	0.0005	02/18/2020		EPA 524.2	96-18-4
1,2,4 Trichlorobenzene	Not Detected	mg/L	0.0005	02/18/2020	0.07	EPA 524.2	120-82-1
1,2,4 Trimethylbenzene	Not Detected	mg/L	0.0005	02/18/2020		EPA 524.2	95-63-6
1,3 Dichlorobenzene	Not Detected	mg/L	0.0005	02/18/2020		EPA 524.2	541-73-1
1,3 Dichloropropane	Not Detected	mg/L	0.0005	02/18/2020		EPA 524.2	142-28-9
1,3,5 Trimethylbenzene	Not Detected	mg/L	0.0005	02/18/2020		EPA 524.2	108-67-8
1,4 Dichlorobenzene	Not Detected	mg/L	0.0005	02/18/2020	0.075	EPA 524.2	106-46-7
2,2 Dichloropropane	Not Detected	mg/L	0.0005	02/18/2020		EPA 524.2	594-20-7
Benzene	Not Detected	mg/L	0.0005	02/18/2020	0.005	EPA 524.2	71-43-2
Bromobenzene	Not Detected	mg/L	0.0005	02/18/2020		EPA 524.2	108-86-1
Bromochloromethane	Not Detected	mg/L	0.0005	02/18/2020		EPA 524.2	74-97-5
Bromodichloromethane	Not Detected	mg/L	0.0005	02/18/2020	0.080	EPA 524.2	75-27-4

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Not Detected: Not detected at or above the reporting limit (RL)
mg/L: milligrams / Liter (ppm)
ng/L: nanograms / Liter (ppt)
MPN: Most Probable Number
CFU: Colony Forming Unit
CAS: Chemical Abstract Service
Laboratory Contact: Marlene Kane

By authority of PA 368 of 1978 as amended
Report Created on: 2/24/2020 1:41:09PM
Page 1 of 3

Sample ID: LL99999
Work Order: 0030000

TESTING INFORMATION					REGULATORY INFORMATION		
Analyte Name	**Result**	**Units**	**RL**	**Date Tested**	**MCL/AL**	**Method**	**CAS #**
Volatile Organic Compounds							
Bromoform	Not Detected	mg/L	0.0005	02/18/2020	0.080	EPA 524.2	75-25-2
Bromomethane	Not Detected	mg/L	0.001	02/18/2020		EPA 524.2	74-83-9
Carbon tetrachloride	Not Detected	mg/L	0.0005	02/18/2020	0.005	EPA 524.2	56-23-5
Chlorobenzene	Not Detected	mg/L	0.0005	02/18/2020	0.1	EPA 524.2	108-90-7
Chlorodibromomethane	Not Detected	mg/L	0.0005	02/18/2020	0.080	EPA 524.2	124-48-1
Chloroethane	Not Detected	mg/L	0.0005	02/18/2020		EPA 524.2	75-00-3
Chloroform	Not Detected	mg/L	0.0005	02/18/2020	0.080	EPA 524.2	67-66-3
Chloromethane	Not Detected	mg/L	0.0005	02/18/2020		EPA 524.2	74-87-3
cis-1,2 Dichloroethylene	Not Detected	mg/L	0.0005	02/18/2020	0.07	EPA 524.2	156-59-2
cis-1,3 Dichloropropene	Not Detected	mg/L	0.0005	02/18/2020		EPA 524.2	10061-01-5
Dibromomethane	Not Detected	mg/L	0.0005	02/18/2020		EPA 524.2	74-95-3
Dichlorodifluoromethane	Not Detected	mg/L	0.001	02/18/2020		EPA 524.2	75-71-8
Dichloromethane	Not Detected	mg/L	0.0005	02/18/2020	0.005	EPA 524.2	75-09-2
Ethylbenzene	Not Detected	mg/L	0.0005	02/18/2020	0.7	EPA 524.2	100-41-4
Fluorotrichloromethane	Not Detected	mg/L	0.001	02/18/2020		EPA 524.2	75-69-4
Hexachlorobutadiene	Not Detected	mg/L	0.0005	02/18/2020		EPA 524.2	87-68-3
Isopropylbenzene	Not Detected	mg/L	0.0005	02/18/2020		EPA 524.2	98-82-8
m & p-Xylene	Not Detected	mg/L	0.0005	02/18/2020	10	EPA 524.2	XYLMP-00-C
Methyl ethyl ketone	Not Detected	mg/L	0.005	02/18/2020		EPA 524.2	78-93-3
Methyl isobutyl ketone	Not Detected	mg/L	0.005	02/18/2020		EPA 524.2	108-10-1
Methyl-tert-butyl ether (MTBE)	Not Detected	mg/L	0.001	02/18/2020		EPA 524.2	1634-04-4
Naphthalene	Not Detected	mg/L	0.0005	02/18/2020		EPA 524.2	91-20-3
n-Butylbenzene	Not Detected	mg/L	0.0005	02/18/2020		EPA 524.2	104-51-8
n-Propylbenzene	Not Detected	mg/L	0.0005	02/18/2020		EPA 524.2	103-65-1
o-Chlorotoluene	Not Detected	mg/L	0.0005	02/18/2020		EPA 524.2	95-49-8
o-Xylene	Not Detected	mg/L	0.0005	02/18/2020	10	EPA 524.2	95-47-6
p-Chlorotoluene	Not Detected	mg/L	0.0005	02/18/2020		EPA 524.2	106-43-4
p-Isopropyltoluene	Not Detected	mg/L	0.0005	02/18/2020		EPA 524.2	99-87-6
sec-Butylbenzene	Not Detected	mg/L	0.0005	02/18/2020		EPA 524.2	135-98-8
Styrene	Not Detected	mg/L	0.0005	02/18/2020	0.1	EPA 524.2	100-42-5
tert-Butylbenzene	Not Detected	mg/L	0.0005	02/18/2020		EPA 524.2	98-06-6
Tetrachloroethylene	Not Detected	mg/L	0.0005	02/18/2020	0.005	EPA 524.2	127-18-4
Tetrahydrofuran	Not Detected	mg/L	0.005	02/18/2020		EPA 524.2	109-99-9
Toluene	Not Detected	mg/L	0.0005	02/18/2020	1	EPA 524.2	108-88-3
Total Trihalomethanes	Not Detected	mg/L	NA	02/18/2020	0.080	EPA 524.2	TTHM-00-C
Total Xylenes	Not Detected	mg/L	NA	02/18/2020	10	EPA 524.2	1330-20-7
trans-1,2 Dichloroethylene	Not Detected	mg/L	0.0005	02/18/2020	0.1	EPA 524.2	156-60-5

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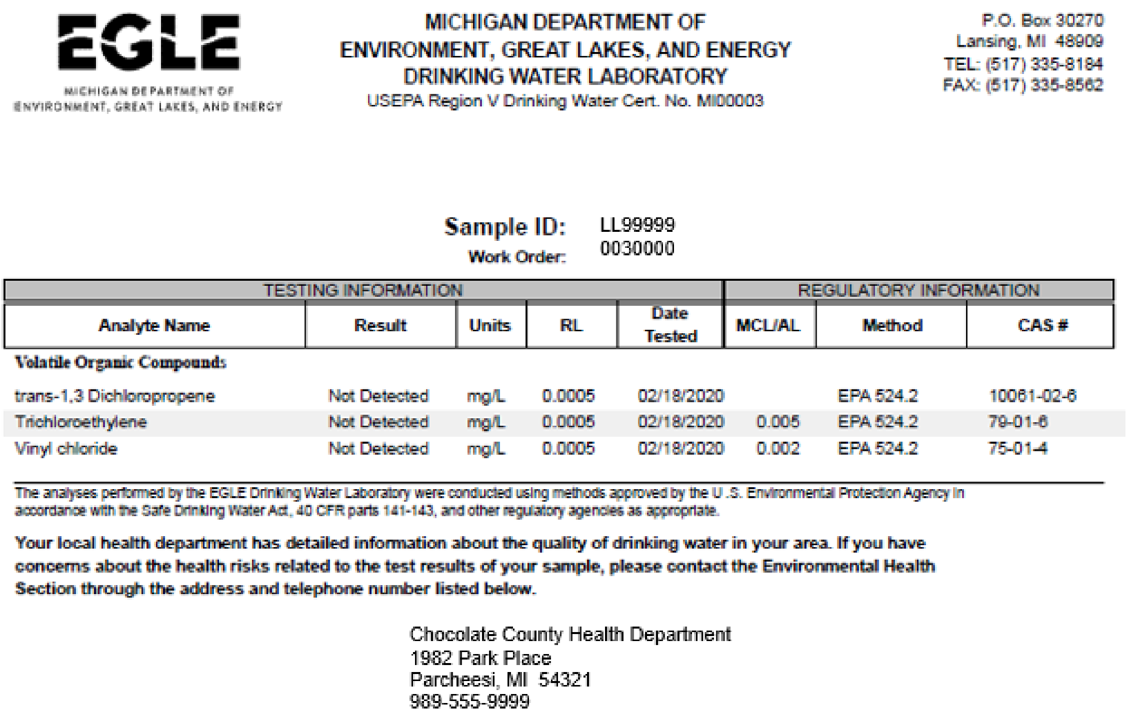
mg/L: milligrams / Liter (ppm)
ng/L: nanograms / Liter (ppt)
MPN: Most Probable Number
CFU: Colony Forming Unit
CAS: Chemical Abstract Service
Laboratory Contact: Marlene Kane



MICHIGAN DEPARTMENT OF
ENVIRONMENT, GREAT LAKES, AND ENERGY
DRINKING WATER LABORATORY
USEPA Region V Drinking Water Cert. No. MI00003

P.O. Box 30270
Lansing, MI 48909
TEL: (517) 335-8184
FAX: (517) 335-8562

Sample ID: LL99999
Work Order: 0030000

TESTING INFORMATION					REGULATORY INFORMATION		
Analyte Name	**Result**	**Units**	**RL**	**Date Tested**	**MCL/AL**	**Method**	**CAS #**
Volatile Organic Compounds							
trans-1,3 Dichloropropene	Not Detected	mg/L	0.0005	02/18/2020		EPA 524.2	10061-02-6
Trichloroethylene	Not Detected	mg/L	0.0005	02/18/2020	0.005	EPA 524.2	79-01-6
Vinyl chloride	Not Detected	mg/L	0.0005	02/18/2020	0.002	EPA 524.2	75-01-4

The analyses performed by the EGLE Drinking Water Laboratory were conducted using methods approved by the U .S. Environmental Protection Agency in accordance with the Safe Drinking Water Act, 40 CFR parts 141-143, and other regulatory agencies as appropriate.

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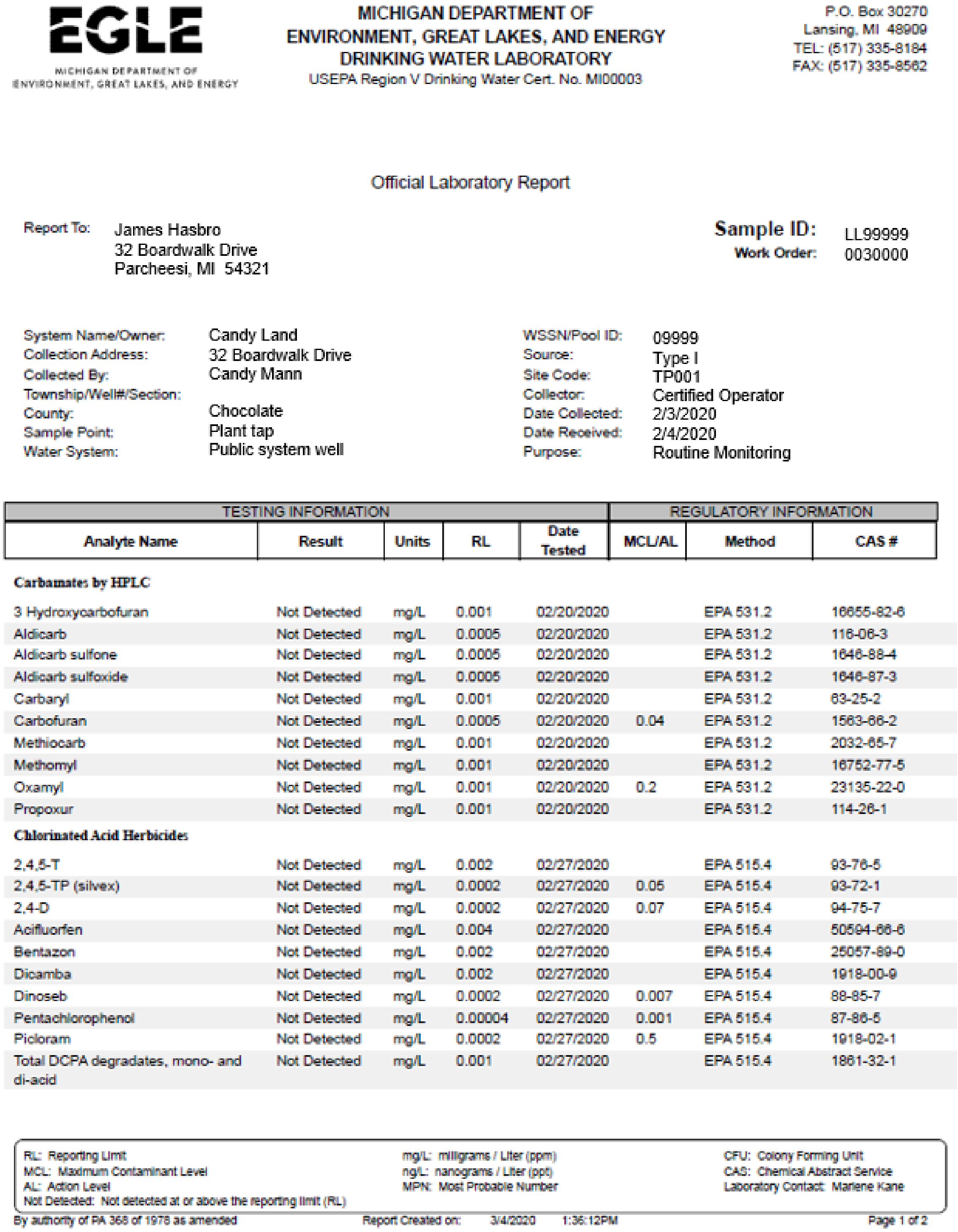
Chocolate County Health Department
1982 Park Place
Parcheesi, MI 54321
989-555-9999

Figure 17.6 Synthetic Organic Volatile Chemicals



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MICHIGAN DEPARTMENT OF ENVIRONMENT, GREAT LAKES, AND ENERGY

MICHIGAN DEPARTMENT OF
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DRINKING WATER LABORATORY
USEPA Region V Drinking Water Cert. No. MI00003

P.O. Box 30270
Lansing, MI 48909
TEL: (517) 335-8184
FAX: (517) 335-8562

Official Laboratory Report

Report To: James Hasbro
32 Boardwalk Drive
Parcheesi, MI 54321

Sample ID: LL99999
Work Order: 0030000

System Name/Owner:	Candy Land	WSSN/Pool ID:	09999
Collection Address:	32 Boardwalk Drive	Source:	Type I
Collected By:	Candy Mann	Site Code:	TP001
Township/Well#/Section:		Collector:	Certified Operator
County:	Chocolate	Date Collected:	2/3/2020
Sample Point:	Plant tap	Date Received:	2/4/2020
Water System:	Public system well	Purpose:	Routine Monitoring

TESTING INFORMATION					REGULATORY INFORMATION		
Analyte Name	**Result**	**Units**	**RL**	**Date Tested**	**MCL/AL**	**Method**	**CAS #**
Carbamates by HPLC							
3 Hydroxycarbofuran	Not Detected	mg/L	0.001	02/20/2020		EPA 531.2	16655-82-6
Aldicarb	Not Detected	mg/L	0.0005	02/20/2020		EPA 531.2	116-06-3
Aldicarb sulfone	Not Detected	mg/L	0.0005	02/20/2020		EPA 531.2	1646-88-4
Aldicarb sulfoxide	Not Detected	mg/L	0.0005	02/20/2020		EPA 531.2	1646-87-3
Carbaryl	Not Detected	mg/L	0.001	02/20/2020		EPA 531.2	63-25-2
Carbofuran	Not Detected	mg/L	0.0005	02/20/2020	0.04	EPA 531.2	1563-66-2
Methiocarb	Not Detected	mg/L	0.001	02/20/2020		EPA 531.2	2032-65-7
Methomyl	Not Detected	mg/L	0.001	02/20/2020		EPA 531.2	16752-77-5
Oxamyl	Not Detected	mg/L	0.001	02/20/2020	0.2	EPA 531.2	23135-22-0
Propoxur	Not Detected	mg/L	0.001	02/20/2020		EPA 531.2	114-26-1
Chlorinated Acid Herbicides							
2,4,5-T	Not Detected	mg/L	0.002	02/27/2020		EPA 515.4	93-76-5
2,4,5-TP (silvex)	Not Detected	mg/L	0.0002	02/27/2020	0.05	EPA 515.4	93-72-1
2,4-D	Not Detected	mg/L	0.0002	02/27/2020	0.07	EPA 515.4	94-75-7
Acifluorfen	Not Detected	mg/L	0.004	02/27/2020		EPA 515.4	50594-66-6
Bentazon	Not Detected	mg/L	0.002	02/27/2020		EPA 515.4	25057-89-0
Dicamba	Not Detected	mg/L	0.002	02/27/2020		EPA 515.4	1918-00-9
Dinoseb	Not Detected	mg/L	0.0002	02/27/2020	0.007	EPA 515.4	88-85-7
Pentachlorophenol	Not Detected	mg/L	0.00004	02/27/2020	0.001	EPA 515.4	87-86-5
Picloram	Not Detected	mg/L	0.0002	02/27/2020	0.5	EPA 515.4	1918-02-1
Total DCPA degradates, mono- and di-acid	Not Detected	mg/L	0.001	02/27/2020		EPA 515.4	1861-32-1

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AL: Action Level
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mg/L: milligrams / Liter (ppm)
ng/L: nanograms / Liter (ppt)
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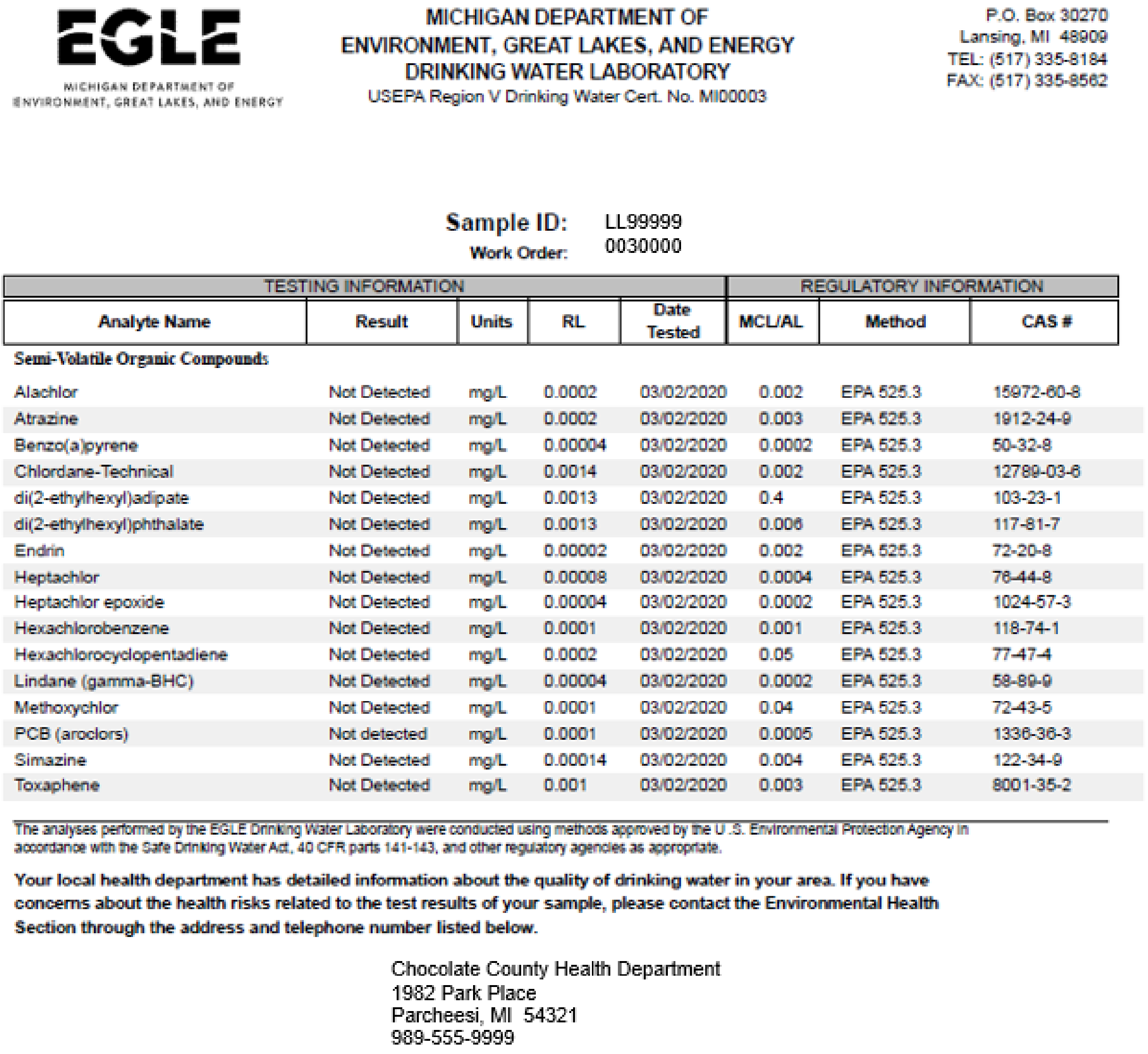
CFU: Colony Forming Unit
CAS: Chemical Abstract Service
Laboratory Contact: Marlene Kane

By authority of PA 368 of 1978 as amended
Report Created on: 3/4/2020 1:36:12PM
Page 1 of 2



MICHIGAN DEPARTMENT OF
ENVIRONMENT, GREAT LAKES, AND ENERGY
DRINKING WATER LABORATORY
USEPA Region V Drinking Water Cert. No. MI00003

P.O. Box 30270
Lansing, MI 48909
TEL: (517) 335-8184
FAX: (517) 335-8562

Sample ID: LL99999
Work Order: 0030000

TESTING INFORMATION					REGULATORY INFORMATION		
Analyte Name	**Result**	**Units**	**RL**	**Date Tested**	**MCL/AL**	**Method**	**CAS #**
Semi-Volatile Organic Compounds							
Alachlor	Not Detected	mg/L	0.0002	03/02/2020	0.002	EPA 525.3	15972-60-8
Atrazine	Not Detected	mg/L	0.0002	03/02/2020	0.003	EPA 525.3	1912-24-9
Benzo(a)pyrene	Not Detected	mg/L	0.00004	03/02/2020	0.0002	EPA 525.3	50-32-8
Chlordane-Technical	Not Detected	mg/L	0.0014	03/02/2020	0.002	EPA 525.3	12789-03-6
di(2-ethylhexyl)adipate	Not Detected	mg/L	0.0013	03/02/2020	0.4	EPA 525.3	103-23-1
di(2-ethylhexyl)phthalate	Not Detected	mg/L	0.0013	03/02/2020	0.006	EPA 525.3	117-81-7
Endrin	Not Detected	mg/L	0.00002	03/02/2020	0.002	EPA 525.3	72-20-8
Heptachlor	Not Detected	mg/L	0.00008	03/02/2020	0.0004	EPA 525.3	76-44-8
Heptachlor epoxide	Not Detected	mg/L	0.00004	03/02/2020	0.0002	EPA 525.3	1024-57-3
Hexachlorobenzene	Not Detected	mg/L	0.0001	03/02/2020	0.001	EPA 525.3	118-74-1
Hexachlorocyclopentadiene	Not Detected	mg/L	0.0002	03/02/2020	0.05	EPA 525.3	77-47-4
Lindane (gamma-BHC)	Not Detected	mg/L	0.00004	03/02/2020	0.0002	EPA 525.3	58-89-9
Methoxychlor	Not Detected	mg/L	0.0001	03/02/2020	0.04	EPA 525.3	72-43-5
PCB (aroclors)	Not detected	mg/L	0.0001	03/02/2020	0.0005	EPA 525.3	1336-36-3
Simazine	Not Detected	mg/L	0.00014	03/02/2020	0.004	EPA 525.3	122-34-9
Toxaphene	Not Detected	mg/L	0.001	03/02/2020	0.003	EPA 525.3	8001-35-2

The analyses performed by the EGLE Drinking Water Laboratory were conducted using methods approved by the U.S. Environmental Protection Agency in accordance with the Safe Drinking Water Act, 40 CFR parts 141-143, and other regulatory agencies as appropriate.

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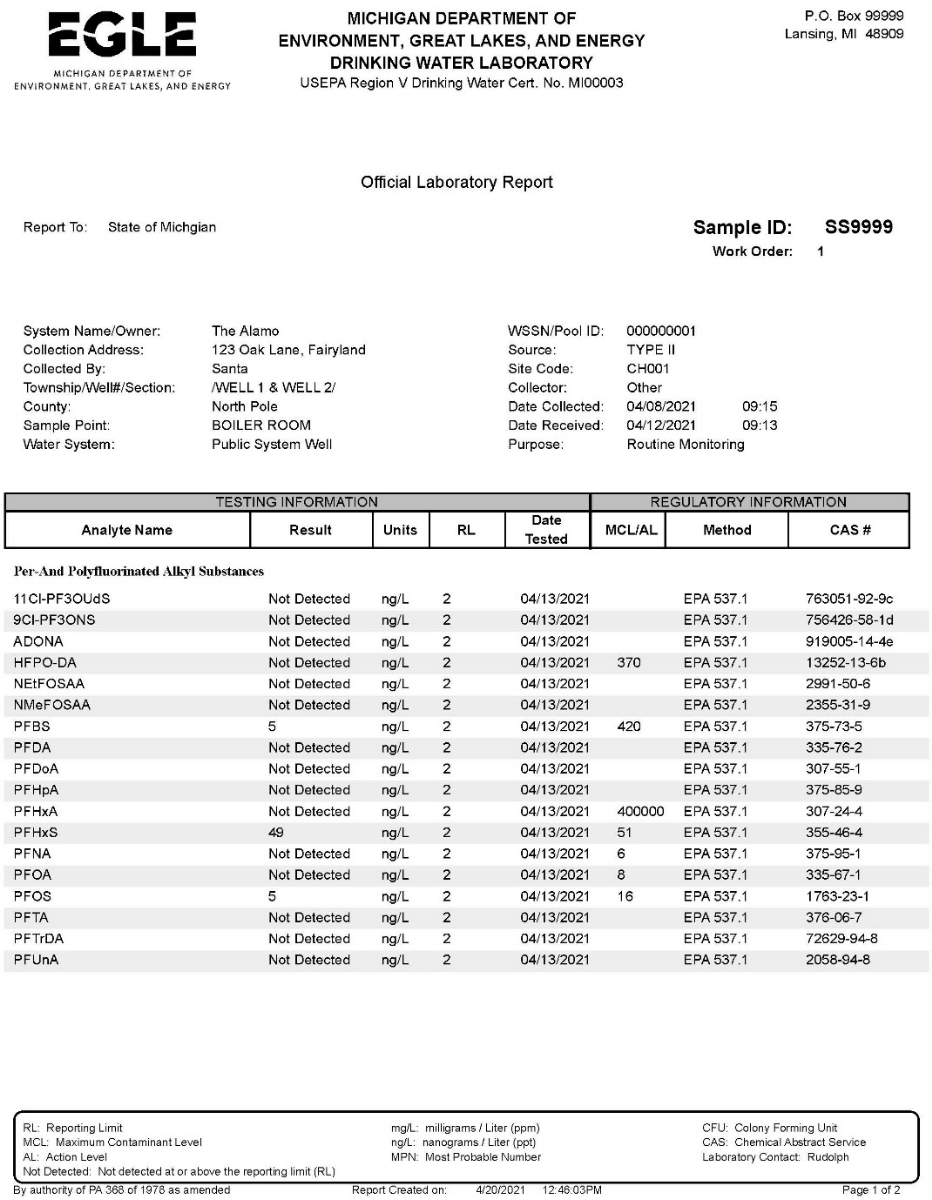
Chocolate County Health Department
1982 Park Place
Parcheesi, MI 54321
989-555-9999

Figure 17.7 PFAS Lab Results



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MICHIGAN DEPARTMENT OF
ENVIRONMENT, GREAT LAKES, AND ENERGY
DRINKING WATER LABORATORY
USEPA Region V Drinking Water Cert. No. MI00003

P.O. Box 99999
Lansing, MI 48909

Official Laboratory Report

Report To: State of Michgian

Sample ID: SS9999
Work Order: 1

System Name/Owner: The Alamo
Collection Address: 123 Oak Lane, Fairyland
Collected By: Santa
Township/Well#/Section: /WELL 1 & WELL 2/
County: North Pole
Sample Point: BOILER ROOM
Water System: Public System Well

WSSN/Pool ID: 000000001
Source: TYPE II
Site Code: CH001
Collector: Other
Date Collected: 04/08/2021 09:15
Date Received: 04/12/2021 09:13
Purpose: Routine Monitoring

TESTING INFORMATION					REGULATORY INFORMATION		
Analyte Name	**Result**	**Units**	**RL**	**Date Tested**	**MCL/AL**	**Method**	**CAS #**
Per-And Polyfluorinated Alkyl Substances							
11Cl-PF3OUdS	Not Detected	ng/L	2	04/13/2021		EPA 537.1	763051-92-9c
9Cl-PF3ONS	Not Detected	ng/L	2	04/13/2021		EPA 537.1	756426-58-1d
ADONA	Not Detected	ng/L	2	04/13/2021		EPA 537.1	919005-14-4e
HFPO-DA	Not Detected	ng/L	2	04/13/2021	370	EPA 537.1	13252-13-6b
NEtFOSAA	Not Detected	ng/L	2	04/13/2021		EPA 537.1	2991-50-6
NMeFOSAA	Not Detected	ng/L	2	04/13/2021		EPA 537.1	2355-31-9
PFBS	5	ng/L	2	04/13/2021	420	EPA 537.1	375-73-5
PFDA	Not Detected	ng/L	2	04/13/2021		EPA 537.1	335-76-2
PFDoA	Not Detected	ng/L	2	04/13/2021		EPA 537.1	307-55-1
PFHpA	Not Detected	ng/L	2	04/13/2021		EPA 537.1	375-85-9
PFHxA	Not Detected	ng/L	2	04/13/2021	400000	EPA 537.1	307-24-4
PFHxS	49	ng/L	2	04/13/2021	51	EPA 537.1	355-46-4
PFNA	Not Detected	ng/L	2	04/13/2021	6	EPA 537.1	375-95-1
PFOA	Not Detected	ng/L	2	04/13/2021	8	EPA 537.1	335-67-1
PFOS	5	ng/L	2	04/13/2021	16	EPA 537.1	1763-23-1
PFTA	Not Detected	ng/L	2	04/13/2021		EPA 537.1	376-06-7
PFTrDA	Not Detected	ng/L	2	04/13/2021		EPA 537.1	72629-94-8
PFUnA	Not Detected	ng/L	2	04/13/2021		EPA 537.1	2058-94-8

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mg/L: milligrams / Liter (ppm)
ng/L: nanograms / Liter (ppt)
MPN: Most Probable Number
CFU: Colony Forming Unit
CAS: Chemical Abstract Service
Laboratory Contact: Rudolph

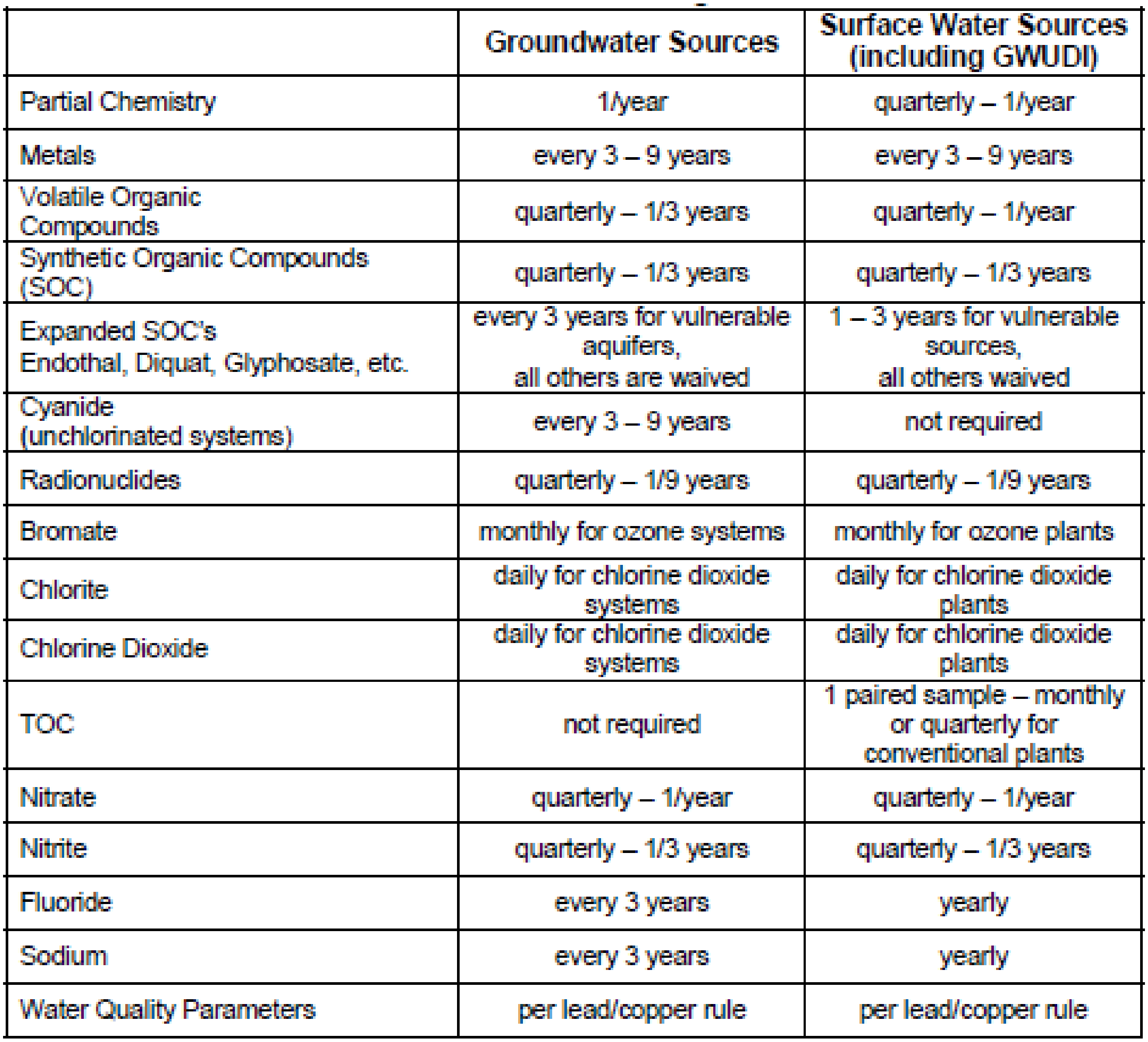
By authority of PA 368 of 1978 as amended Report Created on: 4/20/2021 12:46:03PM Page 1 of 2

These examples show what to look for in a completed report. It is important to completely fill out the sample request form so that the proper PWSID, sample point, etc. is documented on the report. There are other laboratories available for water sample analysis. For a list of certified labs go to the EGLE website at Michigan.gov/Egle, look for “Other Certified Drinking Water Laboratories.”

At the time of this writing, no labs in Michigan do the radiological testing, so those samples will have to be sent to an out-of-state lab from the list. Samples tested at a lab that is not certified will not be acceptable for compliance purposes. Some additional sampling beyond what is listed in the annual Monitoring Schedule may be required as part of an MCL exceedance response, a contamination investigation, or a change in source.

The next two tables summarize general compliance monitoring requirements. However, the compliance monitoring schedule for each supply is unique due to a variety of factors such as the type, age, susceptibility, and number of sources, type of treatment, previous detections, etc. Each PWS receives a unique annual monitoring schedule early each calendar year, which summarizes specific samples required that year. The following charts summarize record-keeping and reporting requirements of a Type I PWS.

Table 17.8 Entry Point Monitoring



	Groundwater Sources	Surface Water Sources (including GWUDI)
Partial Chemistry	1/year	quarterly – 1/year
Metals	every 3 – 9 years	every 3 – 9 years
Volatile Organic Compounds	quarterly – 1/3 years	quarterly – 1/year
Synthetic Organic Compounds (SOC)	quarterly – 1/3 years	quarterly – 1/3 years
Expanded SOC's Endothal, Diquat, Glyphosate, etc.	every 3 years for vulnerable aquifers, all others are waived	1 – 3 years for vulnerable sources, all others waived
Cyanide (unchlorinated systems)	every 3 – 9 years	not required
Radionuclides	quarterly – 1/9 years	quarterly – 1/9 years
Bromate	monthly for ozone systems	monthly for ozone plants
Chlorite	daily for chlorine dioxide systems	daily for chlorine dioxide plants
Chlorine Dioxide	daily for chlorine dioxide systems	daily for chlorine dioxide plants
TOC	not required	1 paired sample – monthly or quarterly for conventional plants
Nitrate	quarterly – 1/year	quarterly – 1/year
Nitrite	quarterly – 1/3 years	quarterly – 1/3 years
Fluoride	every 3 years	yearly
Sodium	every 3 years	yearly
Water Quality Parameters	per lead/copper rule	per lead/copper rule

All chemical analysis lab results records for a public water supply are to be kept for 10 years with an exception to Lead and Copper sample results which are kept for 12 years.

PFAS Sampling Requirements

R 325.10717d Collection and analysis of samples for per- and polyfluoroalkyl substances.
Rule 717d.

(1) Suppliers of community and nontransient noncommunity water supplies shall collect samples and cause analyses to be made under this rule for per- and polyfluoroalkyl substances to determine compliance with the state drinking water standards in R 325.10604g. Each supplier shall monitor at the time designated by the department.

(2) For transient noncommunity and type III public water supplies, the department may require samples to be collected and analyzed at prescribed frequencies for per- and polyfluoroalkyl substances.

(3) A groundwater supplier shall take at least 1 sample at every entry point to the distribution system that is representative of each well after treatment, also known as sampling point. Each sample must be taken at the same sampling point unless conditions make another sampling point more representative of each source or treatment plant.

(4) A surface water supplier, or combined surface water and ground water, shall take at least 1 sample at points in the distribution system that are representative of each source or at each entry point to the distribution system after treatment, also known as sampling point. Each sample must be taken at the same sampling point unless conditions make another sampling point more representative of each source or treatment plant.

(5) If a system draws water from more than 1 source and the sources are combined before distribution, then the supplier shall sample at an entry point to the distribution system during periods of normal operating conditions when water that is representative of all sources is being used.

(6) An existing supplier with one or more samples taken at each sampling point described in subrules (3), (4), or (5) of this rule as part of the State of Michigan's 2018/2019 Statewide PFAS Survey shall conduct initial sampling as follows: (a) A supplier with one or more sample results greater than 50% of the MCL for a contaminant listed in rule 10604g shall collect samples from each sampling point beginning the first full quarter following the effective date of this rule. (b) A supplier with no detection or a detection less than or equal to 50% of the MCL for a contaminant listed in rule 10604g shall collect at least 1 sample from each sampling point within 6 months of the effective date of this rule.

(7) An existing supplier without sampling conducted under subrule (6) of this rule, shall collect samples beginning the first full quarter following the effective date of this rule.

(8) A new community or nontransient noncommunity water supply shall collect samples beginning the first full quarter following the initiation of operations.

(9) If the results of samples collected under subrules (6), (7), or (8) of this rule are below the reporting limits specified in R 325.12708, the department may allow the water supply to monitor annually.

(10) If a contaminant in R 325.10604g is detected above the reporting limit in any sample, then all of the following provisions apply: (a) Each supply shall monitor quarterly at each sampling point that resulted in a detection. The department may decrease the quarterly monitoring requirement specified in this subrule if it has determined that the supply is reliably and consistently below the MCL. A groundwater supplier shall take not fewer than 2 quarterly samples and a surface water supplier shall take not fewer than 4 quarterly samples before this determination. (b) After the department determines that the supply is reliably and consistently below the MCL, the department may allow the supply to monitor annually.

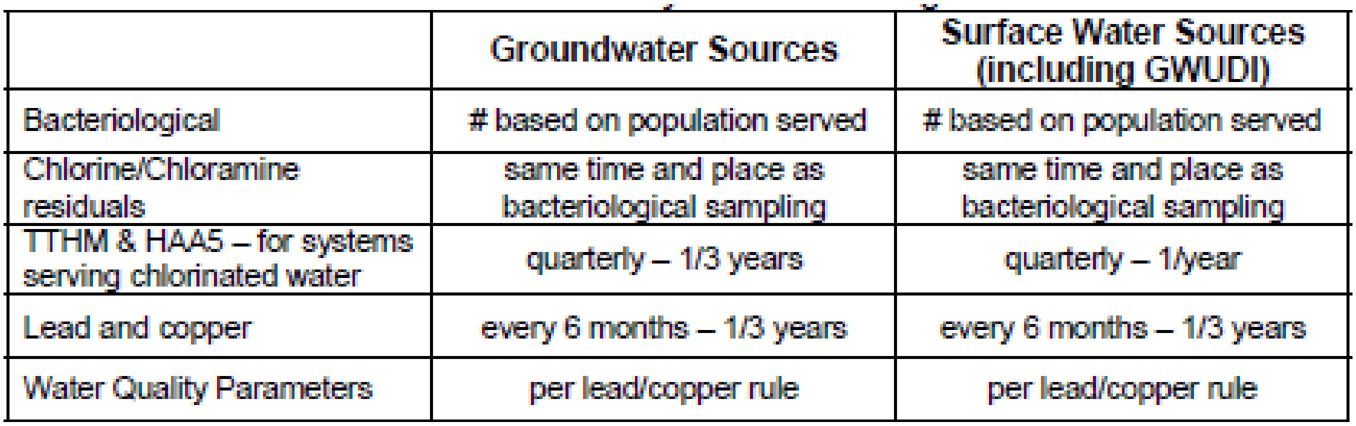
(11) A supplier that violates R 325.10604g shall monitor quarterly. If not fewer than 4 quarterly samples show that the supply is in compliance and the department determines the supply is reliably and consistently below the MCL, then the department may allow the supply to monitor annually.

(12) The department may require confirmation sampling for positive or negative results. If confirmation sampling is required, then the results must be averaged with the first sampling result and the average must be used for the compliance determination. The department may exclude results of obvious sampling errors from this calculation.

(13) The department may increase the required monitoring to detect variations within the system.

(14) All new supplies or supplies that use a new source of water shall demonstrate compliance with the MCLs before serving water to the public. The supply shall also comply with the initial sampling frequencies specified by the department.

Table 17.8 Distribution System Monitoring



	Groundwater Sources	**Surface Water Sources (including GWUDI)**
Bacteriological	# based on population served	# based on population served
Chlorine/Chloramine residuals	same time and place as bacteriological sampling	same time and place as bacteriological sampling
TTHM & HAA5 – for systems serving chlorinated water	quarterly – 1/3 years	quarterly – 1/year
Lead and copper	every 6 months – 1/3 years	every 6 months – 1/3 years
Water Quality Parameters	per lead/copper rule	per lead/copper rule

Table 17.9 Required Reporting for Public Water Supplies

TYPE OF REPORT	AFFECTED SUPPLIES	FREQUENCY	ITEMS TO BE ADDRESSED	REMARKS & CITATION
Monthly Operation Reports (MOR)	Community supplies with treatment; noncommunity supplies with treatment for public health purposes.	Monthly. Due by the end of the month following each month of operation. If MOR is used to report results of required monitoring, then due within timeframe for the particular contaminant, i.e. within 10 days of the following month for total coliform (TCR) or turbidity (SWTR).	1. General operation data. 2. Information on daily pumpage and chemical application. 3. Analyses of general parameters relating to quality of the treated water.	Forms provided by EGLE. Rule 1502(1).
Analytical Results of bacteriological, chemical, and turbidity	All community and noncommunity supplies.	Monthly. Due by 10th of the month following receipt of results or 10 days after end of monitoring period. Report to the department within 48 hours of violating a drinking water standard.	Analytical results of required monitoring.	Results of analyses preformed by the state laboratory are automatically reported to EGLE. Rule 734.
Disinfectant Residuals, Disinfection Byproducts, and Disinfection byproduct precursors	All community and noncommunity supplies that use a chemical disinfectant.	Quarterly, or each monitoring period. Due 10 days after end of each: • quarter, if monitoring quarterly or more frequently, or • monitoring period if monitoring less frequently than quarterly.	Generally: • number of samples taken; • average of results; and, • for disinfection byproducts, the location, date and results of each sample taken. See R325.10719f for more details.	Measure chlorine residual at same time and place as bacteriological sampling unless otherwise noted in disinfection monitoring plan. Rule 719f.
Annual Pumpage Report	Community supplies not submitting MORs; certain noncommunity supplies as determined by DEQ.	March 31st of each calendar year.	Summary of water pumpage and water use.	Form provided by EGLE.
Annual Cross Connection Report	Community supplies with a cross connection program.	March 31st of each calendar year.	Summary of cross connection program activities.	Form provided by EGLE. Rule 1404(4).
Consumer Confidence Report	All community water supplies.	Due to water customers AND EGLE by July 1 of each year.	Required information about the water system, contaminant detections, violations, etc.	Deliver certification form to EGLE by October 1 of each year. Rules 412(1) and (3) and 415(3) to (4).

Figure 17.10 Excerpt from *Community and Noncommunity Water Supply Systems – Required Operations Oversight*, EGLE Policy ODWMA-399-017

POLICY:

The following criteria are established for both standard and interim operation of F, D, and S classified water systems:

F-1, F-2, F-3, F-4, AND F-5 SYSTEMS

STANDARD OPERATION

Under standard operation, an OIC shall be employed by the water supply, make daily visits to the water treatment plant (WTP), be on call 24 hours per day, and supervise/direct staff responsible for daily operations. This includes OIC's that work full time (40+ hours a week) for a single water supply with only one WTP. For systems with certified shift operators, non-traditional work schedules (i.e., four 10-hour days) may be considered acceptable.

For systems with more than one WTP - the OIC shall make daily visits to each WTP, be on call 24 hours per day, and supervise/direct staff responsible for daily operations. For systems with certified shift operators, the requirement to visit each WTP daily may be reduced if there is a plan in place for proper operation of each WTP when the OIC is not on-site. The plan should include the methods of communication, off-site operation capabilities and the expected response time for the OIC to travel to each WTP in emergencies. This approval shall be in writing and re-assessed when either the person leaves the supply, or if system conditions require increased operator oversight.

In cases where an operator is providing OIC services either by contract or an operations agreement - the OIC shall make daily visits to each WTP, be on call 24 hours per day, and supervise/direct staff responsible for daily operations. For these situations, daily means at least 5 days a week, 4 hours per visit.

For F-5 WTPs with acceptable oversight and a plan in place for the proper operation of the WTP when the OIC is not available (such as a trained person on site who is capable of performing the daily duties), visit frequency may be reduced to weekly per approval of the EGLE or Local Health Department staff. System performance should be considered When to be on site when to take readings in the decision to reduce the frequency of visits. This approval shall be in writing and reassessed when either the person leaves the supply, or if system conditions require increased operator oversight.

INTERIM OPERATION

For interim operation when an OIC is no longer available, it is acceptable to provide the supply time to recruit a replacement or promote a staff member to fill the OIC position.

During this interim period, the supply must retain a temporary OIC certified at the appropriate level to visit the WTP daily and be responsible for its daily operation. A temporary OIC for an F-5 supply may be allowed to visit the WTP weekly if approved by the EGLE or Local Health Department staff. The following conditions also apply:

1. If the supply desires to promote a staff member to be the OIC after the staff member has achieved proper certification, this individual must first qualify to write the appropriate certification examination when it is next offered. If this individual fails the examination, the supply must immediately pursue the hiring of a full-time OIC. 2. If the supply does not desire to promote a staff member to be the OIC, then it must immediately pursue hiring a full time OIC. The OIC must be on staff within six months.

Interim Operation may only be considered if ALL of the following apply:

1. The OIC leaves abruptly. 2. The supply cannot or does not immediately appoint an OIC.
3. Properly certified shift operators are present (does not apply to F-5 WTPs).

D-1, D-2, AND D-3 SYSTEMS

STANDARD OPERATION

Under standard operation, an OIC shall be employed by the water supply, make daily visits to the WTP, be on call 24 hours per day, and supervise/direct staff responsible for daily operations. If a supply has acceptable oversight and has a plan in place for the proper operation of the waterworks system when the operator in charge is not available (such as a trained person on site who is capable of performing the daily duties), visit frequency may be reduced to twice per week per approval of the EGLE. The visit frequency for D-3 systems with only chlorine or chlorine and phosphate addition may be reduced to once per week per approval of the EGLE. System performance should be considered in the decision to reduce the frequency of visits. This approval shall be in writing and re-assessed when either the person leaves the supply, or if system conditions require increased operator oversight.

INTERIM OPERATION

For interim operation when an OIC is no longer available, it is acceptable to provide the supply time to recruit a replacement or promote a staff member to the OIC position. During this interim period, the supply must retain a temporary OIC certified at the appropriate level to visit the WTP at least once per week, be on call 24 hours per day, and supervise/direct staff responsible for its daily operation. The following conditions also apply:

1. If the supply desires to promote a staff member to be the OIC after the staff member has achieved proper certification, this individual must first qualify to write the appropriate certification examination when it is next offered. If this individual fails the examination, the

supply must immediately pursue the hiring of a full-time OIC. 2. If the supply does not desire to promote a staff member to be the OIC, then it must immediately pursue hiring a full-time OIC. The OIC must be on staff within six months.

Interim Operation may only be considered if ALL of the following apply:

1. The OIC leaves abruptly. 2. The supply cannot or does not immediately appoint an OIC. 3. The supply has an operator with acceptable knowledge and experience to conduct daily operations under the supervision of the temporary OIC.

D-4 AND D-5 SYSTEMS

STANDARD OPERATION

Under standard operation, an OIC shall be employed by the water supply, make weekly visits to the WTP, be on call 24 hours per day, and supervise/direct staff responsible for daily operations. If a supply has acceptable oversight and has a plan in place for the proper operation of the waterworks system when the operator in charge is not available (such as a trained person on site who is capable of performing the daily duties), visit frequency may be reduced to twice per month per approval of the EGLE or Local Health Department staff. The standard operation for D-5 systems may be reduced to once per month with the approval of the EGLE or Local Health Department staff. System performance should be considered in the decision to reduce the frequency of visits. This approval shall be in writing and re-assessed when either the person leaves the supply, or if system conditions require increased operator oversight.

INTERIM OPERATION – Same as STANDARD OPERATION, above.

S-1, S-2, AND S-3 SYSTEMS

STANDARD OPERATION

Under standard operation, an OIC shall be employed by the water supply, make daily visits to the supply, be on call 24 hours per day, and supervise/direct staff responsible for daily operations. If a supply has acceptable oversight and has a plan in place for the proper operation of the waterworks system when the operator in charge is not available (such as a trained person on site who is capable of performing the daily duties), visit frequency may be reduced to once per week per approval of the EGLE. System performance should be considered in the decision to reduce the frequency of visits. This approval shall be in writing and re-assessed when either the person leaves the supply, or if system conditions require increased operator oversight.

INTERIM OPERATION

For interim operation when an OIC is no longer available, it is acceptable to provide the supply time to recruit a replacement or promote a staff member to the OIC position. During this interim period, the supply must retain a temporary OIC certified at the appropriate level to visit the supply at least once per week, be on call 24 hours per day, and supervise/direct staff responsible for daily operations. The following conditions also apply:

1. If the supply desires to promote a staff member to be the OIC after the staff member has achieved proper certification, this individual must first qualify to write the appropriate certification examination when it is next offered. If this individual fails the examination, the supply must immediately pursue the hiring of a full-time OIC. 2. If the supply does not desire to promote a staff member to be the OIC, then it must immediately pursue hiring a full-time OIC. The OIC must be on staff within six months.

Interim Operation may only be considered if ALL of the following apply:

1. The OIC leaves abruptly. 2. The supply cannot or does not immediately appoint an OIC. 3. The supply has an operator with acceptable knowledge and experience to conduct daily operations under the supervision of the temporary OIC.

S-4 SYSTEMS

STANDARD OPERATION

Under standard operation, an OIC shall be employed by the water supply, make twice a month visits to the supply, be on call 24 hours per day, and supervise/direct staff responsible for daily operations. If a supply has acceptable oversight and has a plan in place for the proper operation of the waterworks system when the operator in charge is not available (such as a trained person on site who is capable of performing the daily duties), visit frequency may be reduced to once per month per approval of the EGLE. System performance should be considered in the decision to reduce standard operation. This approval shall be in writing and re-assessed when either the person leaves the supply, or if system conditions require increased operator oversight.

INTERIM OPERATION – Same as STANDARD OPERATION, above.

S-5 SYSTEMS

Class S-5 systems include CWSs and NCWSs with no treatment and a distribution system limited in extent. The following guidelines shall be used to determine if a distribution system is limited in extent:
1. Any supply with a distribution system comprised solely of building piping. 2. Any supply comprised of an external buried distribution system that does not include water supply

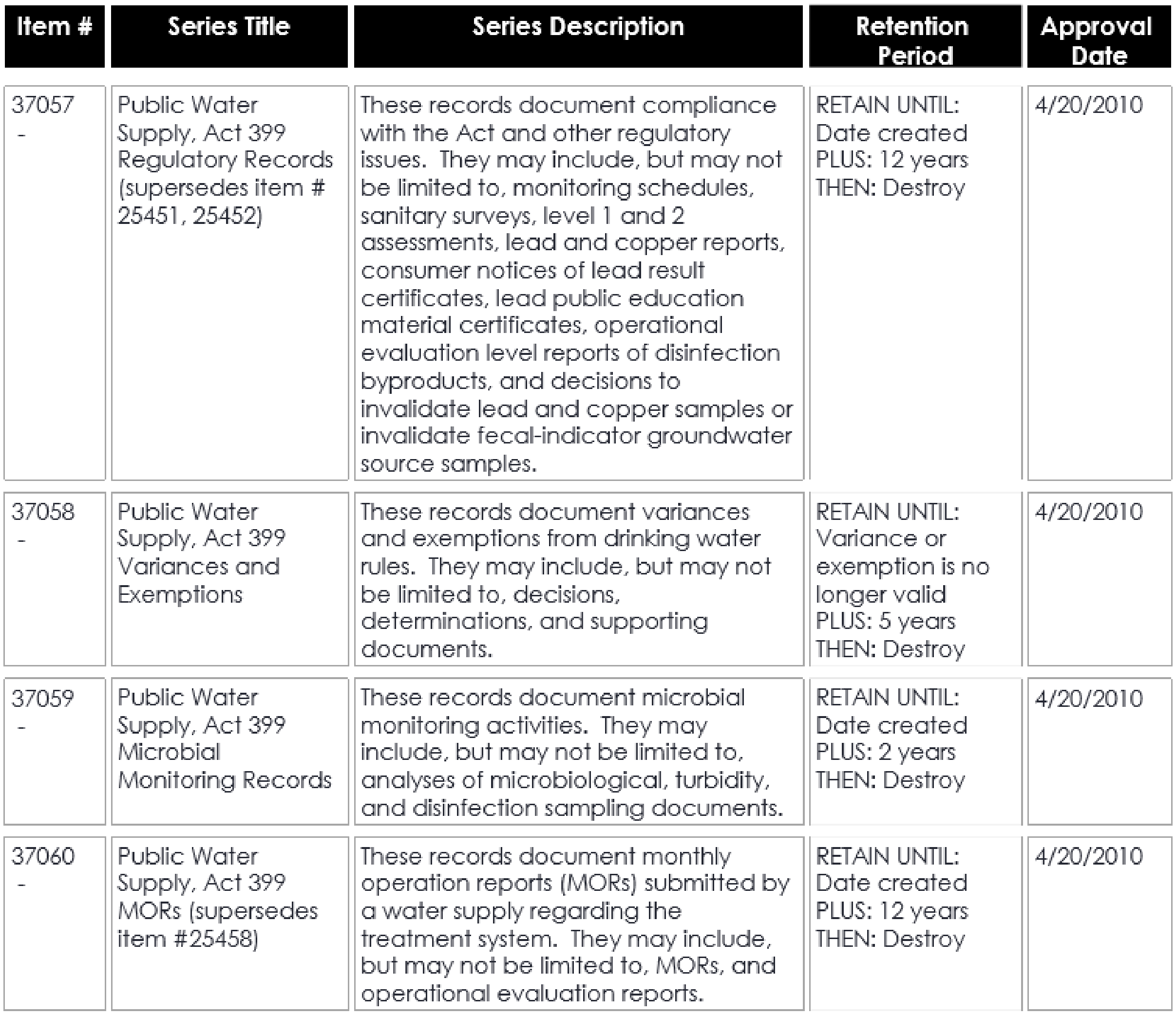
appurtenances that require maintenance such as fire hydrants, system valves, blow-off assemblies, etc.

STANDARD OPERATION

Under standard operation, an OIC shall be employed by the water supply, make monthly visits to the supply, be on call 24 hours per day, and supervise/direct staff responsible for daily operations. If a supply has acceptable oversight and has a plan in place for the proper operation of the waterworks system when the operator in charge is not available (such as a trained person on site who is capable of performing the daily duties), visit frequency may be reduced to once per quarter per approval of the EGLE or Local Health Department staff. System performance should be considered in the decision to reduce the frequency of visits. This approval shall be in writing and re-assessed when either the person leaves the supply, or if system conditions require increased operator oversight.

INTERIM OPERATION – Same as STANDARD OPERATION, above.

Figure 17.11 Record Retention Schedules



Item #	Series Title	Series Description	Retention Period	Approval Date
37057 -	Public Water Supply, Act 399 Regulatory Records (supersedes item # 25451, 25452)	These records document compliance with the Act and other regulatory issues. They may include, but may not be limited to, monitoring schedules, sanitary surveys, level 1 and 2 assessments, lead and copper reports, consumer notices of lead result certificates, lead public education material certificates, operational evaluation level reports of disinfection byproducts, and decisions to invalidate lead and copper samples or invalidate fecal-indicator groundwater source samples.	RETAIN UNTIL: Date created PLUS: 12 years THEN: Destroy	4/20/2010
37058 -	Public Water Supply, Act 399 Variances and Exemptions	These records document variances and exemptions from drinking water rules. They may include, but may not be limited to, decisions, determinations, and supporting documents.	RETAIN UNTIL: Variance or exemption is no longer valid PLUS: 5 years THEN: Destroy	4/20/2010
37059 -	Public Water Supply, Act 399 Microbial Monitoring Records	These records document microbial monitoring activities. They may include, but may not be limited to, analyses of microbiological, turbidity, and disinfection sampling documents.	RETAIN UNTIL: Date created PLUS: 2 years THEN: Destroy	4/20/2010
37060 -	Public Water Supply, Act 399 MORs (supersedes item #25458)	These records document monthly operation reports (MORs) submitted by a water supply regarding the treatment system. They may include, but may not be limited to, MORs, and operational evaluation reports.	RETAIN UNTIL: Date created PLUS: 12 years THEN: Destroy	4/20/2010

37061 -	Public Water Supply, Act 399 Nonmicrobial Monitoring Records (supersedes item # 25460)	These records document nonmicrobial monitoring. They may include, but may not be limited to, analyses of sampling other than of microbiological, turbidity and disinfection, and certifications of water supply compliance with acrylamide and/or epichlorhydrin treatment requirements.	RETAIN UNTIL: Date created PLUS: 12 years THEN: Destroy	4/20/2010
37098 -	Nonpoint Source (NPS) - State Revolving Fund (SRF) Application Reviews	These records document the use of State Revolving Fund (SRF) funds for NPS. They may include, but may not be limited to, reviews of proposals, and correspondence.	RETAIN UNTIL: No longer of reference value PLUS: 5 years THEN: Destroy	4/20/2010

Item #	Series Title	Series Description	Retention Period	Approval Date
37119 -	Wellogic Data (supersedes item # 25369)	These records document data submitted by water well drilling and pump installation contractors. Data may include, but may not be limited to, the location of the well, permit number, owner of the well, well depth, well use, well casing information, static water level, pumping level, pump information, name of drilling machine operator, and name of water well contractor.	Permanent	4/20/2010
37120 -	Water Quality Data (supersedes item # 25370)	These records document water laboratory testing data for water supplies in Michigan. Each water sample is documented independently and the samples date back to 1983. Data may include, but may not be limited to, sample collection name and address, sample collection methods, sample billing name and address, and results of chemical analysis.	Permanent	4/20/2010

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