December 2009

Guidance Document for Preparing Corrosion Control Plans for Drinking Water Systems

FINAL

Guidance for Demonstrating Compliance with

Ontario Regulation 170/03
Schedule 15.1 Lead

made under the *Safe Drinking Water Act*

PIBs # 7463

Protecting our environment. Ontario

FOREWORD

The “Guidance Document for Preparing Corrosion Control Plans for Drinking Water Systems, December 2009” (the Guidance Document) provides guidance on complying with the Corrosion Control Plan content requirements of Schedule 15.1: Lead, of Ontario Regulation 170/03: Drinking Water Systems.

The Guidance Document is intended to provide guidance to ensure the fair and consistent implementation of the Regulation. The Ministry of Environment (MOE) may periodically publish a list of questions and answers to assist in the interpretation of this Guidance Document. This subject matter – and industry’s understanding of corrosion and corrosion control – is constantly changing. Therefore this subject matter may be updated on a regular basis by the MOE. The contents of this document may also be updated from time to time based on public consultation consistent with the Ontario Environmental Bill of Rights legislation. All website addresses referred to in this document are current at the time of release.

While every effort has been made to ensure the accuracy of the information contained in this Guidance Document, it should not be construed as legal advice. In the event of conflict with requirements identified in Regulation 170/03, then the regulatory requirements shall determine the appropriate approach.

For any addenda or revisions to this document please visit the MOE website at:

http://www.ontario.ca/ONT/portal51/drinkingwater/

or contact:

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1.0 INTRODUCTION

1.1 Regulatory Context for Corrosion Control Planning

Schedule 15.1: Lead of Ontario Regulation 170/03: Drinking Water Systems (the Regulation) made under the *Safe Drinking Water Act* (SDWA) is the regulation that is intended to manage lead release specifically and internal corrosion in general in Drinking Water Systems. The Ontario Drinking Water Quality Standard (ODWQS) for lead was not intended to serve as an indicator of corrosion. Per Schedule 15.1 of the Regulation, results for the concentration of lead in drinking water measured in residential and non-residential plumbing in addition to the distribution system are used to identify the source of lead and to assess the effectiveness of corrosion control. If more than 10 percent of samples collected in accordance with the sampling requirements exceed the ODWQS for lead, the Owner and Operating Authority of the Drinking Water System are required to prepare a Corrosion Control Plan as defined in section 11 of Schedule 15.1:

> ***15.1-11. (1) This section applies to a large municipal residential system if,***
>
> ***(a) in two of the three most recent periods described in section 15.1-4 or 15.1-5, more than 10 percent of all the samples taken from plumbing under that section and tested for lead exceed the standard prescribed for lead, according to the results of the tests conducted under section 15.1-7; and***
>
> ***(b) in each of the two periods mentioned in clause (a), the number of samples that exceed the standard prescribed for lead is at least two***

If the conditions of section 15.1-11 (1) apply, the Regulation requires the Owner and Operating Authority of a large municipal residential system (LMRS) to meet the requirements for corrosion control planning, as defined in subsequent subsections of section 15.1-11:

Demonstration of compliance with 15.1-11 (5) begins with the preparation of a Corrosion Control Plan. This Guidance Document provides guidance on complying with the requirements of the Regulation that govern the content of the Corrosion Control Plan. The Guidance Document applies to Schedule 15.1 of Regulation 170/03 which came into force on July 27, 2007. This Guidance Document can be used and referenced by Drinking Water System Owners and Operating Authorities to meet the requirements for corrosion control planning under Regulation 170/03.

(3) Within one year after the last day of the period mentioned in subsection (1) during which the test results are such as to cause this section to apply, the Owner of the system and the Operating Authority for the system shall ensure that a plan that complies with subsection (5) is prepared and submitted to a Director appointed by the Minister under section 6 of the Act in respect of section 32 of the Act.

(4) The plan shall be prepared and submitted in a form and manner approved by the Director.

1.2 Overview of the Corrosion Control Plan

1.1.1 Who is Required to Prepare a Corrosion Control Plan?

The requirement for a Corrosion Control Plan under Schedule 15.1 applies to large municipal residential systems in the following circumstances:

- Lead concentrations are measured above the ODWQS in more than 10 percent of all the samples taken from residential and non-residential plumbing in each of two of the three most recent sampling rounds, and

- At least two samples exceed the ODWQS for lead in each of the two sampling rounds

A large municipal drinking water system is defined under the Regulation as a major residential development serving more than 100 private residences. If a Drinking Water System obtains treated water from another Drinking Water System, requirements for a joint Corrosion Control Plan apply to the Owner and Operating Authority of the system that supplies the treated water as well as the Operating Authority that obtains the treated water.

For small municipal residential systems and non-municipal year-round residential systems that sample for lead under Schedule 15.1, Corrosion Control Plans are not required. Rather, the Owner and Operating Authority of the Drinking Water System shall take steps as directed by the Medical Officer of Health.

Schedule 15.1 of the Regulation does not apply to:

- Large municipal non-residential systems

- Small municipal non-residential systems

- Non-municipal seasonal residential systems

- Large non-municipal non-residential systems
- Small non-municipal non-residential systems

The above listed systems are subject to Schedule 15.2 of the Regulation and a Corrosion Control Plan is not required.

1.1.2 Update of a Corrosion Control Plan

If a significant change in source water quality is observed or if a change in source is considered, the potential impacts on the corrosivity of the water and the need for corrosion control should be considered. If a municipality is considering a change to how the source water is treated, the potential impacts on the corrosivity of the treated water and the need for corrosion control must be evaluated. Candidate treatment changes that could affect corrosion or corrosion control include:

- Any process change that results in a change to the pH and/or alkalinity of the treated water
- Introduction of a coagulant at a plant without prior use of a coagulant
- Introduction of a new acid to the process (such as fluoride, carbon dioxide, sulphuric acid, etc.) or change in how an existing acid is applied (such as a change in the pH target)
- Introduction of a new base (such as lime, sodium hydroxide, etc.) or change in how an existing base is applied (such as a change in the pH target or use in combination with carbon dioxide)
- Change in the chemical used for residual maintenance (free chlorine versus chloramine)

A change in the type of coagulant used at a facility or a change in how the coagulant is applied (e.g., pH of coagulation, coagulant dose, use of a coagulant aid) may in itself not necessitate a full review and/or resubmission of the Corrosion Control Plan. Similarly, a change in the source of chlorine used (sodium hypochlorite versus chlorine gas) may in itself not necessitate a full review and/or resubmission of the Corrosion Control Plan. Only results from lead sampling under Schedule 15.1-4 and 15.1-5 can trigger the submission (or re-submission) of a Corrosion Control Plan.

1.1.3 Contents of a Corrosion Control Plan

The general features of a Corrosion Control Plan are identified in Schedule 15.1-11 (5) of the Regulation. Details for each will be described in the subsequent chapters of the Guidance Document.

> ***(5) The plan shall,***
>
> ***(a) analyze the potential for lead leaching into water as a result of corrosion that occurs in the system's distribution system or in plumbing that is connected to the system's distribution system;***
>
> ***(b) list and analyze possible measures to reduce the potential for lead leaching;***
>
> ***(c) identify the preferred measure or measures;***
>
> ***(d) set out an implementation schedule; and***
>
> ***(e) include a program for monitoring the effectiveness of the preferred measure or measures.***

Templates and worked examples for each section of a Corrosion Control Plan are presented in the appendices.

1.1.4 Retention of a Corrosion Control Plan

Records required by or created in accordance with the Corrosion Control Plan, unless specifically referenced in section 12 of O. Reg. 170/03, shall be retained for at least five years in a location where a provincial officer who is inspecting the treatment system can conveniently review them.

1.1.5 CofA or DWWP/Licence Implications

The development and implementation of the Corrosion Control Plan is not impacted by the phase-in of the MOE's municipal drinking water licensing program. A detailed discussion of the submission process for the plan itself and how this relates to the approval process for the design of new treatment works (if required) is presented in section 8.3.

1.3 How to Use This Guidance Document

Each Owner and Operating Authority will vary in their understanding of metals release and corrosion control and will be at different stages in the development of their corrosion control plan. The content presented in this Guidance Document has been organized to allow the reader to select the chapters of interest, be it on background information, preparing a Corrosion Control Plan, or worked examples. As much as possible, each chapter has been developed to be read as a stand alone chapter and as a result there is some repetition in content.

Background Information

Chapters 1 through 4 provide background information.

- The Guidance Document is introduced in Chapter 1 in the context of the legislated requirements of Schedule 15.1 of O. Reg. 170/03

- Background theory on internal corrosion and water quality is presented in Chapter 2, including an overview on tools to monitor corrosion and the effectiveness of corrosion control; while this discussion is in no means exhaustive on the subject matter, it does provide an introduction and the reader can consult the references for additional sources of information

- Alternative measures for corrosion control are described in the background information of Chapter 3

- The impact that the choice of corrosion control measure has on in-plant treatment and distribution system water quality – referred to as secondary impacts – is discussed in Chapter 4

Preparing the Corrosion Control Plan

Chapters 5 through 9 provide information to assist in the development of the Corrosion Control Plan. Worked examples of key components of the plan are included in the Appendix F.

- Factors to consider in the evaluation of alternative measures for lead control are reviewed in Chapter 5, including a review of alternative chemical agents

- Tools to measure the effectiveness of control measures and suggestions for post-implementation monitoring are presented in Chapter 6

- Secondary impacts are revisited in Chapter 7, along with suggestions for how to evaluate the potential impacts of different alternative measures on process changes and internal corrosion

- General implementation issues for corrosion control are identified in Chapter 8, with the approval process for corrosion control planning detailed in section 8.3

- Explanations for the minimum content of each chapter of the Corrosion Control Plan are contained in Chapter 9, with the mandatory and minimum requirements of the Corrosion Control Plan described in section 9.1

Lead Reduction Strategies

For some systems, chemical-based treatment for metals release may not be feasible and lead reduction strategies may be pursued as an alternative approach. Guidance for this approach is presented in Chapter 10.

Supporting Materials

Acronyms, a glossary and references are provided after Chapter 10. The list of reference includes documents in addition to those cited in Chapters 1 to 10. The appendices include solubility charts, flow charts to identify alternatives for lead control, a proposed table of contents for the Corrosion Control Plan, and worked examples. Mandatory forms are included in Appendix C, including the Notice of Submission of Corrosion Control Plan and the Checklist for the Corrosion Control Plan.

1.4 Theories of Corrosion Control

1.4.1 Overview

This document provides Owners and Operating Authorities with guidance on developing a Corrosion Control Plan to reduce lead levels measured in their system. While this is the main focus of the Corrosion Control Plan, an understanding of how corrosion control for lead can impact other materials in the system (such as iron and copper) will also play a role in determining the most appropriate treatment to implement in each individual system. Therefore, general corrosion theory as it relates to lead in particular, and other metals as well, is provided in this section and in Chapter 2. The remainder of this document focuses specifically on control of lead, with other corrosion by-products (iron and copper) addressed only as it relates to evaluating the secondary impacts of corrosion control for lead.

There may be other methods for reducing the levels of lead in drinking water that do not involve altering the water chemistry to reduce the potential for corrosion. These include the removal of lead sources in distribution and premise plumbing systems. Systems that wish to evaluate the effectiveness and implementation of non-treatment methods as an alternative to the submission of a Corrosion Control Plan should make a request for regulatory relief to the Director. Refer to Chapter 10 for information on lead reduction strategies.

This section provides background information on basic concepts and theories of corrosion, including an overview of internal corrosion and the types of corrosion by-products. Read in combination with the theory presented in subsequent chapters, this information will provide a foundation for understanding corrosion in general, and the release and control of lead into drinking water in particular. Understanding these key concepts is essential when examining alternatives to control corrosion and when developing a Corrosion Control Plan.

1.4.2 What is Corrosion?

Corrosion is the physicochemical reaction between a metal and its environment that results in changes to the property of that metal. Corrosion of water distribution system materials can cause 1) failure of the distribution infrastructure resulting from leakage or reduced hydraulic capacity and 2) release of corrosion by-products, such as lead, copper, iron, and antimony into the water. Lead is used as an indicator of corrosion and for the need for corrosion control in Schedule 15.1. As a result, the focus of this Guidance Document is on lead, although discussions of other corrosion by-products will be addressed.

1.4.3 Ontario Drinking Water Quality Standards

The ODWQS for lead is 0.010 mg/L (or 10 ug/L) and applies at the point of consumption. For information, the aesthetic objective for iron is 0.3 mg/L and the aesthetic objective for copper is 1 mg/L. The operational guideline identified in the ODWQS for pH is a range between 6.5 and 8.5, although it is noted that this recommendation is based on in-plant needs such as coagulation and primary disinfection.

1.4.4 Electrochemical Corrosion Cell

Corrosion is the deterioration of a metallic material, normally through the loss of metal to solution. Corrosion is a “special” form of the oxidation-reduction reaction:

- Oxidation occurs at the anode and this is where metal is dissolved, as the result of the removal of electrons

- Reduction occurs at the cathode and this is where metal accumulates or is deposited as result of the consumption of electrons

The anode is therefore negatively charged and the cathode is positively charged. In order for corrosion to occur, and following components that together make up the electrochemical cell must be present:

1. An anode, where the metal corrodes and goes into solution

2. A cathode, where metal deposition occurs
3. An electrolyte solution (the water), which is in contact with both the anode and the cathode and provides a path for flow of ions (OH-), and
4. An internal circuit (the pipe), which provides the electrical connection between the anode and the cathode, allowing electrons (e-) to flow between them

All of these components need to be present for corrosion to occur. Alternately, if any component is missing, then corrosion cannot occur. Controlling corrosion is based on manipulating the water chemistry or infrastructure to effectively eliminate at least one of the four components of the electrochemical cell. A simplified diagram of an electrochemical cell is shown in Figure 1-1 and a conceptual figure depicting the formation of a lead carbonate scale in a lead pipe (as a Pb(II) scale) is shown in Figure 1-2.

Figure 1-1: Schematic of a Simplified Electrochemical Cell

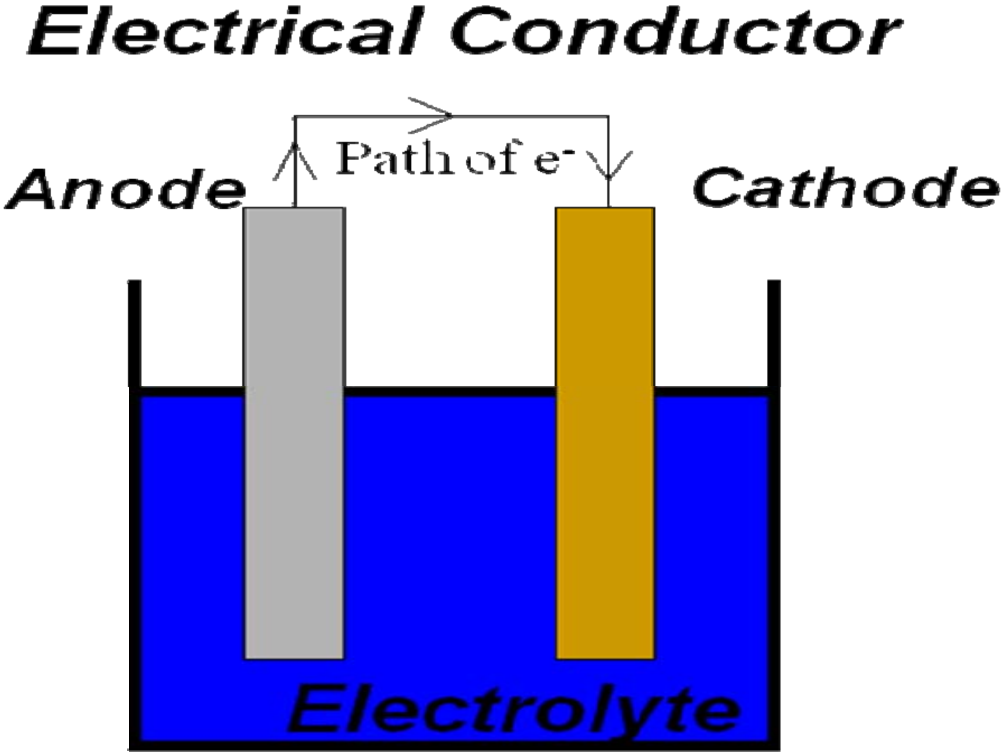
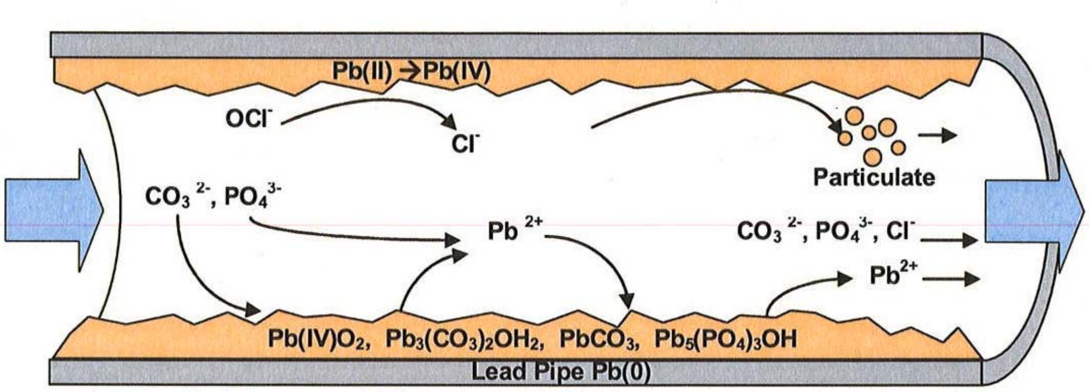


Figure 1-2: Conceptual Figure for the Formation of Lead Corrosion Product in a Lead Pipe (Noel and Giammer, 2008; used with permission by author)



The oxidation and mobilization of metals such as lead into water is driven by the level of oxidant in the water, the pH level, and the complexation of metal by various ions or molecules in the water such as hydroxide, carbonate, and orthophosphate. Depending on water quality characteristics, metal ions formed by the corrosion reaction combine with various constituents in the water to form carbonate compounds on the surface of the pipe (this is referred to as the scale). The properties of the scale will impact the rate of the corrosion reaction, and the solubility of the particular scale that is formed will determine the concentration of the metal in the water. If the scale is relatively soluble, then lead can go into solution. Once in solution, the lead can be transported in the bulk water to the customer's tap. When water chemistry changes, for example when corrosion control treatment is implemented, the scale can be modified to be less soluble, resulting in lower lead levels in the water. Redox diagrams are available that indicate whether or not metals such as lead may be present in their elemental form or bound with carbonate species, and whether they are present as either a solid (particulate) or liquid (solution). This concept is described in more detail in Chapter 2.

1.4.5 Controlling Corrosion and Release of Lead

The primary approaches to control corrosion in drinking water are:

- To modify the water chemistry to make it less corrosive and to encourage formation of less soluble compounds (passivation), and

- To use pipe materials and design the system so that it is not corroded by a particular water

For many municipalities that already have pipe in the ground, controlling corrosion through physical treatment can be difficult. It may be easier to chemically change the water quality to make it less corrosive. The primary alternatives for chemically changing the water quality for lead control are passivation through pH and/or alkalinity adjustment or inhibitor addition. Background on the theory of control of lead release can be found in Chapter 3. Calcium carbonate ($CaCO_3$) precipitation has historically been considered for lead control but there is little research supporting formation of continuous $CaCO_3$ films and therefore the calcium carbonate precipitation potential is more widely used to evaluate potential for secondary problems related to scaling.

1.4.6 Consideration of Other Corrosion By-products

Each municipality should identify the corrosion by-products in addition to lead that are of concern for their system. For example, metals release of concern may include:

- Elevated lead only
- Elevated levels of both lead and copper
- Elevated lead or copper with raw water iron and manganese
- Elevated copper only

This assessment will provide the necessary information with which to determine not only the best approach for reduction of lead levels, but the most appropriate overall corrosion control measures for the system.

In general, increasing pH for lead control will be beneficial for copper pitting and uniform copper corrosion, and corrosion of galvanized pipe, iron, and steel. However the stability of the water will be a factor in iron and steel corrosion. If operating at the pH range for minimal buffering intensity (e.g., pH 8 to 8.5), iron corrosion may be exacerbated due to pH fluctuations in the distribution system and red water may result. Phosphate addition will also be beneficial for copper, galvanized, iron, and steel materials, and zinc orthophosphate may limit deterioration of AC pipe. Polyphosphates, when used alone to sequester iron and manganese, may be ineffective for the control of lead.

2.0 Causes of Internal Corrosion and Water Quality Impacts

This chapter presents guidance on analyzing the potential for lead to leach into water as a result of corrosion that occurs in an Owner and Operating Authority's distribution system or in plumbing that is connected to the Owner and Operating Authority's distribution system. Guidance to identify the materials of construction in the distribution and premise plumbing, to evaluate the cause(s) of internal corrosion to identify the types of corrosion, and to understand water quality impacts and corrosion monitoring approaches are presented in this chapter. This analysis can be completed using historical data and/or new data collected specifically for purposes of development of the Corrosion Control Plan. Assessment of data can provide the background for understanding corrosion in a given system and is the basis for developing alternatives for corrosion control.

2.1 Materials of Construction and Sources of Lead

Lead may occur in drinking water either by contamination of the source water, which is relatively rare, or from corrosion of lead plumbing or fixtures used in both the distribution system and premise plumbing.

Distribution systems are generally made up of large diameter steel, cast and ductile iron, PVC, and asbestos cement pipe. Corrosion of plumbing materials that contain lead is usually the cause of elevated lead levels measured at the tap, particularly corrosion of lead pipe used for service lines and lead contained in premise plumbing. The service line and premise plumbing systems are comprised of smaller diameter lead, copper, plastic, and galvanized piping, lead solder connecting the copper pipe, and brass and bronze components, faucets, and fittings. Corrosion of these lead and copper-based materials may result in measurable lead and copper in the drinking water as by-products of corrosion.

While distribution and premise plumbing systems contain a variety of materials, diameters, and lengths of pipes and components, the major sources of lead are from smaller diameter premise systems. Smaller diameter pipes will have higher lead concentrations than larger diameter pipes because there is more metal surface area per unit volume of water that flows through the pipe. Consequently, smaller diameter pipes will likely have higher lead concentrations after stagnation when compared to larger diameter pipes. The challenge for Owners and Operating Authorities is to develop a corrosion control approach that controls lead and is compatible with all materials used in the distribution and premise plumbing systems.

A schematic of a typical water service connection is shown in Figures 2-1a and 2-1b, and potential sources of lead in a municipality's distribution system and the customer's premise plumbing are identified.

Figure 2-1a: Schematic of a Typical Water Service Connection
(Drawing adapted from City of Ottawa; used with permission)

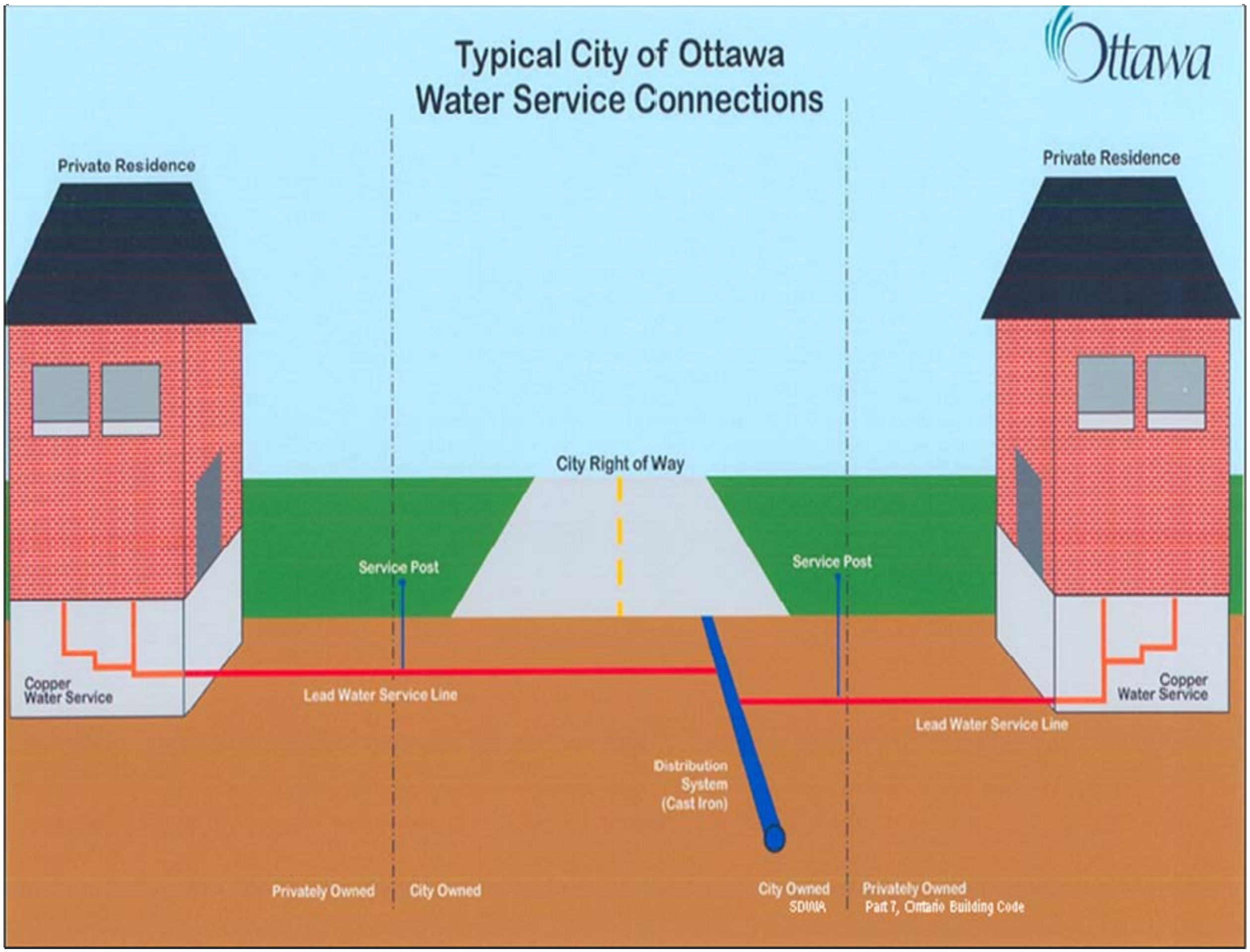
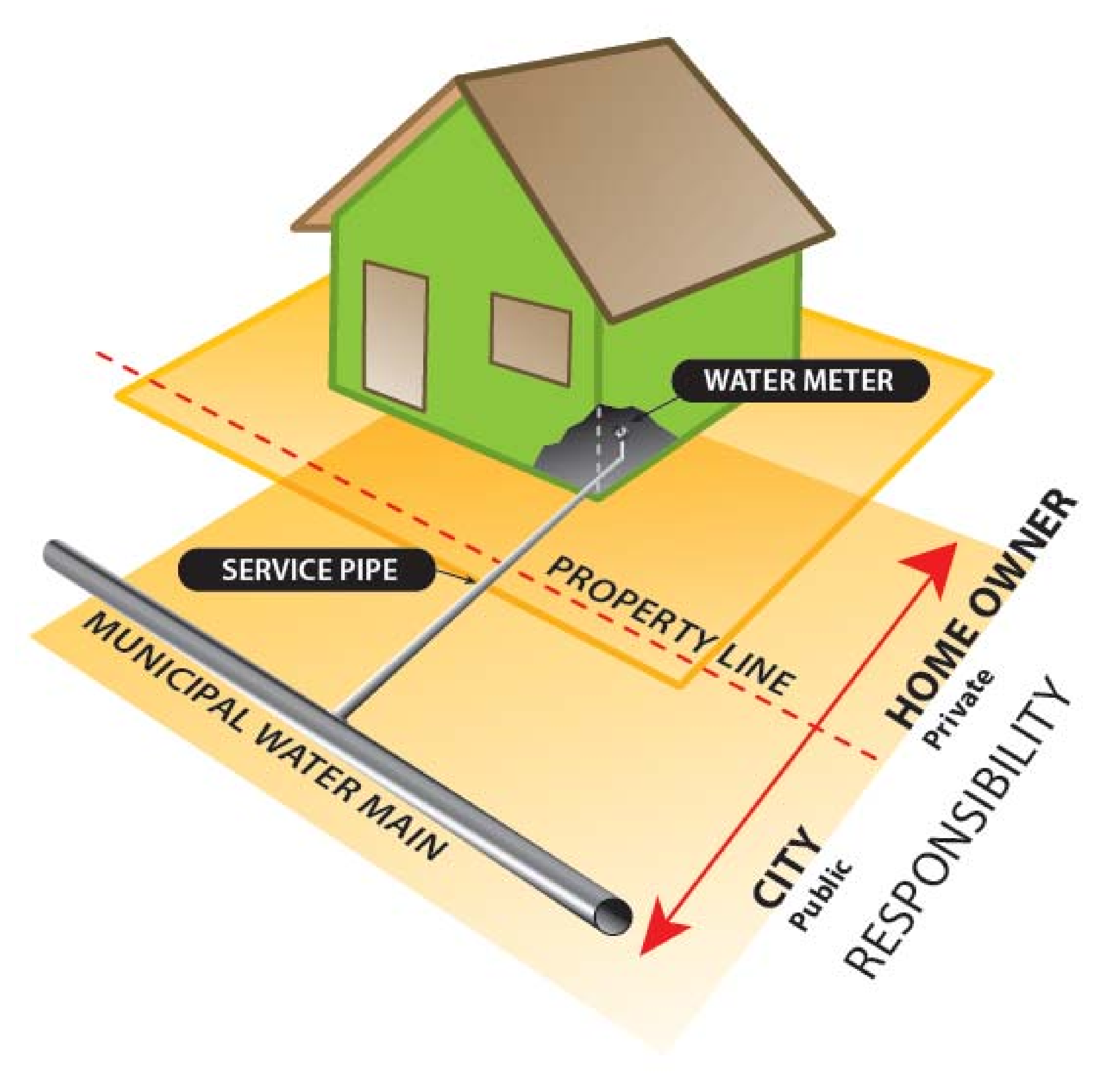


Figure 2-1b: Schematic of a Typical Water Service Connection
(from City of London; used with permission)



These sources of lead include:

- Lead pipe
- Lead based solder used to connect copper piping
- Galvanized pipe

- Brass/bronze faucets, fittings, valves, meters, etc.
- Unplasticized polyvinyl chloride pipe (uPVC)

Lead pipes and lead-based solder are the major contributors to lead levels at the tap. Lead pipes can be found as service piping (connecting the residence to the water main), as lead goosenecks (flexible connectors between the main and the service pipe), and occasionally as piping in the home. Lead-based solders comprised of 50:50 lead:tin were used up until the 1980s in the United States and the late 1980s in Canada. Brasses and bronzes (copper alloys) are used for fittings, valves, meters, and faucets, and can contain various percentages of lead. The zinc coating used on galvanized steel pipes can contain up to 1 percent lead. Older systems may have leaded gaskets in place. Hydrants are likely to contain brass and/or lead components. Unplasticized polyvinyl chloride (uPVC), used in mains and domestic water piping, may have incorporated lead containing stabilizers during manufacturing.

2.2 Types of Corrosion

There are many types of corrosion for which the mechanism of corrosion differs, and therefore the approach to controlling a given type of corrosion will also differ. Uniform corrosion is the most common form of lead corrosion, where the corroding metal acts as both the anode and the cathode with the anode and cathode constantly shifting over the lead surface. The result is that the internal surface of lead pipe is generally coated with a smooth layer of lead precipitate.

Galvanic corrosion occurs when two different types of metal or alloys (such as lead and copper) contact each other and the elements of a corrosion cell are present. In this case, one of the metals serves as the anode and deteriorates, while the other serves as the cathode. For example, galvanic corrosion may occur where a lead service line (LSL) is connected to a copper service line.

If the anode is localized on the surface of metal, a pit or indentation in the metal surface is produced and this is described as pitting. Pitting may continue until the pipe is perforated, which is a common mode of failure of copper pipe. The metal ion that is produced during pitting may dissolve in the water next to the pipe surface, or it may precipitate and form a mound over the pit called a tubercle. Copper pipe tubercles are a blue-green deposit and iron pipe tubercles usually are a reddish-brown deposit. Iron pits often are shallow and many times do not penetrate the pipe wall, presumably because of the structure and composition of the tubercle. Copper pits frequently penetrate the pipe wall, most likely because of the structure and chemistry of the overlying tubercle, and can cause severe problems from leaks as a result. It is very difficult to predict when copper pitting will occur.

Microbiologically induced corrosion (MIC) results from a reaction between the pipe material and organisms such as bacteria, algae, and fungi (Schock, 1990). The chemistry of the water inside or under biofilms is often different than the bulk water chemistry, thus promoting more intense localized corrosion in the vicinity of the biofilm.

2.3 Water Quality Factors Affecting Corrosion

Physical, chemical and biological characteristics of drinking water affect the occurrence and rate of corrosion, scale solubility, and ultimately the release of metals or corrosion by-products to the bulk water. These factors are described below.

2.3.1 Chemical

There are many chemical factors that have an impact on corrosion. Several of these are closely related, and a change in one factor can impact another factor.

pH. The pH is an important factor in corrosion because hydrogen ions (H^+) are one of the major substances that can accept the electrons given up by a metal when it corrodes. At values below about pH 5, iron, lead, and copper corrode rapidly. At values higher than pH 9, these metals are usually protected. The pH also greatly affects the formation and solubility of protective films (Schock, 1999); for example, phosphate-based inhibitors are typically used at pH levels ranging between 7.4 and 7.8, and pH affects the structure of the minerals that make up the scale.

Alkalinity and Dissolved Inorganic Carbonate (DIC). Alkalinity is a measure of the ability of a water to neutralize strong acids and is a measure of buffering capacity against a pH drop (Droste, 1997). Total alkalinity is a function of the concentrations of bicarbonate, carbonate and hydroxide ions. Dissolved inorganic carbonate (DIC) is defined as the sum of all dissolved carbonate-containing species, including bicarbonate, carbonate, carbonic acid, and carbon dioxide (Schock, 1999). Bicarbonate and carbonate affect many important reactions in corrosion chemistry, including a water's ability to form a protective metallic carbonate scale or passivating film (Schock, 1999). The term dissolved inorganic carbon is normally synonymous with dissolved inorganic carbonate.

Knowing the pH, temperature, ionic strength, and alkalinity of a water, the DIC can be calculated. Tables are available in the literature to calculate DIC based on the pH, alkalinity and conductivity of a water sample (e.g., US EPA 2003).

Hardness. Hardness is caused by the presence of divalent cations, predominantly calcium and magnesium. Hard water is typically less corrosive than soft water because if there is sufficient calcium and alkalinity present at a given pH, then a protective film may form (Schock, 1999).

Disinfectant Residual. Gaseous chlorine lowers the pH of the water by reacting with the water to form hypochlorous acid, hydrogen ion and chloride ion. This results in potentially more corrosive water entering the distribution system. This effect can be amplified in waters that do not have a large amount of alkalinity to buffer the pH (Schock, 1999). Thus it is critical to be aware of disinfection changes and their potential impacts on corrosion. The chlorine residual maintained in the distribution system can also affect the type of scale that may form on lead pipe. Higher chlorine residuals may cause lead (IV) scales to form which are less soluble than lead (II) scales.

Dissolved Oxygen. Oxygen is one of the most prevalent agents of corrosion. In many cases it is the substance that accepts the electrons given up by the corroding metal (Schock, 1999). Oxygen enables the formation of Pb(II) and Pb(IV) ions (AwwaRF and DVGW 1996).

Ammonia. Ammonia can form strong soluble complexes with metals, including lead and copper. Ammonia can also interfere with the formation of passivating films and/or increase corrosion rates. If there is excess ammonia in the distribution system, nitrification can occur. Nitrification can lower alkalinity and pH, which in turn can negatively impact corrosion and lead release.

Chloride and Sulphate. Chloride (Cl^-) and sulphate (SO_4^{2-}) may increase corrosion because:

- Chloride and sulphate can react with metals in solution, causing dissolved metals to remain soluble

- Both chloride and sulphate can increase the TDS and conductivity of a water

High chloride-to-sulphate-mass ratios (CSMRs) may result in higher corrosion rates for lead solder connected to copper pipe (Oliphant, 1983; Gregory, 1985). Edwards et al. (1999) compared the CSMR and 90th percentile lead levels reported in a survey of US utilities initial Lead and Copper Rule monitoring results and found that utilities with CSMRs less than 0.58 met the 0.015 mg/L lead action level whereas only 36 percent of utilities with CSMRs greater than 0.58 met the action level. The CSMR is another tool that may be used to assess the corrosivity of a water and the potential for lead release. However, there is a large gray area with the CSMR where more research is needed to determine how water quality can affect the dividing line between a “good” value for the CSMR and a “bad” value in terms of lead release.

Total Dissolved Solids. A high total dissolved solids concentration is usually associated with water that has high conductivity (high ionic strength), and therefore increases a water’s ability to complete the electrochemical circuit and to conduct a corrosive current (Schock, 1999). Therefore, the higher the TDS, the higher the ionic strength and conductivity, and the easier it is for corrosion to occur. The dissolved solids may also affect the formation of protective films. Total dissolved solids are comprised of calcium, magnesium, phosphates, sulphates, nitrates, sodium, potassium, and chloride.

Natural Colour and Organic Matter. Natural organic matter in the water can affect corrosion in several ways. Some natural organic substances may react with the metal surface to form a protective film and reduce corrosion. Others have been shown to react with the corrosion products to increase corrosion. In some cases organic matter becomes food for microorganisms growing in the pipes (Schock, 1999).

Corrosion Indices. The Langelier Saturation Index (LSI) was historically used as an indicator of the corrosivity of water. It is an ineffective indicator because it is based on inhibition solely by carbonate species (carbonate, bicarbonate, and hydroxide ions) and calcium, and from the perspective of DIC (which is a measure of all dissolved carbonate-containing species), this is incorrect. Other compounds can complex with metals, including phosphate and silicate among other anions, and therefore the LSI may not correlate well with the corrosivity of the water.

Summary. When employing a treatment based approach for corrosion control and lead release, the objective is to effectively bind or “tie up” the lead in a scale so that it is not available for release into the bulk water. This can be accomplished by promoting the formation of protective or passivating scales in which the lead is bound within carbonate and/or hydroxide scales, and in the case of phosphate inhibitors, the lead is bound within phosphate and carbonate and/or hydroxide scales.

2.3.2 Physical

Flow and temperature are the main physical characteristics of water that affect corrosion.

Temperature. Theoretically, an increase in temperature will increase the rate of corrosion because for every 10°C rise in temperature, chemical reaction rates typically tend to double. As well, the electrode potential is proportional to the absolute temperature (Schock, 1999). The effect of temperature varies depending on the water characteristics. Water that exhibits no corrosive characteristics may become corrosive at high temperatures. An increase in temperature can lead to a decrease in pH, and as a result, water that is more corrosive. This can be prevented by ensuring that the alkalinity of the water is adequate to buffer any temperature change (Schock, 1999). Hot water may also reduce corrosion by turning non-scaling water into scaling water. For example, calcium carbonate ($CaCO_3$) is less soluble at high temperatures and therefore results in the precipitate forming a protective layer, and in turn reducing corrosion (Schock, 1999).

Flow. Flow or velocity can have varying effects on corrosion. Velocity is directly linked to mass transfer properties of the system. In other words, a high velocity is similar to a high mass flux of lead from the pipe because the lead is being transported faster by the moving bulk water.

High velocities can contribute to corrosion by increasing the rate at which dissolved oxygen comes in contact with pipe surfaces. High velocities are also associated with erosion corrosion (Schock, 1999). However, high velocities can aid in the formation of protective coatings by transporting the protective material to the surfaces at a higher rate. In the case of iron, higher velocities that keep oxygen next to the iron scale can be beneficial in reducing iron release.

At low velocities, the protective properties of inhibited waters are not used to their best advantage because the slow movement does not aid the effective diffusion rate of the protective ingredients to the metal surface. Therefore, a water that behaves satisfactorily at medium to high velocities may still cause incipient or slow corrosion with accompanying red water problems at low velocities (Schock, 1999). Stagnant waters as a result of extremely low velocities may result in corrosion in the form of pitting and tuberculation, especially in iron pipes, as well as the possibility for biological growth which may result in increased microbiologically induced corrosion (Schock, 1999).

2.3.3 Microbiological

Changes in water chemistry from corrosion in the system and from application of corrosion control can influence the environmental conditions to which microbes are exposed. As a result, their growth can be affected by changes in turbidity, presence of tubercles, disinfection levels, pH, or inhibitor concentrations.

2.4 Corrosion and Metal Release Monitoring

Several types of monitoring can be implemented by Owners and Operating Authorities to provide a better understanding of corrosion in their system and/or the extent of metals release. Therefore the purpose of a monitoring program should be determined prior to sampling in order to develop the appropriate protocols. Examples of monitoring programs include:

- Baseline water quality assessment (to assess general corrosion conditions in the distribution system)
- Regulatory
- Special studies to identify the source or extent of corrosion and metal release

There are several key parameters that should be considered when developing monitoring programs. Suggested parameters are listed in Table 2-1, but it should be kept in mind that not all parameters would be monitored for a particular program.

Table 2-1: Possible Sampling Parameters

Metal Levels	Lead Copper	Iron
Other Parameters	pH	Temperature
	Alkalinity, hardness, DIC	Oxidation reduction potential (ORP)
	Chlorides, sulphates	Conductivity
	Chlorine, disinfectant residuals	Total Dissolved Solids
	Dissolved oxygen	Sodium
	Manganese	
Other Parameters, Chloraminating Systems	Free ammonia	Nitrate
	Nitrite	Chloramine speciation
Inhibitors	Phosphate	Silicates

Monitoring sites and frequency of monitoring will be program specific, but in general sites would include raw and treated water, locations in the distribution system, and premise systems. Frequency of collection of parameters will also be program specific, and should be based on an understanding of how that parameter may vary over time and location. Systems with multiple sources that routinely change source waters or blend ratios, and systems with highly varying seasonal water quality differences should attempt to monitor more frequently to obtain a clear picture of how water quality changes in their system, and how those changes may impact corrosion.

2.4.1 Baseline Water Quality Assessment

Baseline monitoring provides a good understanding of corrosion conditions and long-term trends in parameters for the system as a whole. Several corrosion-related parameters can be measured at select locations throughout the distribution system over time, such as pH, temperature, alkalinity, chlorine residual, conductivity, inhibitor concentration, and dissolved oxygen. Interpretation can include evaluating results from different areas of the distribution system to determine if wide shifts in pH (greater than 1 pH unit) are being measured or if chlorine residual or orthophosphate residual is extremely low. These data can be merged with information on lead levels measured at the tap to see if there is a correlation.

2.4.2 Regulatory Monitoring

The requirements for standard sampling are defined in section 15.1-4 of the Regulation, and are repeated below:

(1) The Owner of a Drinking Water System and the Operating Authority for the system shall ensure that, in accordance with sections 15.1-6 and 15.1-7, samples are taken during the periods described in subsection (2),

(a) in plumbing that serves private residences, from at least the number of points set out in Column 3 of the Table to this section opposite the population served by the Drinking Water System;

(b) in plumbing that does not serve private residences, from at least the number of points set out in Column 4 of the Table to this section opposite the population served by the Drinking Water System; and

(c) in the Drinking Water System's distribution system, from at least the number of points set out in Column 5 of the Table to this section opposite the population served by the Drinking Water System.

(2) The samples required by subsection (1) must be taken during each of the following periods:

1. ***The period from December 15, 2007 to April 15, 2008 and the corresponding period in every subsequent 12 month period.***

2. ***The period from June 15, 2008 to October 15, 2008 and the corresponding period in every subsequent 12 month period.***

The number of samples that are collected under Schedule 15.1 as part of standard sampling is presented in Table 2-2.

Table 2-2: Standard Sampling – Number of Sampling Locations per Schedule 15.1-4

Population Served by Drinking Water System	**COLUMN 3** **Number of Sampling Points in Plumbing that Serves Private Residences**	**COLUMN 4** **Number of Sampling Points in Plumbing that Does Not Serve Private Residences**	**COLUMN 5** **Number of Sampling Points in Distribution System**
1- 99	5	1	1
100 - 499	10	1	2
500 - 3,299	20	2	4
3,300 - 9,999	40	4	8
10,000 - 49,999	60	6	12
50,000 - 99,999	80	8	16
100,000 or more	100	10	20

Regulatory monitoring at residential sites includes single and multi-family dwellings. Water is flushed for 5 minutes followed by a 30 minute stagnation time after which two sequential 1-litre samples are collected. Lead is measured in both samples but the higher of the two results is used to determine how many samples exceed the ODWQS of 0.010 mg/L (or the 90th percentile). A third sample volume is collected to measure pH in the field.

The purpose of stagnation samples (e.g., 30 minutes) is to assess the corrosivity of the water at the tap and/or to assess the effectiveness of corrosion control. This sample is most representative of typical water exposure the consumer gets from the tap and this is the purpose of sampling in accordance with Schedule 15.1 of the Regulation. Tap sampling using this protocol forms the basis to determine the percentage of samples with lead levels that exceed the ODWQS.

The ODWQS is the limit for lead in drinking water regardless of how the sample is collected (such as where the sample is collected or flowing versus standing sample) – this is the regulated concentration (standard) for lead in drinking water. The ODWQS for lead applies to any sample in which lead is measured, regardless of how the sample has been obtained: distribution and in-home tap samples, flowing and stagnation samples, or stagnation times.

Non-residential monitoring is designed to evaluate the source of lead within a building, such as places or business or restaurants. Day care facilities and schools are not included in Schedule 15.1 of the Regulation.

Distribution system monitoring is used to identify the source of lead due to fittings or other components used in the distribution system. These samples are flushed samples and must be taken near where premise plumbing samples are taken, and should be collected on the same day as the premise plumbing samples.

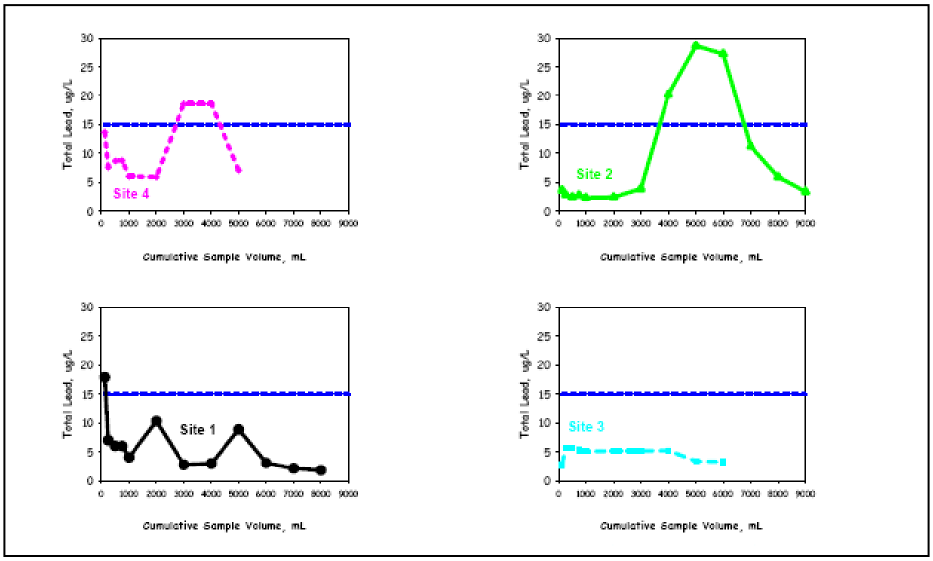
The MOE has identified several situations in which regulatory relief from community lead testing requirements may be granted. These include insufficient residential and non-residential sampling locations due to lack of volunteers. The *“Guide to Filling Out a Request for Regulatory Relief from Lead Sampling Requirements in Schedule 15.1 of Regulation 170/03, Safe Drinking Water Act”* may be consulted for further information about options for regulatory relief.

2.4.3 Special Studies

Special studies can be laboratory studies, pipe loop, scale analyses, and monitoring programs developed to identify where the lead may be coming from. Laboratory pipe loop studies can be used to evaluate metal release under controlled conditions, and scale analyses can provide direct information on the properties of existing scales on the surfaces of the pipe to help determine whether or not they might be more or less likely to release lead into the water. These types of studies are described in more detail in Chapter 3.

Monitoring programs can also be developed to identify where the lead may be coming from. The use of profile sampling, where several sequential stagnation samples are collected at the tap and analyzed for lead, can be used to help determine where and how much lead may be leaching from various areas of the premise system. The lead levels are evaluated based on survey information on materials, lengths, volumes, and diameters of piping from the site. Examples of lead results from profile monitoring are provided to indicate the presence of a lead service and/or lead from brass faucets in (Figure 2-2). Interpretation of these types of programs will involve evaluating lead measured in sequential samples collected at the tap and identifying which part of the premise system or service line each sample represents. If lead levels are high in the initial volumes, then the faucet and premise plumbing may be large contributors to lead levels measured at the tap. If lead levels are high in samples representative of the service, this is an indication that a lead service line exists at that particular site. In Figure 2-2, the presence of a lead service line is clearly indicated for sites 2 and 3 by the higher lead level measured in samples representative of the service. The high initial sample may indicate that a brass faucet is the source of lead. It should be noted that once corrosion control treatment has been implemented, it may be more difficult to identify lead sources due to the reduction in lead levels that would likely result.

Figure 2-2: Example Results, Sampling for Lead to Identify the Source (from Estes-Smarigiasi and Cantor, 2006)



2.4.4 Operational Monitoring

Operational monitoring can encompass several different sampling programs designed to assess process control, whether treatment is being maintained at the entry point to the distribution system (treated water), throughout the distribution system, or at the tap. Parameters include pH, temperature, chlorine residual (free or combined) alkalinity, calcium, inhibitor levels (if used), and conductivity at a minimum. Operational monitoring can also involve evaluating treatment effectiveness based on lead levels measured at the tap, and should be conducted before, during, and after implementation of corrosion control treatment. Reductions in lead levels can be assessed system-wide or site-by-site. Use of median lead levels may be appropriate for evaluations of system-wide effectiveness, rather than the 90th percentile.

Operational monitoring can also include the evaluation of the effectiveness of lead source replacement programs. Again, monitoring before, during, and after the lead source is removed (from the service line or faucet, for example) at the tap or directly from the source may be appropriate. It may also be useful to measure both total and dissolved lead in order to distinguish whether particulate or soluble lead is predominant. If particulate lead is measured for short periods of time after replacement, it may be due to the physical disturbance of the system.

Interpretation of operational monitoring results will depend on the specific program implemented. For example, when interpreting treatment effectiveness, lead levels measured system-wide can be compared in graphical or tabular form, to lead levels measured in the system after corrosion control has been implemented. Statistical tests can be used to understand the confidence in differences in lead levels measured system-wide or in discrete sections of the distribution system.

It should be noted that using lead data to generate site-specific flushing instructions or to comment on the risk of exposure must be done in collaboration with the Ministry of Health (MOH). Working with MOH or the local Medical Officer of Health, lead samples can be collected to develop site specific flushing protocols as an alternative to lead service line replacement, as an interim measure until the service line can be replaced, or to manage the risk of lead exposure in the period following lead service line replacement.

2.4.5 Variability of Lead Levels

Standing lead levels measured at the tap may be quite variable from site to site, even when materials and physical configuration of the sites appear to be similar. Within a single site, different lead levels may be measured from one sample round to the next and this may be the result of particulate lead released from scale due to water quality differences, hydraulics, physical disturbance, or differences in sample collection technique.

This variability has implications for interpreting results when assessing compliance and the need for corrosion control. For example, if results from several rounds of sampling at a particular site indicate highly variable lead levels, then this site should be examined specifically to determine what might be causing the elevated lead levels so corrective action can be taken.

3.0 Corrosion and Metal Release Control Measures

3.1 Introduction

This chapter provides background information on controlling lead release and presents methods to determine the potential effectiveness of treatment alternatives for corrosion, with emphasis on control of lead release.

Completion of a desk-top study is used as a first step for all systems to either i) identify the preferred alternative, or ii) generate a short-list of alternatives worthy of further examination. In this chapter, a number of tools to assess the feasibility of alternatives for corrosion control and metal release are discussed, including using a review of lead control theory, using full-scale experience from other municipalities with similar water quality, or using pipe loop studies. At the end of this chapter, a summary is presented for the measures and tools to highlight the suitable application of each.

The focus of this chapter is on control of lead release, however each system will have specific source, treatment, and distribution system issues which may include controlling corrosion of other by-products (such as copper or iron) which will impact the choice of a corrosion control measure.

3.2 Background on Control of Lead Release

The two primary treatment alternatives for controlling release of lead to the water are

1. pH and/or alkalinity adjustment, and

2. Use of phosphate or silicate based inhibitors

The theory behind these alternatives is described below.

3.2.1 pH and Alkalinity Adjustment

The solubility of lead is a function of the pH and DIC of the water. Lead can form a variety of Pb(II) carbonate/hydroxide compounds and the solubility of these compounds decreases with increasing pH (Schock, 1980, Sheiham and Jackson, 1981; US EPA, 1992; Britton and Richards, 1981; Schock, 1989; Schock et al., 1996). These insoluble compounds form a passivating layer on the lead surface that prevents corrosion of lead.

Theoretical models of lead solubility (for Pb(II) compounds) have been developed that illustrate this relationship. In general, as pH increases, lead solubility decreases.

Solubility is not as dependent on DIC, but there is an optimum DIC for a given pH. The optimum theoretical lead solubility falls in the following pH and DIC ranges (Schock, 1989; US EPA, 1992; Schock et al., 1996):

- DIC: 1 – 8 mg C/L
- pH: 8.8 – 10

With a clear understanding of the pH and DIC of the water, decisions can be made about how these parameters may need to be adjusted to theoretically provide optimal lead reduction. A two dimensional rendering of theoretical lead solubility for Pb(II) is shown in Figures 3-1 and 3-2. Lead solubility is shown as a function of pH and DIC in Figure 3-1 using contours, as would be used on a topographic map. The point of minimum lead solubility is denoted by the “X”.

These figures illustrate that the influence of pH is stronger in low DIC waters when it comes to controlling lead. Similarly, in water with higher pH, lead solubility can be better controlled. Theoretical lead solubility is high at low DIC levels, minimal at DIC levels of approximately 4 to 10 mg C/L, and increases after that for pH levels of 8 to 10. For water at pH 7, the lead solubility decreases with increasing DIC.

Using the moderately buffered water of the Great Lakes as an example (e.g., alkalinity of 100 mg/L, pH 7.5 and calculated DIC of about 25 mg C/L), raising the pH will lower the solubility of lead, thereby minimizing the amount available for release in to the water flow. For a soft water, with DIC less than 5 mg C/L, the effective control of lead is promoted at higher pH. Charts like these can be used to establish the treatment objective for corrosion control.

The US EPA’s Revised Guidance Manual for Selecting the Lead and Copper Control Strategies (2003) suggests that waters with pH greater than 7.8 and alkalinities between 30 and 100 mg $CaCO_3$/L are not corrosive for lead, however alkalinities greater than 100 mg $CaCO_3$/L can be highly corrosive toward copper.

Lead control has historically been based on the formation of Pb(II) compounds, which form under most typical drinking water conditions. These compounds include:

- Hydrocerussite: $Pb_3(CO_3)_2(OH)_2$
- Cerussite: $PbCO_3$
- Plumbonacrite: $Pb_{10}(CO_3)_6(OH)_6O$
- Leadhillite/susannite: $Pb_4(CO_3)_2SO_4\ (OH)_2$

Figure 3-1: Theoretical Lead Solubility Curve Versus pH and DIC (M.R. Schock, 2005; provided by author)

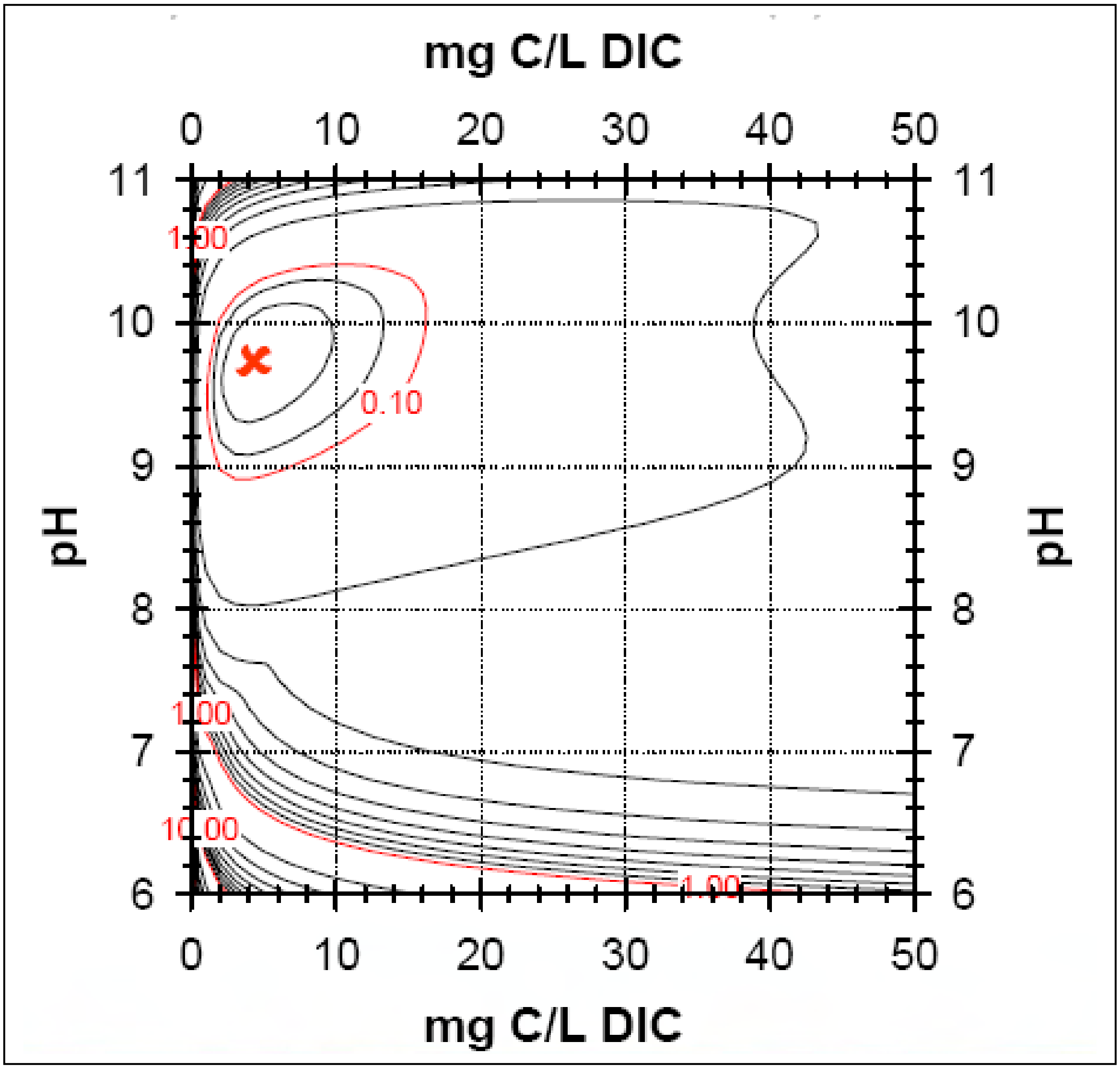
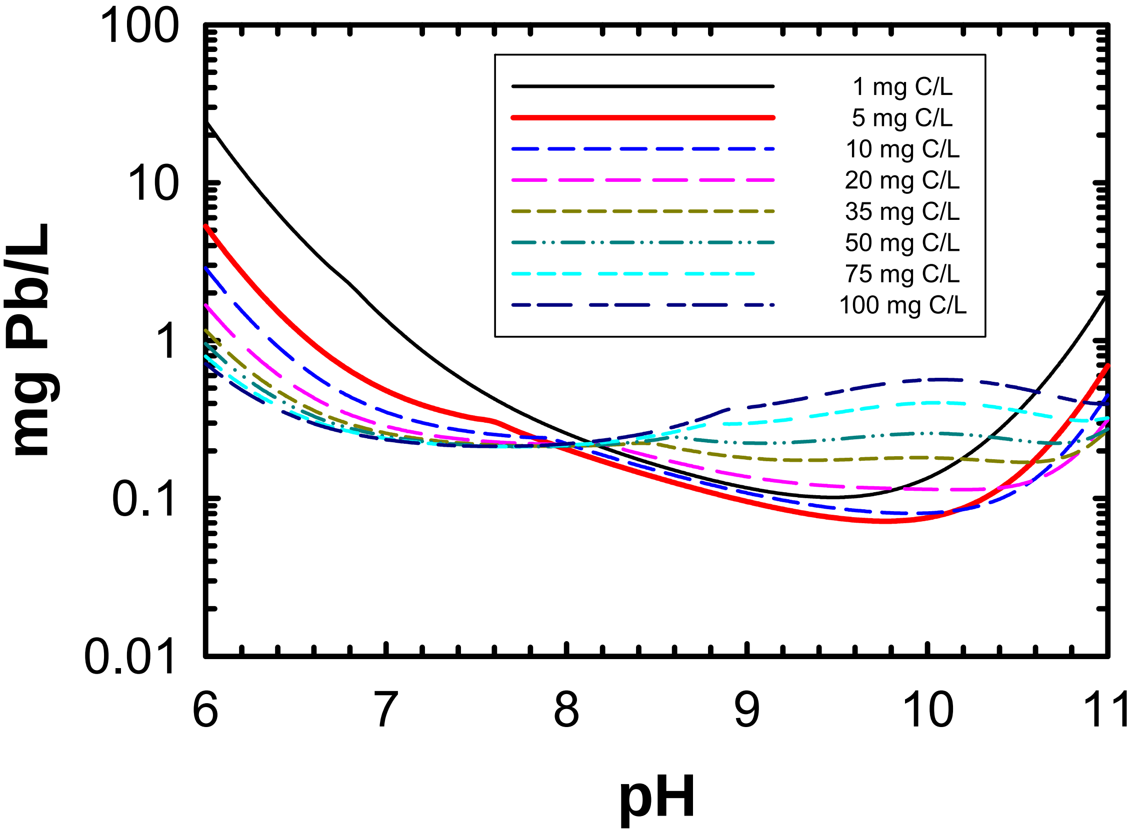


Figure 3-2: Effect of DIC on Pb Assuming both Cerussite and Hydrocerussite (M.R. Schock, 2009; provided by author)



However, more recently, Pb(IV) compounds have been identified in systems with highly oxidizing conditions such as high disinfectant residual (Schock et al.,1996; Schock et al., 2001). Reducing the oxidation/reduction potential of the water – by changing disinfectants from free chlorine to chloramine for example – will create conditions favourable to the more soluble Pb(II) compounds over less soluble Pb(IV) compounds. This potentially destabilizes the solid Pb(IV) compounds and can result in increased lead levels in the water, as was hypothesized to explain the elevated lead levels measured in Washington D.C. Lead (IV) compounds include litharge (PbO) and plattnerite (PbO_2).

The ability to maintain pH in the distribution system is a key factor in successful lead control using pH/alkalinity adjustment, particularly for soft waters. Systems with low DIC (less than 10 mg C/L) that operate in the minimum pH buffering range of 8 to 8.5 may be prone to pH fluctuations in distributed water. Buffer intensity measures the resistance of the water to fluctuations in pH and is an important factor in maintaining pH in the distribution system. Bicarbonate and carbonate ions (and silicate and phosphate under certain circumstances) provide buffering capacity to the water which is greatest at approximately pH 6.3, decreases to a minimum at between pH 8 and 8.5, and increases as pH goes above 9. Water that has low buffer intensity at pH levels between 8 and 8.5 may experience variable pH in the distribution system, particularly waters with low DIC. This would make it difficult to maintain lead corrosion control in the distribution system.

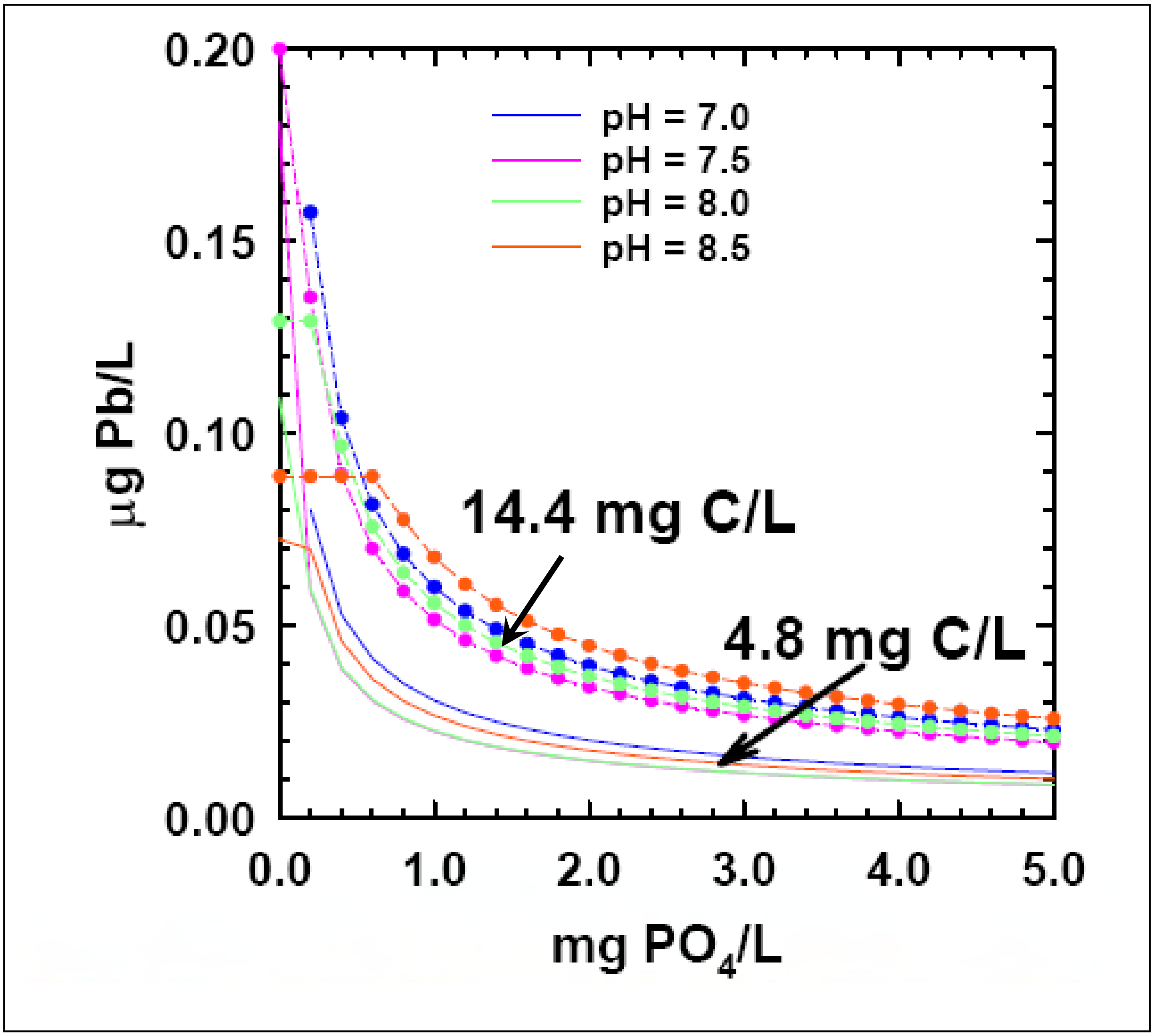
3.2.2 Inhibitor Addition

Phosphate and silicate inhibitors also work for lead control by forming passivating compounds of lower solubility. Orthophosphate is the active agent for phosphate-based inhibition. The solubility of lead phosphate compounds is dependent on pH, DIC and orthophosphate levels. The effective pH range for orthophosphates is 7.4 to 7.8.

Diagrams are available in the literature to illustrate the relationship between theoretical lead solubility, pH, DIC, and orthophosphate level. An example is provided in Figure 3-3 for lead solubility at two different DIC levels. From Figure 3-3, it can be seen that lead solubility decreases with increasing orthophosphate dosages. It is recommended that a minimum orthophosphate residual of 0.5 mg/L as P (as phosphorous, rather than as phosphate, PO_4^-) be maintained in the distribution system, although higher levels may be needed to optimize lead control.

Silicates form metal silicate compounds that serve as anodic inhibitors that passivate the surface. Their effectiveness is dependent on the silicate level, pH, and DIC of the water. Adding silicates can raise the pH. In addition to providing lead control, silicates can sequester iron and manganese if the levels of these constituents aren’t too high. The application of phosphate-based and silicate-based inhibitors for lead control is presented in Chapter 4.

Figure 3-3: Theoretical Lead Solubility versus Orthophosphate and pH (M.R. Schock, 2005; provided by author).



3.3 Evaluating the Effectiveness of Treatment Measures

Evaluating the effectiveness of treatment alternatives for lead control should be based on a thorough understanding of water quality conditions, including lead levels measured at the tap, pH, alkalinity, calcium, sulphate, total chlorine, nitrate, nitrite and iron in both treated and distributed water. Selecting the most appropriate treatment alternative is the first step in developing an overall Corrosion Control Plan which will be municipality specific, and dependent on a variety of other factors (such as secondary impacts or regulatory issues). These factors are described in this chapter. Guidance for an overall approach to selecting the preferred measure(s) to reduce the potential for lead release is contained in Chapter 5.

Alternatives for controlling lead may be assessed by conducting a desk-top evaluation (paper study) and/or conducting testing to estimate reductions in lead realized by various treatment alternatives. For a desk-top study, a variety of information may be evaluated, including historical data on water quality, customer feedback, and previous corrosion studies; a literature review of alternative treatment approaches; assessment of analogous systems with similar water quality, treatment, and materials; and evaluation of any source water issues that may impact overall treatment.

3.3.1 Desk-top Studies

Desk-top studies use current and historical information to characterize the potential for corrosion and lead release. They can make use of a variety of information, including:

- Literature reviews (theory, application research, and case studies)
- Reviews of historical water quality, treatment, materials, and other system data
- Data from other systems with similar water quality, treatment, and distribution systems (analogous systems)
- Diagrams, models and flow charts of theoretical lead release, corrosion characteristics, and typical, proven lead control treatment options

Desk-top studies can be a relatively inexpensive tool to screen a number of potential treatment measures. They may be sufficient for identifying the most effective approach for reducing lead levels, or they can be used to identify the most effective approaches for further study. Results from desk-top studies may also reveal data gaps specific to a system that may require further investigation. For systems where the supply, treatment, and/or distribution system configurations and operations are complex, it may be more appropriate to use this tool in combination with laboratory or field studies to have more confidence in system-specific treatment issues such as when multiple sources supply a common distribution system, alternative sources are used seasonally, or when sources with different water quality characteristics and treatment are blended.

A great deal of literature exists that may provide assistance in understanding corrosion mechanisms and the inter-relationships between lead release and water quality conditions in the system, and effective corrosion control treatment options. The reference section of this Guidance Document provides a partial list of some of the more relevant literature that can be reviewed. Historical data collected by Owners and Operating Authorities, including source and treated water quality data, distribution system water quality data, materials evaluations, existing lead monitoring data (e.g., from the legislated community lead sampling program), modeling results, and results from special studies can be used to identify the most appropriate treatment measures. Having accurate pH and alkalinity data (and the ability to calculate dissolved inorganic carbonate, DIC) is absolutely necessary to know the feasibility of such simple treatments as aeration or limestone contactors, and also the cost associated with chemical additions and chemical delivery systems. Additional water quality data, such as calcium, sulphate, iron, and manganese levels, will help in the assessment of secondary impacts of corrosion control, inhibitor dosing needs, and other treatment and operations issues.

Case studies of systems with similar water quality and treatment situations (analogous systems) can provide information on the potential effectiveness of treatment over time, implementation issues, costs, and other operations data that can be extremely useful in a desk-top study.

Redox charts, solubility diagrams, equilibrium models, and process flow charts can be used to predict the theoretical solubility of lead in water, identify the more general corrosive characteristics of the water, and determine the most typical treatment approaches based on lead corrosion theory. These are described below.

Redox Charts. For some systems, slight changes in pH will be enough to bring a metal into or out of solution. Similarly, a slight change in oxidant (e.g., change in chlorine residual) may also be enough to bring a metal in or out of solution. An example of a redox chart can be found in Montgomery (2005) to show lead speciation as a function of pH and the oxidizing or reducing environment.

Lead Solubility Charts. Lead solubility diagrams, as shown in Figures 3-1 and 3-2, can be used to predict the theoretical amount of lead that could be available in a water under specific water quality conditions and can be used as a general indication of the impact that changing water quality conditions may have on lead release and its control. These diagrams are developed from solubility models based on equilibrium theory. They therefore do not take into account non-equilibrium conditions and variations in system conditions (such as particulate lead release, water usage, scale accumulation, scale structure, etc.) that would impact lead release as measured in tap samples. The diagrams are based on theoretical relationships under particular temperature and ionic strength conditions. For this reason, solubility diagrams should be used as a relative indication of effectiveness, and should not be viewed as an accurate predictor of what would happen in the field. However, their utility lies in the ability to provide an indication of whether or not a certain treatment is expected to decrease the solubility of lead and to provide a rough estimate of the amount of decrease.

An example of a lead solubility diagram that was previously described in this chapter is shown again in Figure 3-4. It shows the relationship between the pH and DIC of the water. Knowing the pH, alkalinity, and ionic strength of a water, the DIC of the water can be calculated using tables available in the literature (see US EPA, 2003 or the table provided in Appendix A). To use the chart, select the appropriate pH and DIC for the water, and determine the corresponding contour line which represents the theoretical solubility of lead under that pH and DIC condition. For example, consider a water at pH 6.4 and with a DIC of 10 mg C/L: the corresponding theoretical lead solubility would be 1.0 mg/L (Point A). By increasing the pH to 9.2, the theoretical lead solubility would decrease to 0.1 mg/L (Point B). Again, keep in mind that these lead solubility models are based on idealized conditions and do not represent actual lead levels that would be measured in the field. They provide an indication of the theoretical level of change in soluble lead, given the change in water quality conditions, and can be used to provide a relative comparison of the impact of different pH and DIC changes on theoretical lead solubility. For this reason, they should always be used in combination with other sources of information related to lead release, such as analogous system information, case studies, literature reviews, and possibly pilot and field corrosion control and metal release studies.

Diagrams such as Figure 3-4 can be used to provide an initial screening of the theoretical change in lead levels with a given pH and/or alkalinity (and consequently DIC) change. The pH/alkalinity changes resulting in the lowest theoretical lead levels can be evaluated further with respect to impacts on existing treatment operations, secondary impacts, and costs.

To assess the effectiveness of orthophosphate, theoretical solubility diagrams that specifically illustrate the relationship between theoretical lead solubility, pH, and orthophosphate level should be reviewed, and a few examples are available in the literature from the US EPA (also see Figure 3-3). An example demonstrating how to apply Figure 3-3 is presented in Figure 3-5. Consider water at pH 7.5 and with a DIC of 14.4 mg C/L. When there is no phosphate in the water, the theoretical lead solubility is 0.2 µg Pb/L (Point A on Figure 3-5), whereas if the orthophosphate level of the water is increased to 1.4 mg PO_4/L, the theoretical lead solubility is reduced to 0.04 µg Pb/L (Point B). Again, these lead levels are higher than what would typically be measured in the field, as they are based on idealized theory of lead solubility. However, they provide a relative indication of the effectiveness of orthophosphate for lead control.

Figure 3-4: Application of Theoretical Lead Solubility Diagram (M.R. Schock, 2005; provided by author)

Example only as charts should be used for a specific temperature and ionic strength. The contour lines represent theoretical lead solubility in mg/L and each contour line represents a 0.1 mg/L change between 0.1 and 1.0; and a 1.0 mg/L change between 1.0 and 10.00.

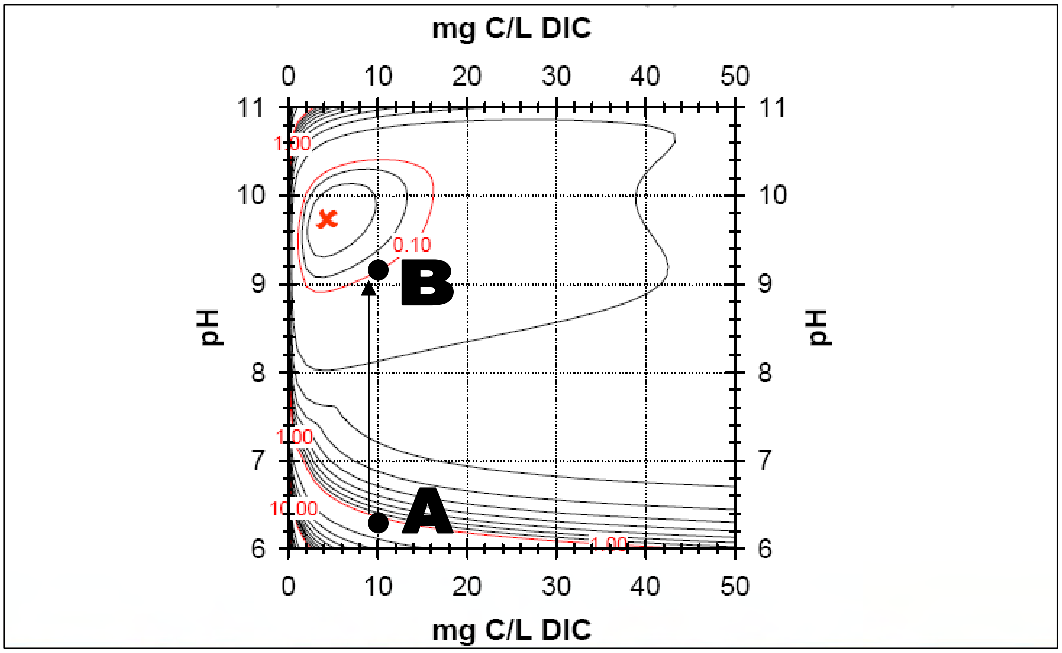
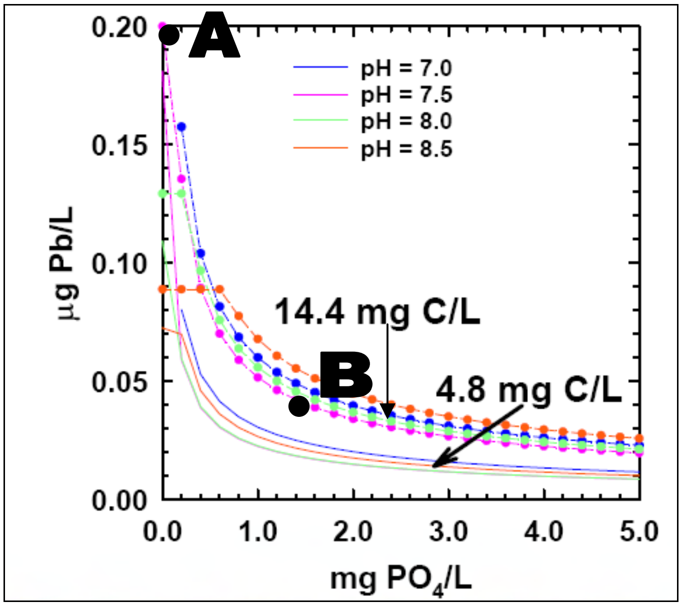


Figure 3-5: Application of Theoretical Lead Solubility versus Orthophosphate and pH (M.R. Schock, 2005; provided by author)



Models. Models are available that can assist in predicting corrosion characteristics, and may be useful for evaluating lead corrosion. The *Rothberg, Tamburini & Winsor Blending Application Package 4.0* (RTW) (AWWA, 2001) is a computer program developed to evaluate water chemistry associated with precipitation/coagulation and corrosion-related characteristics of water. The model predicts typical characteristics of the water (pH, hardness, alkalinity, and LSI) with changes in operating conditions. While it does not predict lead release, this model can be used to evaluate how treatment changes may impact the corrosion characteristics of the finished water. *CORRODE* software (Edwards and Reiber, 1997a,b) is a chemical equilibrium model for identifying corrosion problems and corrosion control strategies, and *PHREEQCI* (Parkhurst and Appelo 1999), an aqueous geochemical model, are two examples of commercial software packages that are available.

Flow Charts. The US EPA's Revised Guidance Manual for Selecting Lead and Copper Control Strategies (2003) provides an easy-to-use series of flow charts to identify the most appropriate treatment approaches for control of lead for various pH and DIC values. The flow charts have been developed for systems that have:

- Elevated lead only

- Elevated levels of both lead and copper

- Elevated lead or copper with raw water iron and manganese

- Elevated copper only

When using the flow charts, accurate data on pH and alkalinity must be available, and DIC should be calculated. The charts are based on the starting pH of treated or filtered water as appropriate prior to the application of corrosion control. An example for how to use these flow charts for a system with high lead and copper levels, with pH less than 7.2, is presented in Figure 3-6. For this system, if the DIC was between 5 and 15 mg C/L, the system would have the option of i) increasing pH using a variety of chemical means or aeration, or ii) adjusting the pH to a range between 7.4 and 7.8 and dosing an inhibitor. These flow charts can be found in US EPA (2003); another example can be found in AwwaRF (1990). Similar flow charts have been adapted for this Guidance Document, and can be found in Appendix B. The reader is also encouraged to consult the original reference (US EPA, 2003) for more information.

3.3.2 Laboratory and Field Testing

Whereas desk-top studies can provide useful tools for evaluating treatment effectiveness, laboratory and field studies can be used to address site-specific issues and in some cases, measure actual changes in corrosion parameters including metals release. This section provides information on the following corrosion assessment tools:

- Pipe loop testing

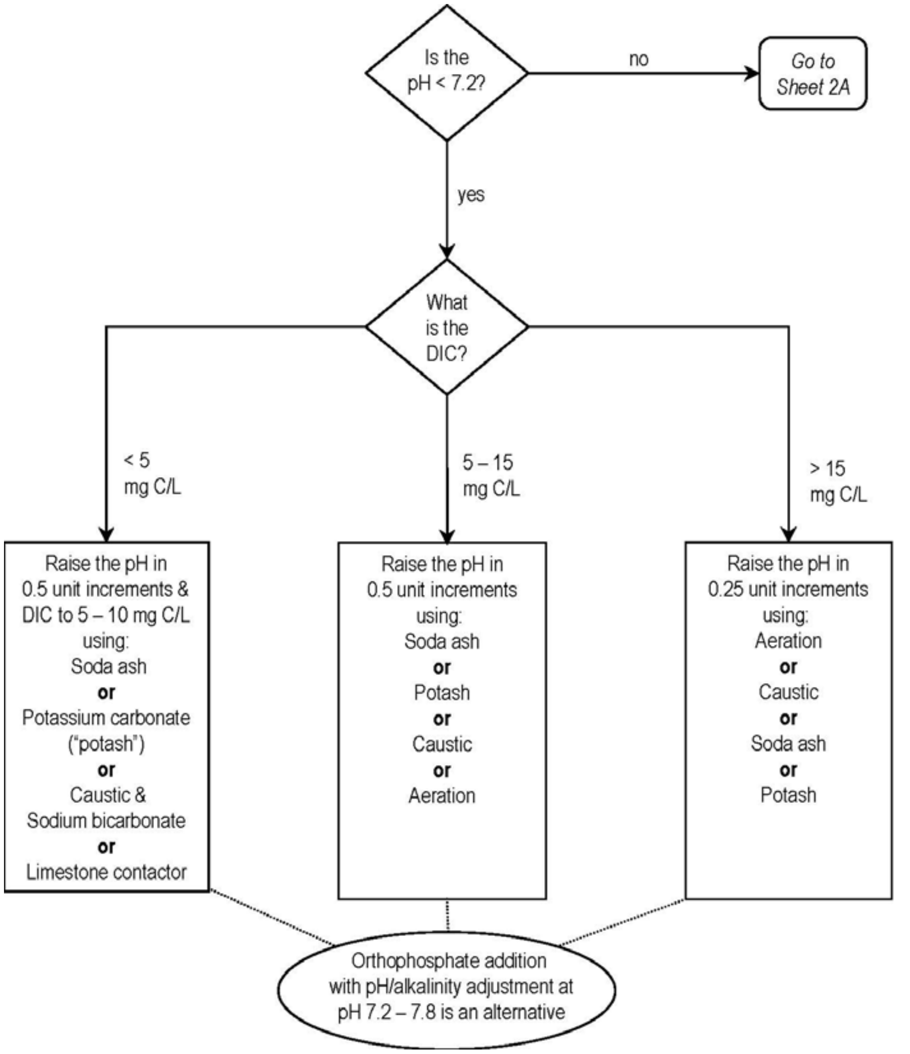
- Partial system testing

- Scale and solids analysis

- Profile sampling

Historically, corrosion has been evaluated using coupon studies to determine corrosion rate measurements, or other electrochemical methods. Coupon studies use flat metal coupons of the material to be evaluated (such as lead, copper, iron, and steel) in static tests (bench-top) or mounted in a flow-through pipe rig or in the distribution system. The coupons are taken out periodically after exposure to the water and weighed to determine total weight loss. Electrochemical techniques, including electrochemical impedance spectroscopy, electrical resistance, linear polarization, and electrochemical noise, provide an instantaneous measurement of the corrosion rate of the metal. These methods may be useful for determining corrosion rates of clean metals, but are not relevant for evaluating lead release and lead control at the tap.

Figure 3-6: Example Flow Chart to Select Corrosion Control Alternatives (adapted from US EPA, 2003)



Pipe Loop Testing. Pipe loop studies can be conducted to measure metals release under various water quality conditions using typical distribution and/or premise plumbing components. They can be designed as either flow-through systems (where water flows through the apparatus once and is discharged to waste) or as recirculating systems (where the same batch of water is continuously recirculated through the loops). A variety of materials can be incorporated into the apparatus including excavated pipes from the distribution system such as lead service lines, new pipes or components such as lead pipe, copper pipe with lead soldered joints, or brass components (faucets or meters). Pipe loop operations can be established that allow for on:off flow cycles to represent typical home water use patterns, and sample collection protocols can be developed to allow for collection of water after a specified stagnation period. Samples collected can be analyzed for metals as well as a variety of corrosion related water quality parameters (pH, alkalinity). There are several references that provide detailed information on the design and operation of pipe loop systems for evaluation of metals release which have been included in the reference section, including AwwaRF and DVGW, 1996; AwwaRF 1990; and Kirmeyer et al., 1994.

Pipe loop studies allow for a relatively controlled comparison of metals release from specific materials of concern, under different corrosion control conditions. They provide an evaluation of metals release which closely simulates actual distribution and premise plumbing conditions. However, these studies are relatively complex and labor intensive, and require a significant commitment of time and resources to complete. It should also be noted that pipe loop studies may need to be conducted for several months before stable metals release data are available, as lead levels measured initially may be highly variable.

Partial System Testing. Partial system testing involves evaluation of a specific corrosion control treatment on a hydraulically isolated portion of the distribution system. Corrosion control and metal release assessment techniques can be applied to this controlled area, including collecting samples from residential taps for metals levels and collecting baseline water quality parameters in the distribution system.

An outreach program should be in place to the customers in that section of the distribution system informing them of the test and any changes which they might experience.

A partial system test may be the most direct way to examine the potential secondary impacts of implementing a corrosion control treatment measure, such as changes in water quality complaints because of increased turbidity or colored water, or disinfection by-product formation that may occur with a change in finished water quality. The partial system area should be selected carefully, as there may be variations in water quality and distribution and premise piping material throughout the distribution system. The area should be representative of either the distribution system, or the specific metals release problem to be evaluated. Partial system testing can be relatively expensive, as it may require installation of temporary chemical feed facilities in addition to the increased labor and analytical costs the system will incur. There should also be close communication with consumers in the demonstration area and both MOE and the local Medical Officer of Health should be consulted before a partial system test is initiated.

Scale and Solids Analysis. Effective corrosion control is accomplished by promoting the formation of protective or passivating scales in which the lead is bound within carbonate or hydroy carbonate scales, and in the case of phosphate inhibitors, the lead is bound within phosphate and carbonate or hydroxy carbonate scales. Therefore, the analysis of actual pipe scale and solids released from pipe scales can provide useful information related to corrosion and the effectiveness of corrosion treatment. There are a variety of techniques that can be used to examine the scale, including visual inspection, X-ray emission spectroscopy, X-ray diffraction, X-ray fluorescence, Raman spectroscopy, and scanning electron microscopy with energy dispersive spectroscopy (EDS). Visual observation can provide a record of the physical appearance of the deposit. X-ray diffraction (XRD) can identify crystalline deposits such as cerrusite and pyromorphite, but not amorphous deposits. Laser Raman spectroscopy allows for confirmation of the oxidation state of the metal ion to distinguish between Pb(II) and Pb(IV) compounds. Samples from the scale can also be pulverized, digested, and analyzed for elemental composition using inductively coupled plasma mass spectroscopy (ICP-MS).

Scale analysis can provide information on the current composition of pipe scales, how that composition may change after implementation of corrosion treatment, and how protective the scale may be in preventing release of lead. The methods are relatively expensive and there is currently no standardized approach for analysis and evaluation of pipe specimens, so results may be difficult to interpret. For more detailed information on techniques and typical results, see Sandvig et al., (2008) and Rego and Schock (2007).

Lead Profile Testing. Lead profile sampling, described previously in Chapter 2, involves collecting flowing samples and several sequential stagnation samples at the tap and analyzing them for lead. This type of sampling can also be used to evaluate the impact of corrosion treatment on lead release from specific parts of the premise plumbing system and the impact of lead source replacement on lead levels. Profile sampling can be completed before and after implementation of treatment, under either partial or full-scale treatment demonstration testing, and before and after lead service line replacement. As mentioned previously, the lead levels are evaluated based on survey information on materials, lengths, volumes, and diameters of piping from each site where profile sampling is done.

3.4 Summary

At a minimum, all systems should undertake some level of desk-top study. For small systems, this may be all that is required. For larger systems, the desk-top study results may be used as a screening tool to determine the necessity for further laboratory or field testing. Selecting what tools to use to evaluate the potential effectiveness of various treatment approaches on lead release and uptake by the water will be system specific and should be based on more than the size of the population served. For example, a desk-top study based on historical system data may be adequate to determine the effectiveness of potential treatment approaches. However there may be system-specific conditions, such as the presence of unlined cast iron pipe, complexities of source water changes, upcoming changes in treatment processes (such as changing disinfectants) that may warrant additional study. In these cases, more complicated evaluation tools may be required. Each system should select the appropriate evaluation tool for their specific situation. Several documents can be referenced for more detailed information on the usefulness and relative costs of these tools (US EPA, 2007; AWWA, 2005; AwwaRF-DVGW, 1996; AwwaRF, 1990; AwwaRF, 2004).

Small and large systems may take different approaches to estimating potential reductions in lead (and copper) from various treatment measures, due to system complexity, labor and cost considerations. Small systems may conduct a paper study using current water quality information, and develop decision criteria for determining the best approach for their systems. Larger utilities may be better equipped to conduct corrosion control and metal release testing, which can involve bench-top studies, pilot studies, partial system testing, and/or other special studies such as scale and solids analysis of materials removed from their system. A summary of the different tools available and their suggested application as a function of system size is presented in Table 3-1.

Table 3-1: **Suggested Tools** for Evaluating Potential Lead Levels Reductions with Treatment*

Approach	**Service Population**		
	≤ 1000	**>1,000 – 10,000**	**>10,000**
Desk-top study	✓	✓	✓
Laboratory Testing	✓	✓	✓
Pipe Loop Studies			X
Scale Analyses		X	X
Field Testing	✓	✓	✓
Partial Demonstration			X
Profile Sampling		✓	✓

✓ Recommended for estimating lead level reductions

X Suggested for more complex systems or systems with a potential for secondary impacts

NOTE: EPA defined large systems as serving populations > 50,000, medium systems with populations > 3, 300 to 50,000, and small systems with populations ≤ 3,300

* This is a summary of the different tools available and their suggested application as a function of system size – these are not ‘requirements’

4.0 Treatment, Compliance with Standards, and Water Distribution Impacts

4.1 Introduction

Developing an overall corrosion control strategy involves more than selecting the most effective treatment alternatives for reducing lead in drinking water. It may be determined that several different treatment options are available to reduce lead levels in water. The Corrosion Control Plan should provide the Owner's and Operating Authority's rationale for selecting what is the most appropriate treatment option for their specific system, taking into account system configuration, economics, simplicity, reliability, operations, secondary impacts, and other site-specific factors. These issues are discussed in this chapter. Information on reducing the sources of lead in the system (such as lead service line replacement) is presented in Chapter 10.

4.2 Impact of Corrosion Control Measures on Water Treatment Processes

4.2.1 pH and/or Alkalinity Adjustment

pH and/or alkalinity adjustment can be accomplished via chemical or non-chemical means. Chemical methods include introduction of a variety of liquid, dry, or gaseous chemicals to the water to alter pH and/or alkalinity. Typical chemicals used for pH/alkalinity adjustment for corrosion control are listed in Table 4-1. Another method is the use of limestone contactors where water flows through a bed of crushed limestone. Aeration is a non-chemical method for adjusting pH. The primary methods for increasing the pH of the treated water include caustic (sodium or potassium hydroxide), lime, soda ash, limestone contactors (calcite filters) and aeration (air stripping). Soda ash, potash, and limestone contactors also increase DIC while aeration decreases DIC.

Chemical Addition

Caustic soda (sodium hydroxide) is a hazardous liquid chemical that can cause burns and eye damage. Sodium hydroxide may be obtained as 25 percent or 50 percent solutions. The higher percentage solution is more hazardous and will crystallize at low temperatures, so proper chemical handling, control of storage room temperature, and heat tracing of chemical lines may be needed. Delivery of the 25 percent solution may come at a cost premium and therefore some municipalities dilute a 50 percent solution upon receiving a delivery on site. When adjusting pH with caustic soda – or any other alkaline agent – it may be difficult to control pH in poorly buffered waters. Sodium levels should be monitored if using caustic soda or other sodium based alkali such as sodium carbonate and sodium bicarbonate.

Table 4-1: Typical Chemical Processes for pH/Alkalinity Adjustment

Chemical	Use	Composition	Alkalinity Change	Notes
Caustic Soda, NaOH (sodium hydroxide)	Raise pH, Convert excess CO_2 to carbonate alkalinity species	93% purity liquid bulk. Colder climates, bulk storage at < 50% purity to prevent freezing	1.55 mg/L $CaCO_3$ alkalinity per mg/L as NaOH	pH control is difficult when applied to poorly buffered water
Hydrated Lime, $Ca(OH)_2$ (calcium hydroxide)	Raise pH, Increases alkalinity and calcium content	95 to 98% purity as $Ca(OH)_2$. 74% active ingredient as CaO. Dry storage with slurry feed	1.21 mg/L $CaCO_3$ alkalinity per mg/L as $Ca(OH)_2$	pH control is difficult when applied to poorly buffered water. Slurry feed can cause excess turbidity. O&M intensive
Baking Soda, $NaHCO_3$, (sodium bicarbonate)	Increases alkalinity with moderate increase in pH	95% purity. Dry storage with solution feed	0.60 mg/L $CaCO_3$ alkalinity per mg/L as $NaHCO_3$	Good alkalinity adjustment chemical, but very expensive
Soda Ash, Na_2CO_3 (sodium carbonate)	Increases alkalinity with moderate increase in pH	95% purity. Dry storage with solution feed	0.90 mg/L $CaCO_3$ alkalinity per ma/L as Na_2HCO_3	More pH increase caused compared with $NaHCO_3$, but less costly
Carbon Dioxide, CO_2	Lowers pH. Converts hydroxide to bicarbonate and carbonate species	Pressurized gas storage. Fed either through eduction or directly	None	Can be used to enhance NaOH or lime feed systems

Adapted from US EPA. 1992. *Lead and Copper Rule Guidance Manual. Volume II: Corrosion Control Treatment*.

Caustic potash – or potassium hydroxide (KOH) – is an alternative that although more expensive than caustic soda, is attractive to some municipalities as it does not impart sodium to water. Potassium hydroxide can be used as an alternative liquid alkaline where sodium levels in treated water are a concern. Potassium hydroxide can be used instead of sodium hydroxide, to top up sodium hydroxide doses, or intermittently during seasonal episodes of elevated sodium in the source water.

Lime is available as hydrated or slaked lime ($Ca(OH)_2$) and quicklime (CaO). It is inexpensive but can be difficult to handle. Lime is slurry fed and can be operations and maintenance intensive. It is somewhat difficult for operations staff to handle and reacts slowly to dosage changes. Lime also imparts aluminum and turbidity to the water through its use. In order to reduce the turbidity caused by lime, it can be dissolved in water and clarified prior to being added to water.

Soda ash (sodium carbonate, Na_2CO_3) and potash (potassium carbonate, K_2CO_3) are dry compounds that are safer to handle than caustic and lime. Baking soda (sodium bicarbonate, $NaHCO_3$) is relatively expensive and used to increase alkalinity. Carbon dioxide is a pressurized gas that lowers the pH, without consuming alkalinity. More detailed information on properties, commercial strength, and other characteristics and operating advantages and disadvantages of these chemicals are available from a variety of references (AwwaRF, 1990 pages 133–143 and US EPA, 2003).

The application point for pH and/or alkalinity adjustment chemicals should be prior to discharge to the distribution system. There are competing objectives for pH targets within the plant, and where to add a chemical agent for pH and/or alkalinity adjustment must be considered in light of the pH needs of other processes such as coagulation, primary disinfection with free chlorine, and chloramine formation. Similarly, the solids imparted by lime addition will collect either within the plant (e.g., the clearwell, and may require periodic removal) or in the distribution system.

Limestone Contactors

Limestone contactors use crushed limestone in a contact chamber through which water passes. As water passes through the contact chamber, limestone dissolves causing pH, alkalinity (or DIC) and calcium levels to be increased. Limestone contactors have been used in small systems settings as they are relatively easy to operate. Guidance on design and application of limestone contactors can be found in AwwaRF 1992; US EPA 2003; Letterman et al 1986, 1991; Letterman 1995; and Letterman and Kathari 1996).

Aeration

Aeration is a non-chemical method of adjusting pH and alkalinity: by introducing air into the water, carbon dioxide is removed and as a result pH increases. In addition to corrosion control by upward pH adjustment, aeration systems can be designed to simultaneously manage other constituents of concern, such as manganese, radon, volatile organic compounds (VOCs) and hydrogen sulfide (H_2S; Schock et al 2002). It may be difficult to control the aeration process (depending on equipment used) to achieve a consistent pH (which is necessary for corrosion control), and therefore it is unlikely that aeration alone would be used for corrosion control although this will depend on source water conditions.

4.2.2 Inhibitor Addition

Phosphate inhibitors are available in a variety of compositions: phosphoric acid, orthophosphate, zinc orthophosphate, polyphosphates, and blends of orthophosphate and polyphosphate. They are generally proprietary compounds (with the exception of phosphoric acid) with varying percentages of orthophosphate, the active agent in the formation of passivating films for lead control. Orthophosphate may be added directly via phosphoric acid, or via a variety of proprietary orthophosphate or orthophosphate/polyphosphate blends. Different blends of proprietary chemicals will have different ratios of orthophosphate to polyphosphate (10 to 30 percent). They are available as liquid feed solutions, and the temperature of the storage and feed equipment is important to prevent freezing (AwwaRF, 1990).

Polyphosphates by themselves can sequester hardness, iron, or manganese. However polyphosphates on their own have been shown to adversely affect lead release and therefore do not appear to be effective for lead control unless the polyphosphate is used in a blend with orthophosphate or if it reverts to orthophosphate in the distribution system. To understand the performance of a phosphate inhibitor on metal release in a given water, pipe loop testing or a review of an analogous system is recommended. Pipe loop testing will provide valuable information on design criteria and operating conditions, and results from pipe loop testing can be used to compare the performance of different types of phosphate inhibitors and assess secondary impacts.

The concentration of phosphate to add will vary depending on the treatment objectives and potential secondary impacts. Some systems operate with more phosphate with the goal of reducing lead at the tap to levels as low as possible to provide more protection with respect to public health. Other systems may have constraints that limit lead reduction to meet the regulatory limit, for example limits on phosphorous loading at the wastewater treatment plant or the added cost of operating the system with more phosphate. For the purpose of corrosion control planning and estimating costs, some examples of different phosphate doses are provided. In 2003, US EPA released guidance to support revisions to the Lead and Copper Rule and in that guidance document the US EPA recommends that 0.5 mg/L as P (as phosphorus, or ~1.5 mg/L as phosphate, PO_4^-) be provided across the distribution system, and preferably 1.0 mg/L as P in the interest of reducing lead levels as low as possible. However, some utilities operate with less than this while effectively controlling lead in their systems. Examples include Detroit and Milwaukee (both using 1.0 mg/L as PO_4^-) and Chicago (using 1 mg/L as PO_4^- with a 50-50 orthophosphate/polyphosphate blend).

Distribution systems exert a demand on orthophosphate, therefore, in order to maintain an adequate residual across the system, the applied dosage must be higher than this. Higher initial orthophosphate doses are usually applied during the initial phase of operation, followed by lower maintenance dosages. When using orthophosphates for lead control, the lead levels may continue to decrease for years due to the slow formation of passivating films. The optimum pH range for use of orthophosphate inhibitors is about 7.4 to 7.8 and it is important to maintain good control of pH in the distribution system.

Silicate inhibitors are mixtures of soda ash and silicon dioxide and are also available as a liquid (US EPA, 2003; AwwaRF, 1990). Again, maintaining room temperatures in the chemical storage and feed equipment area is important to prevent freezing. Silicates have not been used as widely as phosphate inhibitors for lead control, and as a result there is limited information on their application and effectiveness. Silicates form metal-silicate compounds that serve as anodic inhibitors. Their effectiveness is dependent on the silicate level, pH, and DIC of the water. Adding silicates can raise the pH. In addition to providing lead control, silicates can sequester iron and manganese if the levels of these constituents aren't too high. As with phosphates, continuous dosing is required to maintain corrosion control. Silicates are generally more costly than phosphates and relatively high dosages may be required (in excess of 20 mg/L; Schock et al 2005). US EPA recommendations for suitable applications of this treatment include waters with a pH less than 7.2, DIC less than 10 mg C/L, and iron or manganese higher than the ODWQS or where iron release in distribution system is a problem (US EPA 2003, AwwaRF 1990).

4.3 Secondary Impacts and Distribution System Impacts

Secondary impacts associated with corrosion control alternatives can affect disinfection effectiveness, disinfection by-product (DBP) formation, precipitation of calcium carbonate, biological growth, and wastewater discharge and sludge handling. The US EPA Revised Guidance Manual for Selecting Lead and Copper Control Strategies (US EPA, 2003) provides a good assessment of the interactions between various treatment issues of concern when evaluating corrosion control treatment, such as the presence of arsenic, radon, iron, and/or manganese in source waters.

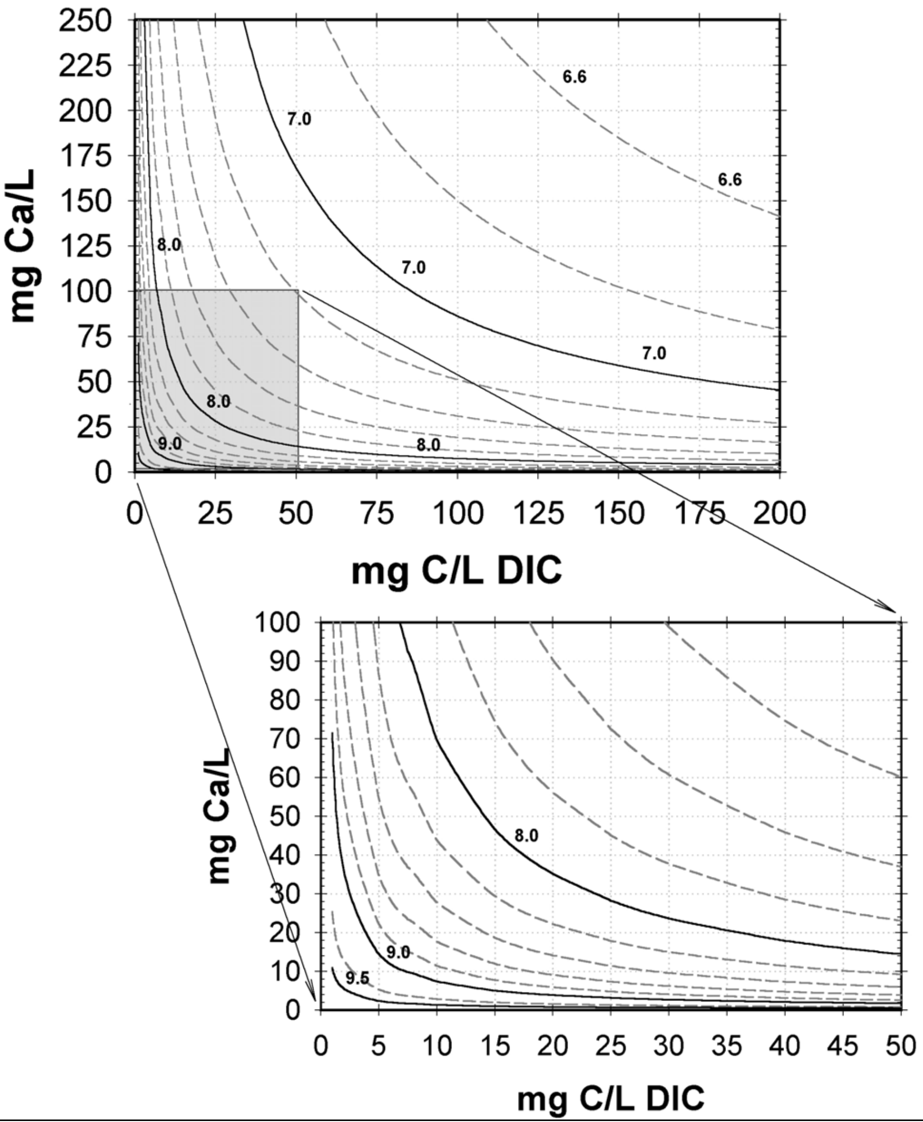
4.3.1 Impacts of pH and/or Alkalinity Adjustment

Disinfection by-product formation is impacted by pH, with total trihalomethane (THM) formation increasing with increasing pH, and haloacetic acid formation (HAA) decreasing with increasing pH. Also, the pH considerations of other treatment processes need to be taken into account, primarily by determining the point of application for pH/alkalinity chemicals so that pH adjustment for corrosion control does not interfere with other treatment processes.

Disinfection effectiveness, such as chlorination, is better at lower pH, so adjusting pH after disinfection would be preferred. Taste and odour and oxidation of iron and manganese (red and black water) may be issues. For calcium carbonate precipitation, the saturation pH should be determined and attempts made to maintain pH below the level that causes scaling, clogging, and turbidity in the system. Normally this level is slightly above the saturation pH. When using chemical pH/alkalinity adjustment for lead and/or copper control, it is important to identify the highest achievable pH for control without creating scaling conditions.

The US EPA's 2003 Revised Guidance Manual for Selecting Lead and Copper Control Strategies includes a figure for estimating the pH level at which calcium would likely precipitate (see Figure 4-1). To use this figure, find the pH level that corresponds to the DIC and calcium level of the water. It is noted that calcium is expressed as calcium (Ca) and not as calcium carbonate ($CaCO_3$). Maintaining the pH lower than the level estimated on the chart should minimize the potential for calcium carbonate precipitation.

Figure 4-1: Saturation pH for Calcium Carbonate Precipitation (from US EPA, 2003)



4.3.2 Secondary Impacts of Phosphate and Silicate Inhibitors

When using phosphate inhibitors, it should be remembered that phosphate is a nutrient and can impact algal growth in open reservoirs, potentially causing aesthetic problems and turbidity. Most water distribution systems are carbon limited; however there may be site-specific instances where phosphorus – rather than carbon – is the limiting nutrient for microbes and biofilm formation. Consumers may also report issues related to sludge build-up and scaling in water heaters, humidifiers, and water fountains. Wastewater treatment plants may have limits on zinc in sludge and/or the discharge of phosphate to receiving streams. These potential limitations, plus costs related to process changes that may be needed to reduce their impact, should be taken into account when evaluating alternative measures for corrosion control. Industrial users may have specific water quality requirements that would be impacted by addition of inhibitors (both phosphate and silicate) for corrosion control.

4.3.3 Impacts of Other Treatment Processes on Corrosion Control and Metal Release

Changing disinfectants can alter the oxidizing conditions of the water, creating conditions where different lead compounds would form. Pre-existing, stable Pb(IV) scales can persist in highly oxidizing conditions (free chlorine), and changing to chloramine may destabilize these scales resulting in lead release. Changing coagulants from sulphate to chloride based formulations can potentially aggravate lead release from lead solder because chloride can aggravate corrosion of lead that is galvanically connected to copper, whereas sulphate may inhibit corrosion (Edwards and Dudi, 2004; Dodrill and Edwards, 1995).

An example of the impact that changing disinfectant (and affecting the oxidation reduction potential) or decreasing pH may have on the type of lead compounds that can form is presented in Figure 4-2. In this figure, the hatched areas represent lead solids, and the un-hatched areas are lead complexes that are in solution. Increasing the concentration of disinfectant residual will result in a higher oxidation reduction potential (ORP) of the water. If the ORP is high enough (as measured by Eh in volts), the lead will be in solid form as Pb(IV) scale (PbO_2), and will not be available – and therefore not measurable – in the water. If ORP drops (such as when the chlorine residual is lowered), then lead will be in the form of a metal ion (Pb^{2+}) or as soluble lead complexes ($Pb(CO3)_2^{2+}$ or $PbCO_3$) which will be available - and therefore will be measurable – as lead in the water.

To understand what type of lead scales are present in the system (e.g., Pb(II) or Pb(IV)), pipe sections can be removed and subjected to a scale analysis as described in section 3.3.2. To prevent lead problems if Pb(IV) scales are dominant, Owners and Operating Authorities can either:

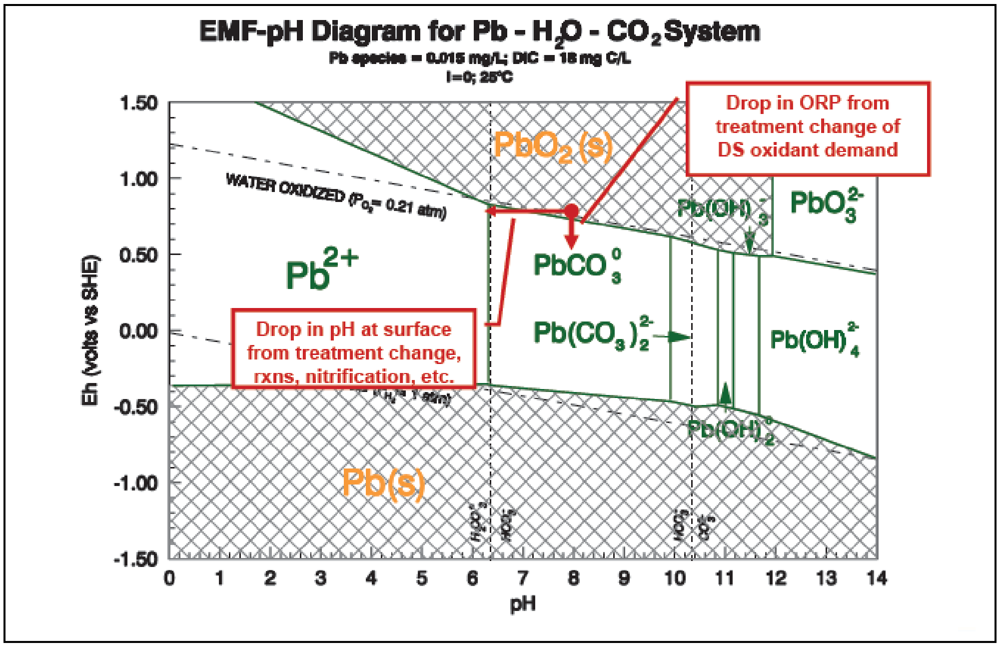
1. Maintain current conditions

2. Adjust the pH/DIC to convert to insoluble Pb(II) passivating films (pH greater than approximately 9, DIC 5 to 10 mg/L as C), or

3. Use orthophosphate

Feeding orthophosphate before a change from free chlorine to chloramine would very likely be beneficial.

Figure 4-2: Example Use of EMF/pH Diagram (M.R. Schock, 2007; provided by author)



4.4 Costs

A detailed comparison of chemical costs is beyond the scope of this guidance, as cost will vary based on many factors (for example location and transportation costs). In general, lime is the cheapest chemical alternative for adjusting pH and alkalinity. Sodium hydroxide is considerably more expensive than lime, and has a volatile pricing history, and potassium hydroxide is more expensive the sodium hydroxide. Prices for the proprietary phosphate compounds will vary.

5.0 Selecting Corrosion and Metal Release Control Measures

5.1 Introduction

Ontario Regulation 170/03: Drinking Water Systems, Schedule 15.1-11 Corrosion Control, requires that the Corrosion Control Plan identify the preferred corrosion control measure for reducing the potential for lead leaching.

Under subsection 15.1-11 (5) of the Regulation – Contents of a Corrosion Control Plan:

“(5) The plan shall,

> ***(c) Identify the preferred measure or measures;”***

The purpose of this chapter is to provide an overview of the type of evaluation factors that can be considered when evaluating alternative measures for corrosion control. A general framework is presented that can be used to select the preferred corrosion control measure.

General categories for evaluation criteria are identified to address the following:

- Corrosion control performance
- Implementation
- Secondary impacts
- Operations and maintenance
- Customer acceptance
- Life-cycle costs

The purpose of this section is to introduce the range of factors that could influence the selection of the preferred corrosion control measure to meet the needs of a given system. However, as each system’s situation is unique, not all of the evaluation factors may be applicable in a given situation; similarly, additional factors may be necessary to adequately compare and evaluate alternatives for corrosion control.

The criteria used to select the preferred corrosion control measure should be chosen to differentiate among the alternative corrosion control measures. Although the goal is to control the potential for lead leaching, unexpected consequences that could compromise other water quality parameters need to be considered in the evaluation as well.

Evaluation factors appropriate for the choice of corrosion control approach (e.g., lead carbonate passivation, phosphate inhibition, or the role for LSL replacement) will be presented first in this chapter, followed by considerations related to the choice of chemical agent used. Evaluation factors are identified at the conceptual level to prompt the Owner and Operating Authority to consider a range of factors. Although the actual evaluation itself is not presented, the intent of this section is to provide caution in terms of what to look for.

5.2 Factors to Evaluate the Choice of Corrosion and Metal Release Control Measure

A summary of evaluation factors that can be considered when evaluating alternatives for corrosion and metal release control is presented in Table 5-1 for the six general categories of evaluation factors identified in section 5.1. For each general category, applicable evaluation factors are identified and comments are provided. When selecting evaluation factors, consider the following:

- Choose the factors that make a difference when comparing alternatives: if the outcome is the same for all alternatives, the factor need not be included in the evaluation
- Choose as few factors as absolutely necessary to conduct the evaluation: ask if each identified factor is truly different from the others will help to reduce the list of factors
- Choose only those factors that can be quantitatively measured or quantitatively estimated: for example, if upward pH adjustment is employed, by how much would disinfection by-product formation be affected?

Avoid factors which are related to cost; these factors should be captured in the life-cycle cost part of the evaluation

Table 5-1: Summary of Factors to Evaluate the Choice of Corrosion and Metal Release Control Measure

General Factor Category	Evaluation Factor	Comment
Corrosion control performance	Controls lead	
	Controls copper	
	Controls iron	
	Other issues identified (asbestos cement, cement mortar)	

General Factor Category	Evaluation Factor	Comment
Implementation	Requires pilot testing prior to full-scale implementation	
	Affects industrial users potentially	
	Requires pH adjustment for suitable application in addition to an inhibitor	
	Requires independent adjustment of both pH and alkalinity	For example, two chemicals are needed: hydroxide to raise the alkalinity (which can result in unacceptably high pH in soft water such as pH 10 or higher), and then carbon dioxide to adjust the pH downward without consuming alkalinity
	Requires multiple chemical storage and metering systems at a number of individual treatment works feeding into a common distribution system	If so, how many?
Secondary impacts	Compromises primary disinfection	Is CT maintained? Or is CT compromised by elevated pH?
	Influences chloramine speciation	Is chloramine formation performed at a pH that favours monochloramine formation?
	Increases DBP formation	THMs increase with increasing pH; HAAs increase with decreasing pH
	Increases chlorine decay to affect residual maintenance	
	Increases phosphorus loading at wastewater treatment plant impacts	Estimate the potential phosphate loading and determine whether or not there is available digester capacity
	Impacts phosphorus loading to receiving waters if not removed during waste treatment	
	Aggravates iron and/or manganese release from scale	
	Aggravates copper release	
Operations and maintenance	Requires daily/continuous operator attention to maintain service	
	Increases dependence/number of instruments used for process	

General Factor Category	Evaluation Factor	Comment
	control	
	Increases the number of chemical systems – and types of chemicals – requiring maintenance	
	Requires the use of a proprietary chemical	Is there more than one chemical supplier?
	Favours operator acceptance	Some chemicals are less accepted by operators than others due to health and safety concerns
Customer acceptance	Imparts a “new” taste to the water	
	Requires (some) industry users to modify water prior to use	
	Necessitates the addition of a new or multiple chemical(s), some of which may not be present in natural waters	
Cost	Incurs a capital cost of $TBD	Estimate the capital cost
	Incurs costs for chemical consumption of $TBD/year	Estimate the annual cost for consumables Some chemical systems require a contract for storage tank rental and product supply
	Consumes power at TBD kW/hr	Estimate the annual power cost
	Necessitates long travel distances for truck delivery	Influences the carbon footprint of chemical use
	Requires a large energy input during chemical production	Influences the carbon footprint of chemical use
	Threatens environmental damage if an accidental release occurs	Can the release be contained?

TBD = To Be Determined, and should be calculated to address site specific needs.

To apply the evaluation factors, a general prioritization of the factors should be identified by the Owner and Operating Authority: the evaluation factors identified and ultimately used in the evaluation of alternatives must reflect the needs and priorities of the Owner and Operating Authority. Although there are a number of different ways to do this, a matrix approach is presented in Table 5-2 to suggest a possible prioritization. This must be customized for each Owner and Operating Authority and documented in the Corrosion Control Plan.

Table 5-2: **Example** Matrix of Evaluation Factors

General Factor Category	High Importance	Medium Importance	Low Importance
Corrosion and metal release control performance	Lead control	Iron control	Copper control
Implementation		Time to implement Need for pipe loop testing	
Secondary impacts	Disinfection	Disinfection by-products	Sodium in treated water
Operations and maintenance	Ability to use existing chemical	Requires use of a proprietary chemical[1]	
Customer acceptance			Industrial users may need to modify process
Life-cycle cost	*Cost items should be addressed separately*		

1. If this has a cost impact rather than an impact for purchasing (e.g., sole source material contract), than address in life-cycle cost

5.3 Factors to Evaluate the Choice of Chemical Agent

A summary of evaluation factors that can be considered for specific chemicals is presented in Table 5-3. For each chemical, different evaluation factors are listed along with a suggestion for how to address the concern in italics.

Table 5-3: Summary of Factors to Evaluate the Choice of Chemical Agent

Application	Chemical*	Evaluation Factor
Upward pH Adjustment and/or Upward Alkalinity Adjustment	Caustic soda (sodium hydroxide)	Imparts sodium to treated water *Estimate sodium contributions from all sources used at the treatment plant (e.g., sodium hypochlorite, sodium bisulphite) and add to source water levels* *Compare total sodium to the concentration at which the local Medical Officer of Health is notified (20 mg/L)*
		Exhibits very volatile pricing history *Account for average and maximum price when calculating life-cycle costs*
		50 percent solution extremely hazardous with respect to material handling

Application	Chemical*	Evaluation Factor
		Crystallizes at temperatures around 12 to 15°C, if using a 50 percent solution *Assess need for heat tracing, heating jackets, and/or room heaters, or use of carrier water to eliminate or reduce need for heat tracing* A 25 percent solution does not have the same temperature issues as a 50 percent solution *Purchase a 25 percent solution (cost impact) or dilute on-site (review impacts of heat release during this reaction)*
		Requires engineering controls for storage and handling *Review MSDS and building code requirements for storage and handling (e.g., materials of construction, health and safety requirements)*
	Quick lime or slaked lime (CaO) or hydrated lime ($Ca(OH)_2$)	Imparts aluminum to treated water *Estimate contribution of aluminum to treated water due to lime use in addition to other sources (such as coagulant use)* *Compare total aluminum to the Operating Guideline of 0.10 mg/L*
		Imparts non-microbiological turbidity to treated water *Review alternatives to remove turbidity prior to distribution; this may require a dedicated tank or grit removal facilities* *Account for cost to remove and dispose of solids accumulated in the plant due to lime use*
		Requires regular operator attention for routine operations and maintenance *Account for labour needs in life-cycle cost*
	Sodium carbonate (Na_2CO_3) or sodium bicarbonate ($NaHCO_3$)	Imparts sodium to treated water *Estimate sodium contributions from all sources used at the treatment plant (e.g., sodium hypochlorite, sodium bisulphite) and add to source water levels* *Compare total sodium to the concentration at which the local Medical Officer of Health is notified (20 mg/L)*

Application	Chemical*	Evaluation Factor
		Requires dry chemical feed system *Account for operations and maintenances needs in life-cycle cost*
Downward pH Adjustment	Carbon dioxide (CO_2)	Requires contract for product storage and supply *Account for equipment lease in life-cycle cost; alternatively, purchase storage tank with a maintenance contract*
		Requires engineering controls for storage *Review MSDS and building code requirements for storage (e.g., building access)*
Phosphate Based Inhibitor	Phosphoric acid	Requires care for storage and handling *Review MSDS requirements for storage and handling (e.g., materials of construction, health and safety requirements)*
		May require a second chemical for pH adjustment to operate within optimum performance range *Account for second chemical system*
	Orthophosphate	May require a second chemical for pH adjustment to operate within optimum performance range *Account for second chemical system*
	Polyphosphate	Requires conversion to orthophosphate for effective control of lead *Confirm conversion to orthophosphate*
		May require a second chemical for pH adjustment to operate within optimum performance range *Account for second chemical system*
	Orthophosphate/ polyphosphate blends, Zinc orthophosphate	May be a proprietary product *Ask for product formulation* *Account for operations and maintenances needs in life-cycle cost*

*Chemicals should be certified to NSF requirements

5.4 Information Sources

Resources are available to evaluate alternative measures for corrosion and metal release control and are listed below in the context of evaluating the alternatives. These resources are described in more detail in earlier chapters:

- Use results from the legislated community lead sampling program to establish baseline conditions

- Use bench-scale testing to determine the dose necessary to achieve a desired pH and/or alkalinity change, impact on chloramine speciation, chlor(am)ine decay, and DBP formation

- Use pilot testing to assess performance and establish design and operating conditions (e.g., dose, pH, residual)

- Use full-scale testing in a hydraulically isolated portion of the distribution system to assess performance and establish design and operating conditions (partial system test)

Alternatively, results from analogous systems can be used if water quality conditions are comparable with respect to the parameters that can affect corrosion, metal release, and corrosion control.

5.5 Applying the Evaluation Factors

Background and theory on alternative measures for corrosion and metal release control was presented in Chapters 2 and 3 but how to apply the alternative measures to a water system was not described. The purpose of this section is to provide guidance on how to describe the alternative measures with the intention of determining a preferred approach. For each alternative corrosion control measure under evaluation, the following should be identified in the Corrosion Control Plan:

- Treatment objective as defined by operational targets for pH, alkalinity, and/or DIC, and residual in the case if an inhibitor

- Choice of chemical agent(s) to achieve the treatment target

Example. Different treatment objectives can be evaluated using the same selection of chemical agents. Consider the example of a soft water with filtered water characterized by an alkalinity of 15 mg/L as $CaCO_3$ and pH 7. Corrosion control measures under consideration by this example municipality include lead carbonate passivation and phosphate inhibition (see Table 5-4). As part of a desk-top study, and in the absence of pipe loop results, the municipality wants to compare the performance and cost of different treatment objectives. To examine how high the pH should be adjusted upward, alternatives 1 and 2 have been developed for evaluation. More chemical (lime in this example) would be needed to achieve the higher pH target, and therefore the operating costs would be higher. Because it is unlikely that a stable pH could be maintained in this soft water by lime addition alone, a third alternative was introduced to allow the alkalinity of the water to be increased above a threshold level that would be expected to stabilize the target pH. To examine the need for and benefits of adjusting both pH and alkalinity – and therefore the need for carbon dioxide in addition to lime – alternative 3 was developed. Two additional alternatives were developed to evaluate the use of phosphate inhibitors: one with phosphoric acid (to provide the source of phosphate) and one using a proprietary product (alternative 5) which may be effective at a lower pH and therefore save in lime costs while possibly having higher phosphate costs due to the use of a proprietary product.

Table 5-4: **Example** List of Alternative Corrosion Control Measures

Alternative	Description	Treatment Objective[1]	Source of Chemical Adjustment
1	Carbonate passivation	pH 9.0 ± 0.2	Lime
2	Carbonate passivation	pH 9.5 ± 0.2	Lime
3	Carbonate passivation	pH 9.0 ± and alkalinity > 40 mg/L $CaCO_3$	Lime + carbon dioxide
4	Phosphate inhibition	pH 7.6 ± 0.2 0.5-1.0 mg/L as P	Phosphoric acid + lime
5	Phosphate inhibition	pH 7.6 ± 0.2 0.5 to 1.0 mg/L as P	Orthophosphate + lime

1. The numbers shown under treatment objective are provided for example only

Starting points for the treatment objectives should be drawn from the literature on corrosion theory and supplemented with experience from analogous systems and pipe loop testing (if available). The treatment objectives will vary by Owner and Operating Authority depending on the level of lead control desired. For some, reducing lead levels as low as reasonably achievable in the interest of providing maximum public health protection may be desired. For others, constraints may be in place that limit how corrosion control is provided such that lead is controlled to meet regulatory limits. For example, systems that coagulate with alum may find that relatively higher doses of phosphates can cause turbidity problems due to the formation of an aluminum phosphate precipitate, potentially affecting the C factor of the pipes. Or, phosphorous loading at the wastewater plant may limit how much phosphate can be applied: while it may be possible to add enough phosphate to achieve regulatory compliance, reducing lead to levels as low possible without incurring secondary impacts may be difficult.

It is emphasized that these are only examples for the purpose of discussion. How an Owner and Operating Authority establish their targets for pH and/or inhibitor residual should be described in the Corrosion Control Plan and reviewed with the MOE. Alternatives can be evaluated to compare the performance and cost of different treatment objectives to meet regulatory compliance for lead or to reduce lead levels as low as reasonably achievable.

5.5.1 Corrosion and Metal Release Control Performance

For the purpose of the evaluation of alternatives, an estimate or assessment of performance in terms of lead release as well as secondary impacts is needed. This can be based on corrosion and lead control theory (e.g., solubility charts), results from case studies in the literature, data from analogous systems, or when available, results from pipe loop testing and partial system testing. If the goal in determining the preferred approach is to create a short-list of alternatives for a more detailed review, desk-top approaches may be appropriate to generate an assessment of performance for the long list of alternatives.

It is important that baseline conditions (e.g., treated water and distribution system water quality) be documented before implementation of lead control measures. This will allow an assessment of existing conditions versus performance associated with the new treatment, such as red water occurrence and turbidity.

5.5.2 Implementation Needs and Schedule

Different time lines for implementation will be associated with the alternative corrosion control strategies and this should be addressed as part of the evaluation of alternatives. For example, will pipe loop testing or partial system testing be conducted prior to the design and construction of new treatment works? If so, this could potentially add three to 12 months to the schedule for implementation. Can existing chemical systems be used for corrosion control and therefore can the schedule for implementation be accelerated? For example, if a lime system is available for alkalinity adjustment for coagulation, can that system be expanded to provide the storage needs for pH adjustment for corrosion control as well?

In general, when a lead control strategy involves a downward adjustment in pH from historical operations in combination with a phosphate based inhibitor, pipe loop or partial system testing is recommended. Phased implementation of upward pH adjustment can be accomplished at full-scale without pipe loop or partial system testing assuming that a thorough review of results from analogous systems has been made. Again, either approach will affect the schedule for implementation.

5.5.3 Operations and Maintenance

The level of operator attention and effort required to maintain the facilities associated with each alternative will vary. With respect to the evaluation of alternatives, the impacts of labour needs and maintenance costs should be addressed. For example, older slaked lime systems may require daily operator attention to run the slaker, and routine maintenance to remove any lime solids that collect within the treatment plant. In contrast, the operator and maintenance attention associated with liquid chemical systems may be much less onerous. However if multiple chemical systems are added to a treatment plant (e.g., orthophosphate inhibitor, sodium hydroxide, and carbon dioxide), additional time to receive more chemical deliveries and to maintain the additional chemical metering pumps should be allowed for in the assessment of operations and maintenance needs. For the purpose of the evaluation, the operations and maintenance needs should be presented as an annual cost (labour, parts, etc.).

5.5.4 Customer Acceptance

In the context of determining the preferred approach, some consideration should be given to customer acceptance. This can include the community served by the system as well as industrial users who potentially may need time to prepare for a change in water quality parameters. Consultation is recommended to determine the preferences and priorities of the community and stakeholders.

5.5.5 Life-cycle Cost

Using the treatment objectives referred to in section 5.5, the chemical dose necessary to provide for that treatment objective can be determined from lab generated pH-dose response curves or by using commercially available water chemistry models. Results can be used to size chemical storage and metering facilities. An estimate of the annual quantity of chemicals consumed coupled with budgetary pricing from chemical suppliers can be used to cost the alternative control strategies.

With respect to guidance on equipment needs for chemical metering and storage facilities (e.g., redundancy for pumps, storage capacity, containment), the reader is referred to MOE’s Design Guidelines for Drinking Water Systems (2008) and the Ten State Standards (2007). To cost the alternative control strategies, basic building needs should be identified in addition to the equipment needs (space requirements, location, heating and ventilation systems, electrical needs, instrumentation and control, etc.).

The capital cost, annual operations and maintenance costs, and the estimated life-cycle cost should be determined for each alternative control strategy.

5.6 Implications for the Corrosion Control Plan: Summary of the Evaluation

Quantified estimates for implementation, performance, and cost (sections 5.5.1 to 5.5.5) need to be developed for each alternative under consideration. Once quantified, the results from the evaluation of each alternative are combined using predetermined weighting factors to allow each alternative to be scored. As part of the process to identify the preferred corrosion control measure, the following items should be addressed in the Corrosion Control Plan to document the evaluation of alternatives:

- List of alternative measures for corrosion control and assumptions
- Evaluation factors and associated weighting
- Assumptions for the application of the evaluation factors (e.g., expected reductions in lead release, equipment needs, life-cycle costs)
- Results from the evaluation of alternative measures for corrosion control
- Identification of the preferred corrosion control measure including the rationale for it's selection and assumptions for implementation and operations
- Assessment and evaluation of potential impacts of the preferred approach

A worked example is provided in Appendix F.

6.0 Evaluating Corrosion Control Effectiveness

6.1 Introduction

Assessing the effectiveness of corrosion control after implementation is critical to ensuring that the desired reductions in the potential for internal corrosion (particularly with respect to lead level reductions) have been achieved and maintained in the system without adversely affecting other drinking water parameters.

Ontario Regulation 170/03: Drinking Water Systems, Schedule 15.1-11 Corrosion Control, requires that the Corrosion Control Plan include a recommendation for monitoring the effectiveness of the preferred measure(s) for reducing the potential for lead leaching.

Under subsection 15.1-11 (5) of the Regulation – Contents of a Corrosion Control Plan:

"(5) The plan shall,

> ***(e) Include a program for monitoring the effectiveness of the preferred measure or measures."***

The purpose of this chapter is to provide guidance on monitoring programs that can be conducted after implementation of the preferred corrosion control measure. This includes information on monitoring protocols and assessment techniques for evaluating both the effectiveness of corrosion control measures, the suitability of operating conditions, and the occurrence of secondary impacts. The goals of these programs will vary by system, but in general the goals are to evaluate:

- The ability to maintain recommended operating conditions for the preferred treatment approach
- The ability to achieve expected reductions in lead levels and other corrosion related parameters in the distribution and premise system, and
- The occurrence of secondary impacts that may occur

This chapter addresses these goals, and discusses water quality monitoring programs, aesthetic and customer complaint tracking, and laboratory studies that can be implemented. It also provides information on typical start-up issues related to corrosion control treatment, and presents recommendations for a post-implementation evaluation program for inclusion in the Corrosion Control Plan.

6.2 Water Quality Monitoring

A water quality monitoring program to evaluate corrosion control effectiveness should provide information on water quality at the point-of-entry to the distribution system, at representative sites in the distribution system (e.g., hydrants), at residential and non-residential plumbing sites (e.g., at the tap), and at sites that have been identified or suspected of having water quality problems.

As part of the Corrosion Control Plan, operating ranges for the following key corrosion parameters will be identified (at a minimum, see section 5.5):

- pH
- Alkalinity, and
- Inhibitor concentration (orthophosphate if orthophosphate inhibitors are applied, silica if silicate inhibitors are applied)

These operating parameters must be measured in treated (point-of-entry) and distributed water. In addition, metals levels should be measured in treated and distributed water, and residential and non-residential plumbing (at a minimum). The occurrence of secondary impacts can be assessed by measuring water quality and aesthetic parameters at key distribution system and residential sites, as well as areas of the system that may be considered “problem areas”, such as dead-ends. A summary of recommended parameters and monitoring locations is provided in Table 6-1. This section describes the issues associated with water quality monitoring programs designed to evaluate the effectiveness of corrosion control and the occurrence of secondary impacts.

Point-of-entry monitoring will provide information on the consistency of treated water quality and forms a basis for comparison with distribution system water quality. The recommended frequency of monitoring at the point-of-entry should be selected to provide assurances that treatment is being applied as reliably as possible, taking into account the variability that might occur given the available pH and alkalinity of the treated water, and treatment characteristics that might impact the variability of these parameters. The type of chemical used to adjust pH and/or alkalinity will impact the potential for variations in treated water pH. For example, if sodium hydroxide is used for pH adjustment, it may be difficult to control pH if the water is poorly buffered. This situation might necessitate a more frequent evaluation of treated water pH to insure that operating goals for corrosion control are being met.

Table 6-1: **Recommended** Parameters and Locations for Post-Implementation Monitoring

Parameters	**Point-of-Entry**	**Distribution System**	**Residential and Non-Residential Taps**	**Distribution System Dead Ends and Areas of Low Chlorine Residual**
Lead	X	X	X	X
Alkalinity, pH	X	X	X	X
Orthophosphate and/or silicate	X	X	X	X
Temperature, TDS, specific conductance	X	X	X	X
Dissolved oxygen		X		
Iron, manganese		X		X
Chloride, sulphate		X		X
Turbidity, colour		X		X
Calcium, zinc, aluminum		X		X
Microbiological parameters (coliform, HPC)		X		X
Nitrate, nitrite, free ammonia*		X		X

*For systems that operate with chloramine for residual maintenance in the distribution system.

Point-of-entry data can also provide a comparison to distribution system data to determine how parameters may change as they travel through the system. For example, pH levels may increase or decrease depending on the size of the distribution system, buffer intensity of the water, flow, and age and type of plumbing material. It is important to maintain the target pH and alkalinity levels measured at the point-of-entry throughout the distribution system to minimize lead levels at the tap. Keeping distribution system pH within +/- 0.2 pH units from point-of-entry pH levels should provide adequate control. An important water characteristic is the buffer intensity of the water, which is a measure of the resistance of water to changes in pH. Buffering is greatest at pH 6.3, and reaches a minimum at pH levels between 8 to 8.5, before increasing again at pH of 9 and higher. Therefore, if systems operate within this minimum pH for buffering, they may experience highly variable pH levels in the distribution system. Even if operating pH levels are consistent at the point-of-entry, the variability in pH measured in the system would be detrimental to maintaining adequate corrosion control.

When orthophosphate or silicate inhibitors are applied, the maintenance of the inhibitor residual in the distribution system is of paramount importance. For most systems to maintain a residual of 0.5 mg/L orthophosphate (as P, equivalent to approximately 1.5 mg/L as PO_4), they will need to provide a higher dose of orthophosphate at the point-of-entry to the distribution system. This is because the distribution system exerts a demand on inhibitors, similar to disinfectant demand. Inhibitors must be continually fed to be effective for lead control. This demand may be greater when treatment is initiated, but levels off over time at which point dosages can be adjusted. Another critical issue for application of orthophosphate is the importance of maintaining the pH in the distribution within the range of 7.4 to 7.8. This is the range in which orthophosphates are effective for lead control. Within this pH range, lead is bound in a phosphate-hydroxide or phosphate-carbonate based scale and therefore unavailable for release into the bulk water. Operating outside these ranges will render the treatment ineffective in reducing lead levels measured at the tap. Finally, it is also important to have a clear understanding of how inhibitor levels are reported, to insure that the correct dosage is applied, for the purpose of comparing performance with other systems, and when generating cost estimates. They can be reported as phosphate (P), or as orthophosphate (PO_4). Either approach is acceptable as long as the basis of reporting is specified.

Distribution system monitoring provides information on the maintenance of key operating parameters (pH, alkalinity, inhibitor levels) in the distribution system, as well as overall baseline water quality in the system. In addition to pH, alkalinity, and inhibitor levels, additional water quality parameters that affect corrosion and corrosion control can be measured including hardness, dissolved oxygen, disinfectant residual, calcium, zinc, aluminum, iron, manganese, conductivity, turbidity, temperature and microbiological parameters (coliform, HPC). These parameters would be measured from flushed samples representative of distributed water and therefore can be measured at hydrants, pump stations, or the customer’s tap.

Results from distribution system monitoring can provide background data on the current state of corrosion within the distribution system for comparison to pre-treatment conditions and identify specific areas that may have more corrosive conditions or are experiencing adverse secondary impacts. It can also provide an indication of areas of the system where inhibitor residual may be low, and/or pH levels that are highly variable. Selecting sites that are representative of the system and at varying distances from the point-of-entry will allow for a better spatial representation of water quality in the system as well as provide the background data for evaluating the impact of future treatment changes. For example, systems that are contemplating a change from free chlorine to chloramine should have good baseline distribution system data before and after the change to evaluate the potential impact on lead release. As discussed in Chapter 3, if highly oxidizing conditions occurred in the distribution system under free chlorine, then the change to chloramine may alter the lead scale from a predominantly Pb(IV) based scale to a predominantly Pb(II) based scale, resulting in the potential for lead release. Use of chloramine can also cause nitrification to occur in the distribution system, which can decrease pH and alkalinity which could have a negative impact on lead control.

The recommended program for evaluating the effectiveness of treatment can expand upon the current regulatory requirements for distribution system sampling, as shown below in Table 6-2. As stated in the Regulation, systems that serve from 100 to 499 people must take distribution system samples at two sites, whereas systems that serve from 50,000 to 99,000 must collect samples at 16 sites. Expanding distribution system monitoring beyond these required number of sites, as well as collecting samples more frequently to assess seasonal differences in corrosion control characteristics, will provide a greater degree of confidence in understanding corrosion in the system and optimizing corrosion control in terms of chemical consumption and performance (for example, can the pH target be decreased without compromising lead control?).

Table 6-2: Number of Distribution System Sampling Locations

Population Served by Drinking Water System	**Number of Sampling Points in Distribution System**	
1- 99	1	1
100 - 499	2	1
500 - 3,299	4	2
3,300 - 9,999	8	3
10,000 - 49,999	12	4
50,000 - 99,999	16	8
100,000 or more	20	10

From Regulation 170/03, section 15.1-4 ***NOTE: This table may be revised pending passage of December 2009 amendments.***

Residential and non-residential monitoring includes collection of stagnation tap samples for metals levels and other aesthetic parameters at the tap. Results will provide an indication of reductions in lead levels, and data can be used to determine if corrosion problems are occurring in the distribution or premise piping system. Four different types of sites can be used for data collection:

1. Regulatory tap monitoring sites from private residences
2. Regulatory tap monitoring sites from non-private residences
3. Additional selected residential or non-residential sites, and
4. Residential sites in problem areas of the distribution system.

Expanding the monitoring program beyond sites required for regulatory sample collection (supplemental tap monitoring) will allow a greater level of confidence in the results. Current regulatory sampling, for both initial sampling and reduced sampling, is shown in Table 6-3.

Table 6-3: Standard Sampling – Number of Sampling Locations

Population Served by Drinking Water System	Number of Sampling Points in Plumbing that Serves Private Residences		Number of Sampling Points in Plumbing that Does Not Serve Private Residences	
	Initial	Reduced	Initial	Reduced
1- 99	5	3	1	0
100 - 499	10	5	1	1
500 - 3,299	20	10	2	1
3,300 - 9,999	40	20	4	2
10,000 - 49,999	60	30	6	3
50,000 - 99,999	80	40	8	4
100,000 or more	100	50	10	5

From Regulation 170-03, sections 15.1-4 and 15.1-5. ***NOTE: This table may be revised pending passage of December 2009 amendments.***

In addition to collecting samples at more sites than required by the Regulation, samples can also be collected at a greater frequency than required to provide a greater understanding of the variability in lead levels measured in the system. Reductions in lead levels can be assessed system-wide or site-by-site. Use of median (or 50th percentile, rather than 90th percentile) lead levels may be appropriate for evaluations of system-wide effectiveness. When evaluating treatment effectiveness, lead levels measured system wide before and after implementation can be compared in graphical or tabular form. Statistical tests can be used to understand the confidence in differences in lead levels measured system wide or in discrete sections of the distribution system.

Profile sampling can also be conducted at the tap (using a series of sequentially collected samples) to help determine which of the major lead sources in the system (faucets, soldered joints, service lines, etc.) have exhibited reductions in lead release after implementation of treatment. This supplemental tap water sampling can include analysis of both particulate and dissolved lead to provide information on whether lead release is related to solubility or particulate release from scales. Obviously, these supplemental tap monitoring programs will require a great deal of coordination from consumers, and are relatively labor intensive to implement. However, the increased confidence in the assessment of corrosion control effectiveness in reducing metals levels may be necessary.

Several references are identified in the list of references that provide guidelines and recommendations for developing monitoring programs after implementing corrosion control and evaluating the data, including Kirmeyer et al (2000, 2002, and 2004).

6.3 Customer Feedback Tracking

Programs to track customer feedback or complaints will provide information on secondary impacts as well as the possibility of providing information on problem areas in the distribution and premise systems that might be more likely to exhibit elevated lead levels. Customer feedback that may be related to corrosion include observations of colour/discoloured water, taste and odour, fixture staining, and sediments or particulates in the water. Red/rust coloured or yellow water can be an indication of iron corrosion, as can black water, which can be caused by formation of ferrous iron in areas of the system where oxygen may be depleted. Black water can also be caused by high manganese levels. Blue water and blue staining is an indication of copper corrosion. Tracking these complaints provides another source of data with which to assess secondary impacts of corrosion and corrosion control treatment.

6.4 Laboratory Studies

Laboratory studies, as described in Chapter 3, are typically used to determine the most effective corrosion control measure prior to implementation. However these methods can also be used on an on-going basis to track the effectiveness of the implemented measure. These corrosion assessment tools include:

- Pipe loop testing
- Scale and solids analysis

Pipe loops can be operated continually, and used to provide frequent sampling and data that can be collected under more controlled conditions than can be collected at residential taps. Since pipe loop studies can be designed to incorporate typical distribution and/or premise plumbing components, they can provide an evaluation of how metals release might change over time with corrosion control treatment, seasonal water quality changes and/or variability in treatment. Pipe loop studies generally need to be conducted for several months before stable metals release data are available. They can also provide specimens for scale analyses and how scale characteristics may have changed with the onset of corrosion control. Assessments of scale can also be made on pipe specimens excavated directly from the distribution system (such as the lead service pipe).

Whenever a new treatment process is installed or implemented at a water treatment plant, there is the potential for adverse impacts to occur. Enhanced monitoring during start-up is recommended to monitor pH and inhibitor levels (if applicable) in the distribution system, particularly at the ends of the system to insure that the desired changes in water quality have extended to the entire system, and evaluating other water quality parameters during the start-up phase to assess secondary impacts.

6.5 Guidance for Post-Implementation Monitoring Programs

Recommendations for monitoring the effectiveness of measures to reduce the potential for lead release should be included in the Corrosion Control Plan. This recommendation should include water quality sampling, and may also include provisions for customer feedback and complaint tracking and additional laboratory studies if warranted. Water quality sampling recommendations should indicate the number and location of sampling sites (point-of-entry, distribution, residential and non-residential), parameters to be measured, frequency of measurement, and sample collection protocols (flushed, stagnation, sample volume, etc.). Recommendations for post-implementation monitoring programs based on population served are presented in Table 6-4. Results from point-of-entry and distribution system sampling will be compared to the operating conditions recommended for the preferred measure(s). If the Owner and Operating Authority collect additional water quality samples from point-of-entry or the distribution system, the results should be included in the assessment.

In addition to monitoring the effectiveness of corrosion control, the operating conditions should be monitored to confirm that the desired water quality is indeed produced. For example, this can include monitoring pH (e.g., pH 7.0 ± 0.2), the target for chemical dosing within the plant (e.g., lime dose from a minimum of 5 mg/L to a maximum of 20 mg/L), and the target for operating conditions or residual chemical concentrations within the distribution system (e.g., maintain residuals of at least 0.5 mg/L as P across the distribution system).

Table 6-4: Post-implementation Monitoring **Recommendations**

Population Served by Drinking Water System	**Monitoring Program (1)**				
	Point-of-Entry Sampling	**Distribution System Flushed Samples**	**Residential and Non-Residential Stagnation Samples**	**Supplemental Tap Sampling**	**Other**
1- 99	Daily pH 1/month alkalinity, inhibitor levels	Number of sites as specified in Regulation Frequency of 1/month	Number of sites as specified in Regulation Frequency of 1/month	n/a	Track customer complaints
100 - 499					
500 - 3,299					
3,300 - 9,999	Daily pH 2/month –			Additional tap sampling	
10,000 -					

Population Served by Drinking Water System	**Monitoring Program (1)**				
	Point-of-Entry Sampling	**Distribution System Flushed Samples**	**Residential and Non-Residential Stagnation Samples**	**Supplemental Tap Sampling**	**Other**
49,999	alkalinity, inhibitor levels				
50,000 - 99,999	Daily or continuous pH Weekly alkalinity, inhibitor levels			Additional tap sampling and Profile sampling	Track customer complaints Evaluate continued operation of laboratory studies (e.g., pipe loops)
≥100,000					

1. Frequencies are minimums. In many cases, municipalities will monitor these parameters more frequently. If continuous pH monitoring is in place, provide a recommendation for assessing consistency of pH measurements. Post implementation monitoring results should be compared to operating ranges recommended in the Corrosion Control Plan.

7.0 Process Changes and Internal Corrosion

7.1 Introduction

This chapter describes methods to determine the impact of ongoing process changes within the water treatment plant on the potential to increase internal corrosion within the distribution system.

The corrosion control planning process should be revisited if changes in treatment, source water, or other operational issues occur, as the (preferred) corrosion control measure identified in the Corrosion Control Plan may no longer be valid. The preparation of a new Corrosion Control Plan or revisions to the current Corrosion Control Plan are only required in response to results from monitoring conducted under Schedule 15.1-4 and 15.1-5 of O.Reg 170/03, or as a condition of a Certificate of Approval (CofA) or municipal drinking water Licence and Drinking Water Works Permit (DWWP) if considered necessary by the MOE.

Under Subsection 15.1-5 of the Regulation – Reduced Sampling

"(6) This section ceases to apply to a Drinking Water System, and section 15.1-4 applies again, if in any period described in subsection (5), more than 10 per cent of all the samples taken from plumbing under that subsection and tested for lead exceeded the standard prescribed for lead, according to the results of the tests conducted under section 15.1-7."

Water quality parameters that affect corrosion and corrosion control were reviewed in Chapter 2 and provide a good starting point for a review of the potential impacts of a process change on corrosion.

A good example of the potential impact of process changes on internal corrosion is provided in the experience of Washington, D.C. In summary, it was a combination of factors that contributed to release of lead in this system. The presence of lead service lines, increased chlorine residual dosing in the mid-1990s, pH variations and a relatively low operating pH in the distribution system, and conversion from free chlorine to chloramine for residual maintenance all served to change the nature of the lead scales present in the system. As the water quality changed (either in the plant as a result of treatment changes) or in the system (as a result of varying pH), the susceptibility of the scales to release lead changed, causing the system to no longer be in compliance with the US EPA's Lead and Copper Rule.

7.2 Changes in Treatment and Internal Corrosion

Treatment changes that affect either the chemistry (such as the electrochemical potential or Eh, or pH and metal solubility) or that affect the protective passivating layer represent a potential concern. A change in pH, coagulant, or disinfectant are types of process changes that are discussed in this section.

The **pH** greatly affects the formation or solubility of protective films (Schock, 1999) and therefore any change in the treatment plant that results in a change in the pH of water discharged to the distribution system needs to be reviewed with respect to corrosion control and metals release. For example, the addition of aeration can raise the pH of water and therefore potentially affect its corrosivity. The bicarbonate and carbonate concentrations affect many important reactions in corrosion chemistry, including a water's ability to form a protective metallic carbonate scale or passivating film (Schock, 1999).

Changing disinfectants can alter the oxidizing conditions of the water, creating conditions where different lead compounds will form. Pre-existing, stable Pb(IV) scales can persist in highly oxidizing conditions (free chlorine), but changing to chloramine may destabilize these scales resulting in lead release. Gaseous chlorine lowers the pH of the water by reacting with the water to form hypochlorous acid, hydrogen ion and chloride ion. This results in potentially more corrosive water. This effect can be amplified in waters that do not have a large amount of alkalinity to buffer the pH (Schock, 1999). In contrast, sodium hypochlorite is a base and when applied can serve to increase the pH of the water. Thus it is critical to be aware of the source of chlorine in addition to disinfection changes and their potential impacts on corrosion.

Changing coagulants from alum (aluminum sulphate) to chloride based formulations may aggravate lead release from lead solder: chloride may aggravate corrosion of lead that is galvanically connected to copper, whereas sulphate may cause lead solder corrosion (Edwards and Dudi, 2004; Dodrill and Edwards, 1995).

Chloride (Cl^-) and sulphate (SO_4^{2-}) may increase corrosion because:

- Chloride and sulphate can react with metals in solution, causing dissolved metals to remain soluble

- Both chloride and sulphate can increase the TDS and conductivity of a water

The chloride-to-sulphate-mass ratio (CSMR) is another tool that is used to assess the corrosivity of a water. A change in coagulant can affect the corrosivity of water, and the CSMR attempts to explain why this happens. Note that changes to the operating conditions of coagulation (pH of coagulation, dose) or a change in the type of coagulant used can affect the corrosivity of the water. Studies in the United Kingdom suggested that waters characterized with a relatively low CSMR were able to maintain lead levels below regulatory limits, while waters with a relative high CSMR were more likely to exceed regulatory limits. Although values for the CSMR at which this occurs have been identified in the literature, there is a large gray area with the CSMR where more research is needed to determine how water quality can affect the dividing line between a "good" value for the CSMR and a "bad" one in terms of lead release.

Changing how softening is practiced at a treatment plant can affect corrosion and corrosion control. Hardness is caused by the presence of divalent cations, predominantly calcium and magnesium. Hard water is less likely to be corrosive than soft water: if there is sufficient calcium and alkalinity present at a given pH, then a protective film may form (Schock, 1999). If the water is substantially under saturated with calcium carbonate ($CaCO_3$), calcium will not have much of an effect (and magnesium does not affect scale formation). It is the alkalinity available in the water that will have a major impact on corrosion control and metal release. Therefore if the conditions or treatment objectives for softening are changed, the impact on metal release should be considered. Further, softening may potentially affect the CSMR of the treated water.

7.2.1 Example: Changing Disinfectant Conditions for Residual Maintenance

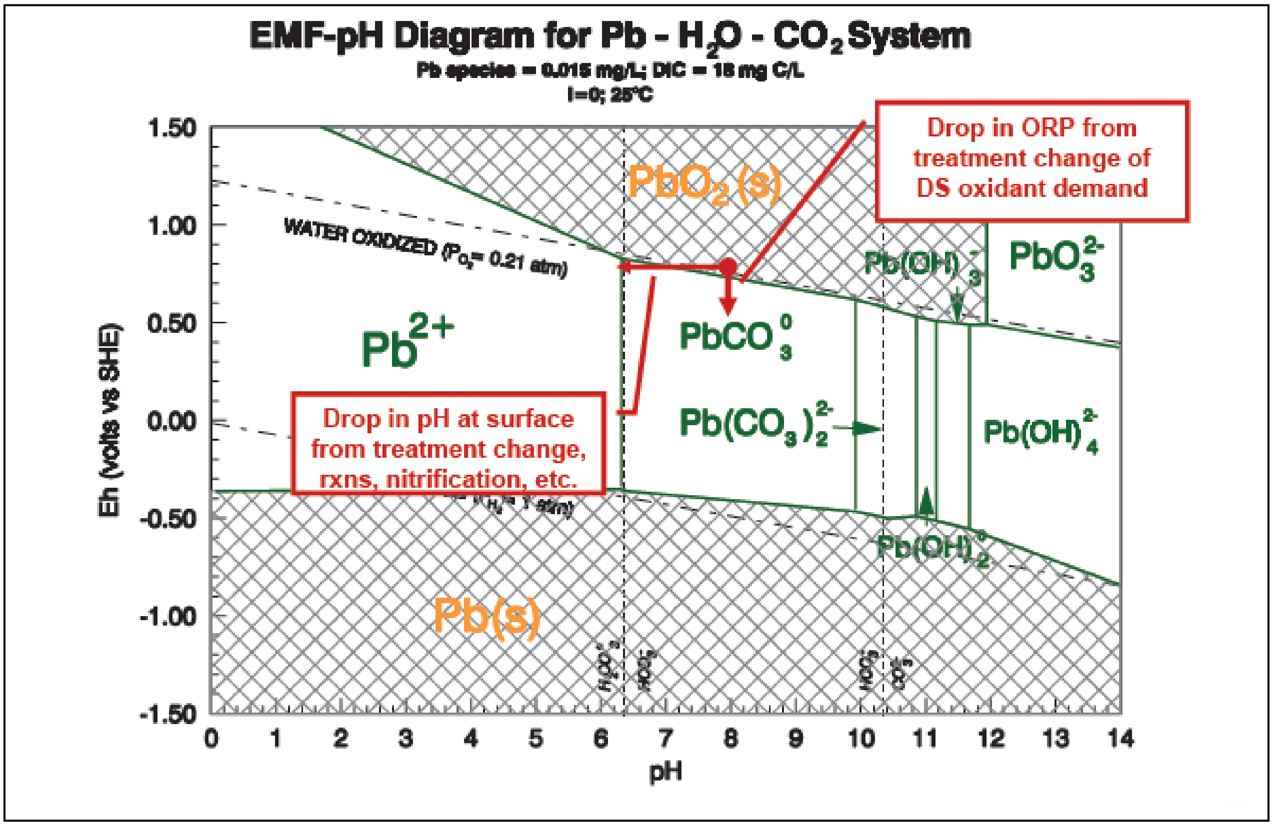
An example of the impact that changing disinfectant or decreasing pH may have on the type of lead compounds that would form is presented in Figure 7-1. This provides a visual display of how changing disinfectants and lowering the oxidation potential may have contributed to elevated lead levels in the water. To prevent lead problems if Pb(IV) scales are dominant, utilities can either:

1. Maintain current conditions
2. Adjust the pH/DIC to convert to insoluble Pb(II) passivating films (by operating with pH greater than approximately 9 and alkalinity greater than 30 mg/L as $CaCO_3$,) or
3. Use orthophosphate to form passivating films

Buffer intensity or pH stability should also be considered. Buffer intensity measures the resistance to change in pH due to bicarbonate and carbonate ions. Buffering capacity is at a minimum at pH values from about 8 to 8.5. In low DIC waters in this pH range, pH values can fluctuate in the distribution system for a variety of reasons such as uncovered storage, nitrification, and corrosion of iron or AC pipe.

For a detailed review of Washington, DC's experience with changing pH and changing disinfectant type on lead release, the reader is referred to the 2007 US EPA report titled Elevated Lead in DC Drinking Water – A Study of Potential Causative Effects, Final Summary Report.

Figure 7-1: Example Use of EMF/pH Diagram
(Diagram courtesy of M.R. Schock, 2005)



7.3 Changes in the Source Water and Internal Corrosion

The corrosivity of the water can be affected by changes in the choice of source water, or changes in the water quality characteristics of the supply. If there is any change in the parameters that affect corrosion or metal release, then consideration should be given to how this would affect lead as measured at the tap. For gradual changes in the source (for example, in response to a fire event in the watershed, or changing storm patterns), results from lead sampling per Schedule 15.1-4 could be used to indicate the impact that changing source water conditions has on corrosion. However, this is not a proactive way to manage lead release. If there are planned changes to the choice of source supply (e.g., purchasing water from another municipality or supplementing an existing groundwater supply with a new surface water supply), then water quality characteristics can be reviewed for potential impacts on lead release and addressed during the planning stages of introducing that new source.

7.4 Other Operational Changes and Internal Corrosion

7.4.1 Distribution System Practices

Changes to how the distribution system is operated may affect corrosion and/or corrosion control. Examples include:

- Changes to the hydraulics of the system to practice blending or isolating a portion of the system; are there changes to flow pattern or will the system be expanded and what effect will this have on (longer) travel times or the occurrence of dead ends?

- Changes to flushing practices

- Changes to booster chlorination or the use of breakpoint chlorination

7.4.2 Nitrification

For systems that use chloramine, nitrification monitoring and prevention is recommended. This is relevant to lead control in that one of the side effects of nitrification is reduced pH: if the distributed water is soft enough or does not have enough buffering capacity, lead may go into solution and be available for release into the bulk water. A review of experience from the City of Ottawa is presented to illustrate this point.

In response to a customer request for sampling, lead levels were observed in mid-August 2002 in the City of Ottawa's distribution system in Old Ottawa South well above historical levels (lead was measured greater than 10 ug/L in 33 homes out of 290 tested). Extensive sampling was conducted to assess the extent of the problem, which confirmed that the problem was localized and the culprit was linked to nitrification. Observations during this event included the following:

- Noticeable decrease in pH (from approximately 8.5 to the 7.8 range), decrease in chlorine residual, change in distribution of chlorine speciation, and increase in heterotrophic plate counts, all of which are symptoms of nitrification

- Increase in nitrite, indicating that the nitrification process was underway (ammonia is first converted to nitrite and then to nitrate when nitrification is complete)

- The pH drop was enough to influence lead levels (recall lead solubility curves of Chapter 3)

To manage the lead levels, the pH in water discharged to the distribution system was raised from 8.5 to 9.2 on August 31st, resulting in lead levels declining overnight.

Improvements in lead control were quickly observed (from a flowing average of 14.7 ug/L at pH 8.5 to 6.5 ug/L at pH 9.2, using 12 test sites), with lead levels further reduced as temperatures dropped through the fall. Observations of localized pH decreases still do occur in the system in areas known or suspected to have nitrification, but the pH stability and buffer intensity provided at pH 9.2 compared with pH 8.5 limits this decrease to about 0.2 pH units, thereby reducing the impacts that the pH decrease has on lead release.

7.5 Summary of Process Changes and Internal Corrosion

A summary of water quality conditions suitable for managing corrosion – or alternatively, exacerbating corrosion – is presented in Table 7-1. A change in water quality may change the nature of the scales present in the distribution system piping and the effectiveness of corrosion control, and as such may cause an increase in the release of metals. This table can be referenced when considering a process change to answer the question: will water quality changes occur that result in less than ideal conditions for corrosion and corrosion control? Treatment changes that can potentially affect the corrosivity of treated water are identified in Table 7-2. The content of Tables 7-1 and 7-2 are presented for guidance only and the content should be used by the reader to identify potential conditions suitable for corrosion and impacts potentially associated with a treatment change.

Table 7-1: Typical Ranges for Managing Water Quality to Control Corrosion

Parameter	Lead	Copper	Iron
pH	(High)	High	High
Alkalinity	> 35 mg/L so that constant pH can be maintained	> 100 mg/L is corrosive to copper	Maintain > 35 mg/L and pH > 9
Dissolved Inorganic Carbonate	If using phosphate: Increase DIC to decrease lead (when operating at 7 < pH < 8); little effect at higher pH	> 30 mg C/L will cause copper to increase	
Hardness	Calcium/ magnesium are less soluble at higher pH and may cause secondary water quality impacts		
Buffer Intensity	Minimum at pH 8 to 8.5; maximum at pH 6.3 and pH > 9		
Chlorine	Inhibits microorganisms and is toxic to ammonia oxidizing bacteria (which are necessary for nitrification to occur) Oxidation of metals may lead to some metal release		
Orthophosphate	Maintain 7.4 < pH < 7.8 (typical), and maintain orthophosphate residuals across the distribution system		

Table 7-2: Treatment Changes and Corrosivity

Treatment Change			Impact on Corrosivity
Coagulation	Change operating conditions	pH	Review impact with respect to the solubility curve of the target metal
		Coagulant dose	May affect the pH of coagulation (in poorly buffered waters) May affect the chloride:sulphide mass ratio of the water
	Change chemical		May affect the chloride:sulphide mass ratio of the water
Disinfection	Chlorine	Dose and pH	Increases in chlorine dose may increase corrosion, although this is strongly linked to pH of water
	Chloramine	Nitrification and excess ammonia	Excess ammonia may complex lead and increase lead release As well, excess ammonia may result in nitrification leading to further lead release
	Ozone		Will create greater oxidation
	Chlorine Dioxide	Chlorite	Chlorite is used for nitrification control in some systems that use chloramine
	Softening		Less calcium will strongly influence overall corrosion control strategy May affect the CSMR of the treated water

7.6 Process Changes and Corrosion Control Planning

A proposed checklist or approach that can be used when considering process changes is presented in Figure 7-2. This checklist can be used as a starting point for consideration and must be tailored to the unique needs and features of each Drinking Water System.

For the purpose of the Corrosion Control Plan, if an Owner or Operating Authority intends to undertake a potential change in source water, treatment, or distribution system operations, a brief description of the potential change may be described, included as a factor in the evaluation of alternatives, and considered in the discussion of the preferred measure for corrosion control.

Figure 7-2: Checklist for Review When Considering a Process Change

Checklist for Review When Considering a Process Change

1. Identify potential treatment change

    - Identify directly and indirectly affected process units

2. Determine the water quality impacts as a result of that treatment change

    - Consider water quality parameters that are:
        - Critical to the corrosivity of the water
        - Critical to corrosion control for the water

3. Examine whether or not corrosion control needs or the effectiveness of corrosion control will change

    - Review theory for corrosion and lead release
    - Review theory for corrosion control and lead control
    - Assess relationship with a change in water quality as a result of the process change
    - Identify appropriate mitigation efforts

8.0 Implementing Corrosion Control

8.1 Introduction

Ontario Regulation 170/03: Drinking Water Systems, Schedule 15.1-11 Corrosion Control, requires that the Corrosion Control Plan identify the implementation schedule for the corrosion control measure recommended to reduce the potential for lead leaching. The plan must also identify the post-implementation monitoring efforts that will be used to confirm the effectiveness of the corrosion control measure.

Under Subsection 15.1-11 (5) of the Regulation – Contents of a Corrosion Control Plan:

"(5) The plan shall,

> ***(d) set out an implementation schedule; and***
>
> ***(e) include a program for monitoring the effectiveness of the preferred measure or measures."***

The purpose of this chapter is to describe the implementation of corrosion control and the approval requirements. Features of the post-implementation monitoring plan were described in Chapter 6. A review of design features (e.g., materials of construction, redundancy needs, or temporary chemical feed system during construction) is not discussed in this document; rather, the reader is referred to the MOE's Design Guidelines for Drinking Water Systems (2008) and the Ten State Standards (2007).

8.2 Implementation

8.2.1 Components of the Implementation Plan

Typical components and their likely sequence of application when implementing a Corrosion Control Plan are listed in Table 8-1. When developing the implementation schedule as part of the overall Corrosion Control Plan, each Owner and Operating Authority will need to determine which components of Table 8-1 are appropriate for their unique situation. For example, pipe loop testing and full-scale demonstration testing may exceed the resources available of small system users, and therefore a desk-top study and review of analogous systems may be identified as the pre-requisite for design and construction.

Table 8-1: Sequence of Components of an Implementation Plan

Tool	Application	Comment
Desk-top study	Starting point for Corrosion Control Plan	
Corrosion/water chemistry modelling	Optional: Suitable for use when developing and evaluating alternative measures for corrosion control (e.g., estimate chemical dosage to achieve a desired pH and/or alkalinity target)	May require bench-scale testing to calibrate model results to a specific water
Bench-scale testing	Optional: May be used to i) identify design criteria with respect to chemical dosing, and ii) confirm results from modelling	Data generated from testing are limited to chemical dosing and some secondary water quality impacts (such as chlorine decay as a function of pH, pH-dose response curves, and aluminum levels as a function of lime dose)
Pipe loop testing	Recommended for alternative measures that involve phosphate use with downward pH adjustment to assess performance, design criteria, operating conditions, and secondary impacts	Pipe loop testing should be conducted long enough to establish conditions at the pipe wall (e.g., protective scales) that are a result of the treatment
Partial system testing	Optional: If a portion of the distribution system can be hydraulically isolated from the rest of the system, demonstration testing may be used in lieu of or in addition to pipe loop testing to assess performance, design criteria, operating conditions, and secondary impacts	To operate a partial system test may require discussions with MOE and the local Medical Officer of Health prior to implementation
Consultation with industry users	Recommended: The implementation schedule may need to accommodate industrial users that need to make their own modifications to receive treated water from the system	
Design and construction	Per the requirements of the municipality, if applicable	The preferred corrosion control measure may include new chemical storage and metering systems, or may involve modifying how existing chemical systems are used
Implementation and contingency planning	Recommended: Identify the potential risks of implementation and generate remedial or control measures, such as adding temporary chemical feed systems, enhanced flushing, or modifying the schedule of phased implementation	
Post-implementation monitoring	Required	

Once the components of implementation are identified, the implementation schedule can be developed using appropriate time lines. Three examples are included in Appendix F.

8.2.2 Considerations for Phased Implementation

A phased approach to implementation may be appropriate when a change in the pH of the treated water is necessary for the preferred corrosion control measure. To allow the distribution system to respond and establish a new equilibrium, pH changes should be implemented with caution. For example, if the treated water has historically been discharged to the distribution system with an average pH of 7 and the target pH of 8.2 is identified as the preferred corrosion control measure, it may be prudent to slowly raise pH in increments of 0.3 pH units over a 12-month period (or increase the pH by 0.3 every three months). Other systems have used increments of 0.2 pH units per week to accommodate a higher target pH in treated water. The rate of implementation should be determined for each system, with consideration given to potential secondary impacts as the distribution system re-establishes equilibrium and the magnitude of lead levels requiring control.

8.2.3 How Long Can Corrosion Control Planning Take?

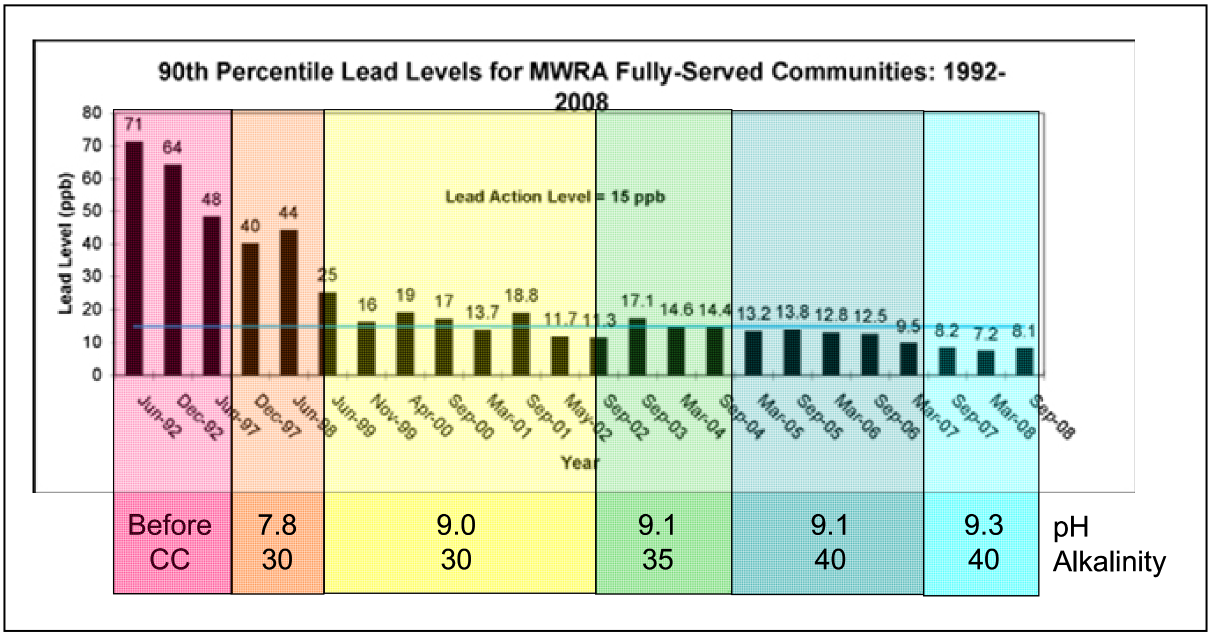
The timeframe to complete and implement a Corrosion Control Plan will vary by Owner and Operating Authority. For example, the duration of the decision making period from the start of the study (to assess the occurrence of corrosion and to evaluate the alternatives to implementation and commissioning of the new chemical systems in the City of Ottawa was approximately 4 ½ years. Initiated in 1997, this study was undertaken to respond to aging equipment; compliance was achieved under the then current regulations.

In the case of the City of London, additional sampling for lead was undertaken from fall 2006 through March 2007 after elevated lead levels were first measured in the late fall of 2006, After extensive sampling at the customer’s tap and four months of pipe loop testing, a new caustic soda metering and storage system was designed and made operational in January 2008. The City of London continues to optimize system performance in addition to the use of lead service line replacement to control the particulate lead present in this system.

8.2.4 How Long can it Take to See Results?

The time needed to see results from the addition of corrosion control can take from three to six months or longer, although this will vary by system and will depend on the nature or type of lead scales formed. For example, increasing the pH from 8.5 to 9.2 overnight in the City of Ottawa’s system resulted in a noticeable decrease in lead levels within days. In the case of the Massachusetts Water Resources Authority (MWRA), pH levels have been slowly adjusted since implementation in 1999 (see Figure 8-1). As the lead scales are established in response to exposure to water with increasing pH, lead levels continue to decrease.

Figure 8-1: Timeline for Treatment Objective Changes and Lead Levels (viewed at http://www.mwra.com/04water/html/qual6leadinfo.htm)



For one Great Lakes user, demonstration testing provided useful information related to timeframes needed for orthophosphate residual to be measured at the end of the system. Partial system testing in an isolated portion of the distribution system of this Great Lakes utility was also carried out to establish the operating conditions suitable for their old cast iron system. An initial dose of 1 mg/L as PO_4 was gradually increased to 3 mg/L as PO_4 for the next seven months. The demonstration lasted for approximately 18 months, with standing lead levels collected before, during, and after implementation of treatment. Lead levels stabilized after 12 weeks and a 48 percent reduction in average lead levels was measured after treatment. It took three weeks for PO_4 to reach the target dose at the far ends of the system.

8.3 Approvals

Under Part V of the *Safe Drinking Water Act* (SDWA) and the Drinking Water Systems Regulation (O. Reg. 170/03), Owners of municipal Drinking Water Systems serving major residential developments (small and large municipal residential systems) are required to obtain a CofA or a municipal drinking water Licence and a Drinking Water Works Permit if they intend to establish, alter, extend, replace or operate new or existing municipal Drinking Water Systems. The Approvals and Licensing Section of the MOE's Safe Drinking Water Branch reviews applications for the CofA and municipal drinking water DWWP/Licence including engineering design and specialized technical features of the works needed to demonstrate compliance with the SDWA, its regulations, and good engineering practice.

A CofA under Part V of the SDWA provides Owners with the authority to establish/alter a Drinking Water System as well as the authority to operate this system. The existing Drinking Water System CofA program is being replaced by a new Drinking Water System approvals framework which provides the system Owner separate authority to establish/alter works through a drinking water works permit and the authority to operate the system through a municipal drinking water Licence. This new licensing program incorporates concepts of quality management as recommended in Justice O'Connor's Walkerton Inquiry Part II Report. The transition from the CofA to the DWWP/Licence is being achieved through O. Reg. 188/07 (Municipal Drinking Water Systems Regulation), which contains schedules with dates by which the listed groups of Drinking Water System Owners must apply for their first DWWP/Licence. Until specific system Owners receive their first DWWP/Licence for their systems, these Owners are required to continue operating these systems (including any system alternations) under the current CofA program.

8.3.1 Submission of Corrosion Control Plan

The O. Reg. 170/03 requirements for the preparation and submission of Corrosion Control Plans only apply to large municipal residential systems and only if results from two of the three most recent sampling periods trigger the need for a Corrosion Control Plan for a particular system, as stipulated in section 15.1-11 of the Regulation. The submission due dates for the Corrosion Control Plan are defined in subsection (3) of that section:

Under Subsection 15.1-11 (3) of the Regulation – Corrosion Control:

"(3) Within one year after the last day of the period mentioned in subsection (1) during which the test results are such as to cause this section to apply, the Owner of the system and the Operating Authority for the system shall ensure that a plan that complies with subsection (5) is prepared and submitted to a Director appointed by the Minister under section 6 of the Act in respect of section 32 of the Act."

The requirements for preparing a Corrosion Control Plan in Schedule 15.1-11 are linked to results from lead sampling conducted under Schedule 15.1-4 (Standard Sampling) of the Regulation. All the sampling results obtained for lead monitoring pursuant to this schedule are submitted to MOE after each round of sampling. If test results from more than ten percent of plumbing samples in two of the most recent three sampling periods exceed the ODWQS (O. Reg. 169/03) for lead of 10 ug/L, the requirement to prepare a Corrosion Control Plan is triggered. A single sample with a lead result above the standard does not trigger a Corrosion Control Plan by itself, but does require the Owner to notify and take direction from the local Medical Officer of Health.

The Corrosion Control Plan is developed by the Owner and Operating Authority of the Drinking Water System. The plan will be submitted to the Director, Part V*, Safe Drinking Water Act,* at the MOE's Safe Drinking Water Branch, Approvals and Licensing Section, and the receipt of the plan will be acknowledged in writing.

8.3.2 Requirements for the Joint Preparation and Submission of a Plan

Under Subsections 15.1-11 (6) and (7) of the Regulation – Corrosion Control:

(6) If subsection (3) applies to a Drinking Water System that obtains treated water from another Drinking Water System,

(a) subsection (3) also applies to the Owner of the other system and to the Operating Authority for the other system;

(b) the plan mentioned in subsection (3) shall be a joint plan; and

(c) the Owner and Operating Authority mentioned in clause (a) shall, jointly with the Owner of the system that obtains the treated water and the Operating Authority for that system, ensure that the plan is prepared and submitted.

(7) If the Drinking Water System referred in clause (6) (a) itself obtains treated water from another system, subsection (6) also applies to that other system.

Where a system that is exceeding the criteria in Schedule 15.1-11(3) receives water from another Drinking Water System, Schedule 15.1-11(6) imposes a joint responsibility on the Owners and the Operating Authorities of the supplying and subsequent system to ensure that a Corrosion Control Plan is prepared and submitted.

Because water chemistry adjustments may have to be made by the supplying system, both system Owners and their Operating Authorities must work together, and the plan submitted must be a joint plan outlining the roles and responsibilities of each system Owner. The requirements for a joint plan will be fulfilled by both Owners and Operating Authorities signing the Notice of Submission of Corrosion Control Plan, contained in Appendix C-1.

8.3.3 Approval Requirements Related to Corrosion Control

The Corrosion Control Plan itself is accepted and not "approved", as O. Reg. 170/03 does not require director approval of the plan. If the submitted Corrosion Control

Plan is accepted by MOE, an acceptance letter will be sent from the approving Director under Part V, SDWA. The Owner must still obtain an amended CofA or DWWP/Licence for requirements related to the implementation of the plan before the Owner can proceed with implementation of corrosion control measures included in the plan. The anticipated date of application for amended CofA or DWWP/Licence will need to be identified in the implementation schedule included with the Corrosion Control Plan.

Under Subsection 15.1-11 (8) of the Regulation – Corrosion Control:

"(8) If the plan mentioned in subsection (3) requires the Owner or the Operating Authority to do anything in connection with implementing measures under the plan or monitoring their effectiveness, the Owner shall, at the same time as the plan is submitted to the Director, apply to the Director to amend the system's Approval or municipal drinking water licence to reflect the requirements of the plan."

The Owner will have to apply to receive an amended CofA or DWWP/Licence in cases where the plan would require the Owner to alter/modify works in the Drinking Water System or make operational changes and undertake special monitoring. This criterion applies to all cases involving changes to the characteristics of the treated water or water within the distribution system. Subsection 15.1-11 (8) requires the Owner to submit to the Director, along with the Corrosion Control Plan, an application for amendment to their CofA or DWWP/Licence, if the plan would require the Owner to "do anything in connection with implementing measures under the plan or monitoring their effectiveness." The submission of the Corrosion Control Plan provides an opportunity for direct input by the MOE to identify areas of deficiency or non-compliance, and the MOE may request that modifications to the plan be made before it is accepted. The timelines for implementation must be proposed by the system Owner in the implementation schedule included with the Corrosion Control Plan. As such, the MOE is clarifying that the submission of the application for amendment of the CofA or DWWP/Licence can be made after acceptance of the Corrosion Control Plan, in accordance with agreed timelines.

Under Subsection 15.1-11 (9) of the Regulation – Corrosion Control:

"(9) If the Director has amended the system's approval or municipal drinking water licence under subsection (8) and the Owner or Operating Authority is carrying out the monitoring program described by clause (5) (e), the requirements for taking samples set out in subsection 15.1-4 (1), subsection 15.1-4 (3), subsections 15.1-5 (3) and (4) and subsection 15.1-5 (8) cease to apply to the Drinking Water System."

Upon the issuance of a CofA or DWWP/Licence for implementation of the plan, the system may be exempt from the sampling requirements of Schedule 15.1. Instead, the Owner will comply with conditions imposed in the CofA or DWWP/Licence. If post-implementation results from lead sampling required by the CofA or DWWP/Licence indicate that the samples continue to exceed lead standards in accordance with the criteria in Schedule 15.1-11(1), the Corrosion Control Plan may need to be amended and re-submitted to the MOE. The Owner may also apply for regulatory relief from lead sampling requirements while the Corrosion Control Plan is being prepared and the MOE will consider the value of additional sampling before making a decision to grant this relief.

The requirements of Schedule 15.1 are performance based in that results from lead sampling are used to confirm compliance. The Owner will identify corrosion control operating conditions (e.g., pH 7.0 ± 0.2), the target for chemical dosing within the plant (e.g., lime dose from a minimum of 5 mg/L to a maximum of 20 mg/L), and the target for operating conditions or residual chemical concentrations within the distribution system (e.g., maintain residuals of at least 0.5 mg/L as P across the distribution system). The Owner will also identify corrective measures to be taken when operating targets are not met. While the MOE will not impose the operating conditions or dosage levels, the CofA or DWWP/Licence will require that these be monitored and maintained within the ranges contained in the Owner’s Corrosion Control Plan, both within the plant and the distribution system. The CofA or DWWP/Licence will require that the corrective actions proposed by the Owner be implemented if the operating conditions are not being met for extended periods of time. The periods of time, and the allowable percentage of drinking water distributed to users that is not within plan ranges will be identified as conditions in the CofA or DWWP/Licence. Operating outside the range of a parameter in the plan will not constitute an adverse test result for the purposes of Schedule 16 of O. Reg. 170/03, however, the need to maintain compliance with site specific CofA or DWWP/Licence conditions will require action to restore the parameter to the operating range within a reasonable time period.

The Owner will have to demonstrate to Ministry Drinking Water Inspectors that compliance with the CofA DWWP/Licence for the Corrosion Control Plan implementation is being achieved, including any monitoring for operational parameters such as chemical dosage and residuals.

8.3.4 Regulatory Relief from Requirement to Prepare a Corrosion Control Plan

The requirements for corrosion control planning under Schedule 15.1-11 and the contents of this Guidance Document only apply to adjustments to the characteristics of treated water or water within the distribution system to make the water less corrosive. Non-treatment approaches, such as reducing sources of lead, are a viable means to address exceedences resulting from corrosion in the distribution system and premise plumbing. However, source reduction is not considered a Corrosion Control Plan satisfying Schedule 15.1-11 unless source reduction is implemented in conjunction with chemical adjustments.

For systems considering a non-treatment approach only, the Owner and Operating Authority should apply to the Director for regulatory relief from the provisions of Schedule 15.1-11. The consideration of non-treatment approaches should take into account the unique features of the system and the population it serves. In assessing the appropriateness of a non-treatment approach to manage elevated lead levels in drinking water, the Director will consider many different factors including the source or raw water and type of treatment, the presence of vulnerable populations, and the geographic locations of lead exceedences in the system. The Owner will have to provide a schedule of implementation for lead source reduction and propose interim measures to identify and protect vulnerable populations while source reduction is being phased in. For partial lead service line replacement, ongoing sampling will be important in quantifying the reduction of lead and demonstrating regulatory compliance.

9.0 Explanation of Required Elements of a Corrosion Control Plan

9.1 Introduction

The mandatory submission requirements are identified in Table 9-1. The minimum requirements of the Corrosion Control Plan are described in Table 9-2 consistent with the Regulation. The purpose of this chapter is to:

1. Clarify the mandatory submission requirements for Corrosion Control Plans, and

2. Identify the minimum content requirements for Corrosion Control Plans that are submitted

All systems must submit the Notice of Submission, which is found in Appendix C-1. Systems that serve less than or equal to 1,000 people will submit the "**Corrosion Control Plan Treatment Recommendations Form for Systems Serving Less than or Equal to 1,000 People**", which is found in Appendix D. Systems that serve more than 1,000 people will submit the "**Checklist for the Corrosion Control Plan**" (Appendix C-2) and a **Corrosion Control Plan**. These requirements are discussed in more detail below.

Table 9-1: Overview of Mandatory Submission Requirements

Mandatory Submission Requirement	Systems with ≤ 1,000 People	Systems with > 1,000 People
Notice of Submission (Appendix C-1)	✓	✓
Checklist for the Corrosion Control Plan (Appendix C-2)	Not Mandatory	✓
Corrosion Control Plan Treatment Recommendations for Systems with Less Than or Equal to 1,000 People (Appendix D)	✓	Optional
Corrosion Control Plan	Not Mandatory	✓

The **"Notice of Submission"** (Appendix C-1) is a mandatory submission form that must be included in every Corrosion Control Plan. The Notice of Submission identifies the municipalities name and contact information. Where the Owner is not the Operating Authority of the Drinking Water System, both the Owner and the Operating Authority must sign the Notice of Submission. Where an Owner supplies a subsequent system or downstream user with water, and if that subsequent system is also required to submit a Corrosion Control Plan, both the Owner and the subsequent user must sign the Notice of Submission.

The **“Checklist for the Corrosion Control Plan”** (Appendix C-2) must be completed and submitted with the Corrosion Control Plan by systems serving more than 1,000 people. It is expected that the site specific needs of each municipality will result in each municipality following their own path to develop their Corrosion Control Plan, and equally expected that the outcome of the Corrosion Control Plan will be unique to each municipality. The purpose of the Checklist is two-fold:

1. It provides a road map to help municipalities develop their Corrosion Control Plan and the necessary content, and

2. It streamlines the review process undertaken by MOE to indicate what content is provided in each Corrosion Control Plan

For systems that serve less than or equal to 1,000 people, the **“Corrosion Control Plan Treatment Recommendations Form for Systems with Less Than or Equal to 1,000 People”** included in Appendix D can be submitted in lieu of the Checklist (Appendix C-2). The Corrosion Control Plan Treatment Recommendations Form for Systems with Less Than or Equal to 1,000 People (Appendix D) provides a series of tables for the Owner to complete. The tables of Appendix D follows the requirements of the Checklist, and as a result, systems with less than or equal to 1,000 people need only submit Appendix D.

For systems serving more than 1,000 people, the Checklist can be used to identify the content required for the Corrosion Control Plan. At a minimum, all systems serving greater than 1,000 people must include a desk-top study as part of their Corrosion Control Plan. The following items must be included in the desk-top study:

- Notice of Submission
- Checklist
- Executive Summary
- Introduction and System Description
- Identification of Internal Corrosion Problems and Sources
- Assessment of the Significance of Contaminants and Sources
- Identification of Alternative Corrosion Control Measures and their Impacts (this is based on a review of analogous systems, literature reviews; this does not necessary include pipe loop testing or other field work)
- Identification of Preferred Measure for Corrosion Control

- Public Notification and Stakeholder Consultation
- Monitoring Corrosion Control Effectiveness (this is the post-implementation monitoring plan)
- Corrosion Control Plan Implementation (this is the plan and schedule for implementation)

Voluntary field work and pipe loop testing are considered beyond a desk-top study and may in fact be a recommendation as part of the implementation plan. If a municipality has conducted a pipe loop study or voluntary field work either before or as part of the development of the Corrosion Control Plan, then these results should be included in the Corrosion Control Plan. There is a place on the Checklist to identify optional items completed or tasks undertaken (e.g., pipe loop testing) as part of corrosion control planning to alert the MOE reviewer.

The minimum requirements of the Corrosion Control Plan are described in Table 9-2 consistent with the Regulation. Chapters 1 through 9 of the Guidance Document provide more explanation of the contents identified in Table 9-2. See Appendix E for an example format for a Table of Contents for a Corrosion Control Plan that follows the sequence of content of the Checklist. Where there is any conflict between the Corrosion Control Plan requirements in this Guidance Document and the requirements in Ontario Regulation 170/03: Drinking Water Systems, Schedule 15.1-11 Corrosion Control, then the requirements in the Regulation take precedence.

Under Subsection 15.1-11 (5) of the Regulation – Contents of a Corrosion Control Plan:

" (5) The plan shall,

> ***(a) analyze the potential for lead leaching into water as a result of corrosion that occurs in the system's distribution system or in plumbing that is connected to the system's distribution system;***
>
> ***(b) list and analyze possible measures to reduce the potential for lead leaching;***
>
> ***(c) identify the preferred measure or measures;***
>
> ***(d) set out an implementation schedule; and***
>
> ***(e) include a program for monitoring the effectiveness of the preferred measure or measures."***

Table 9-2: Summary of Minimum Requirements for Corrosion Control Plan

Corrosion Control Plan Chapter	Minimum Requirements	See…
Executive Summary	Overview of the Corrosion Control Plan and preferred measure for corrosion control.	This Document 9.2
Introduction and Drinking Water System description	The system description should be provided in adequate detail to select and justify the preferred corrosion control measure.	This Document 9.3
Identification of internal corrosion problems and sources of contamination	Provide details to identify the source and significance of corrosion and geographical extent of corrosion occurrence (map). Review water quality in source, treated, and distribution system water. Identify materials of construction used in the distribution system and premise plumbing.	This Document 9.4 Chapter 2 Regulation 15.1-11 (5) (a)
Assessment of the significance of contaminants and sources	Assess the significance of sources and contaminants and eliminate negligible ones from further analysis. The Corrosion Control Plan must provide an explanation of how it was determined that an amount of a contaminant is negligible. The source summary table is used to identify the potential corrosion by-products for which control is necessary and the sources of contamination should be identified. Establish baseline water quality conditions that will be used to develop alternatives measures for control.	This Document 9.5 Regulation 15.1-11 (5) (a)
Identification of alternative corrosion control measures and their impacts	Identify alternative measures for corrosion control and the conditions for application. For each alternative measure for corrosion control, identify the treatment objectives, rationale for consideration, and expected performance. Describe the impacts of the alternative corrosion control measures in terms of reducing corrosion, secondary impacts, and life-cycle costs.	This Document 9.6, 9.7 Chapters 3, 4 Regulation 15.1-11 (5) (b)
Preferred measure(s) selected, with rationale	Identify the preferred measure(s) for corrosion control, including treatment objectives and operating procedures. Provide the rationale or justification of the selection of the preferred measure.	This Document 9.8 Chapter 5 Regulation 15.1-11 (5) (c)

Corrosion Control Plan Chapter	Minimum Requirements	See…
Public notification and stakeholder consultation undertaken	Describe public notification and stakeholder consultation, including with industrial users and health care providers.	This Document 9.9
Monitoring corrosion control effectiveness	Provide details of the monitoring plan that will be used to assess the effectiveness of corrosion control and to confirm the operating procedures or conditions.	This Document 9.10 Chapter 6 Regulation 15.1-11 (5) (e)
Corrosion control plan implementation	Describe the features of the implementation schedule, including key tasks, timelines, and expected outcomes for each task. Include a review of risks of implementation and contingency planning.	This Document 9.11 Chapter 8 Regulation 15.1-11 (5) (d)
Appendices	Explanation of the identification of insignificant sources and contaminants, supporting calculations, and other associated materials.	This Document 9.12

9.2 Executive Summary

The purpose of the Executive Summary in the Corrosion Control Plan is to provide an overview of the Drinking Water System, the corrosion control challenges of the system, the recommended measure for corrosion control, and implementation schedule to reduce the potential for lead leaching. Therefore, the Executive Summary must summarize all of the information required by section 15.1-11 (5) of the Regulation to be included in the Corrosion Control Plan and must specifically include the source summary table. It is also recommended that the Executive Summary indicate the basis on which the Corrosion Control Plan has been prepared (e.g., the Corrosion Control Plan is required to satisfy section 15.1-11 (5) of the Regulation; or, a change to the water treatment plant resulted in elevated lead levels triggering a Corrosion Control Plan, etc.).

9.3 Introduction and Drinking Water System Description

The purpose of the Drinking Water System description in the Corrosion Control Plan is to provide a summary of the features and operations of the system that may contribute to corrosion or may affect corrosion control. The system description is intended as an overview of system features and operations and relevant data to support the assessment of the sources, the significance of corrosion, and the selection of the preferred measure of corrosion control.

Information must be provided in sufficient detail to support the identification of the operating conditions that correspond to the occurrence of corrosion. The system description may be expressed in a general manner including an overview of:

- The source water supply
- The source water supply characteristics
- The rated capacity of the facility or facilities discharging into the distribution system (in m^3/d)
- The annual average, minimum, and maximum flow from the facility or facilities discharging into the distribution system
- The treatment or basic unit processes (including a simplified process flow diagram) provided at the facility or facilities, including:
    - The coagulant used (type, dose, and target pH of coagulation)
    - The disinfectant used for residual maintenance in the distribution system (source of chlorine, type of residual be it free or combined, target residual in treated water)
    - The chemicals used for downward or upward pH adjustment in the plant (e.g., sulphuric acid for coagulation), if any (type, dose, and target pH)
    - The chemical(s) used for corrosion control, if any (type, dose, and treatment objective)
    - Any other chemical addition such as fluoride or ammonia; identity the type and dose used
    - Any proposed or planned changes to operations that could potentially affect corrosion or corrosion control
- The features of the distribution system:
    - Map showing the geographical extent of different ages and materials of water mains (to identify areas suspected of having lead service lines)
    - Map showing the geographical extent of expected/confirmed lead service line use
    - Map showing the location of remote station(s) relative to the treatment plant(s)
    - Map showing the area of the distribution system typically served by each treatment plant and supply, where multiple treatment plants or source supplies are used

- Summary of lead service line replacement program (phasing, budget, estimated number of full and partial lead service lines, number of replacements per year)

A worked example is included in Appendix F. Note that the requirement for how many data to review are not listed here; the water quality that results from the treatment is key, and this is described in more detail in the following sections.

9.4 Identification of Internal Corrosion Problems and Sources of Contamination

The purpose of this portion of the Corrosion Control Plan is to provide an initial listing of the internal corrosion problems and individual sources of contaminants in the system in accordance with paragraph (a) of section 15.1-11 of the Regulation. The results will ultimately be used to assess the significance of sources and contaminants in section 9.5.

A summary of the data for location, parameter, frequency, and duration that may be reviewed and described in the Corrosion Control Plan is presented in Table 9-3. The purpose for the inclusion of each parameter or group of parameters is also described. Examples for how to present, analyze, and interpret the data are presented in Appendix F (Worked Example).

Table 9-3: Sources of Contamination

Location	Parameter	Frequency	Duration[1]	Purpose
Raw Water	Lead Copper Iron Manganese	As available	5 years	To confirm or dismiss occurrence in the raw water To determine what contaminants need to be controlled in addition to lead, as this will influence the choice for corrosion control measure
Treated Water	pH Alkalinity Temperature	Daily (as available)	3 years	To assess conditions that may or may not favour lead release To evaluate the feasibility of alternative measures for corrosion control
	Dissolved inorganic carbonate (DIC)	As available	3 years	If data are unavailable, use average annual values for pH and alkalinity to calculate DIC
	Chlorine residual (and	As available	3 years	To comment on the

Location	Parameter	Frequency	Duration[1]	Purpose
	type)			oxidation reduction potential of the water
	Conductivity Total dissolved solids Oxidation reduction potential Dissolved oxygen Chloride Silicates Sulphate	Results submitted to MOE for quarterly/annual sampling	5 years	To comment on the potential corrosivity of the water To determine the CSMR
Distribution System	Lead Copper Iron Manganese	As available	5 years	To determine what contaminants need to be controlled in addition to lead, as this will influence the choice for corrosion control measure
	pH	As available	3 years	To assess pH variability across the system
	Chlorine residual (and type)	As available	3 years	To comment on the oxidation reduction potential of the water
	Nitrite Nitrate Free ammonia	As available	3 years	To assess the system's vulnerability to nitrification, for systems that chloraminate
Premise Plumbing	Lead, pH, alkalinity	May 2007[2]	20 samples	To assess lead in flushed samples at the customer's tap
	Lead, pH	Per Schedule 15.1-11 and the legislated community lead testing program	2 years	To assess lead in flushed and standing samples at the customer's tap (residential and non-residential), and flushed samples from the distribution system
	Total and particulate lead	As available	As available	To identify the form that lead is present (soluble or particulate) and to identify the potential source or cause of release
	Non-legislated lead sampling requested by customers	As available	Summer 2007 and beyond	To assess lead in flushed and standing samples at the customer's tap
	Copper Iron Manganese	As available	As available	To assess the quality of flushed and standing samples at the customer's

Location	Parameter	Frequency	Duration[1]	Purpose
				tap
	Lead profiles[3]	As available	As available	To identify the source of lead in the premise plumbing
	Lead profiles[3] before and after lead service line replacement	As available	As available	To estimate the impact of full and partial lead service line replacement on lead control

1. Duration refers to the years of historical data for review.
2. Data collected in response to the Director's Order, as applicable.
3. See Figure 2-2 for an example of a lead profile.

A reference to the method that was used to identify the expected contaminants should be provided for lead, copper, iron and manganese with an indication of the detection limit.

9.5 Assessment of the Significance of Contaminants and Sources

The purpose of the Assessment of the Significance of Contaminants and Sources in the Corrosion Control Plan is to review the data compiled as part of the identification of internal corrosion problems and sources of contamination. When developing the description that may be included in the Corrosion Control Plan, the following tasks may be undertaken:

1. Assess the nature of corrosion in the system with respect to the magnitude and extent of lead release and the occurrence of other by-products, the results from which will be presented in the source summary table

2. Identify the factors that can control or promote the release of lead using the background information described in Chapters 2 and 3

3. Establish the baseline water quality conditions and treatment objectives to develop alternatives measures for corrosion control

Baseline conditions need to be identified for the target compound(s) requiring control and the conditions under which corrosion control would be applied. Identify the target metal and the typical concentrations observed at the tap (in the case of lead or copper) or distribution system (in the case of iron) in the source summary table (see Appendix F). This will provide an indication of the relative degree of control required.

Using results from the review of historical water quality data in treated water and the distribution system, identify the typical ranges for those parameters that have been identified as affecting corrosion and corrosion control in your system. At minimum, typical ranges for pH, alkalinity, DIC, and temperature should be identified. This information can subsequently be used to establish chemical dosing needs. A worked example, including the source summary table, is presented in Appendix F.

9.6 Identification of Alternative Measure(s) for Corrosion Control

For each alternative corrosion control measure under evaluation, the following should be identified in the Corrosion Control Plan:

- Treatment objective as defined by operational targets for pH, alkalinity, and/or DIC, and residual in the case if an inhibitor
- Choice of chemical agent(s) to achieve the treatment target

A worked example is provided in Appendix F.

9.7 Impacts of Measures on Treatment, Water Quality, and Distribution

This section of the Corrosion Control Plan is used to identify and evaluate alternative corrosion control measures and their impacts. An estimate or assessment of performance in terms of lead release should be based on corrosion and lead control theory, results from case studies in the literature, data from similar systems, or when available, results from pipe loop testing or partial system testing. Information provided in Chapters 2 and 3 in the Guidance Document provide detailed information on corrosion and metal release control theory which can be used to identify suitable alternatives and to assess their impact on controlling metal release.

An assessment of implementation issues, secondary impacts, operations and maintenance issues, and life-cycle costs should also be included. Suggested factors to consider are identified in Chapters 5, 6, 7 and 8 of the Guidance Document.

A worked example is provided in Appendix F and an additional example is included in section 5.4.

9.8 Preferred Measure(s) Selected, with Rationale

In this section of the Corrosion Control Plan the alternative measures for lead control are systematically evaluated and the preferred measure is identified. The following list of information provides some suggestions for the type of content to include in this evaluation although this will be customized to each unique system:

- Main categories of evaluation criteria (e.g., corrosion and metal release control performance, implementation, secondary impacts, operations and maintenance, customer acceptance, and life-cycle costs)

- Subcategories of evaluation criteria and basis of application in the evaluation (be specific and quantitative)
- Prioritization or weighting of evaluation factors
- Summary of each alternative measure included in the evaluation, with each measure defined by the treatment objective and choice of chemical agent(s)
- Results from the application of the evaluation factor to each alternative
- Discussion of results
- Recommendation for the preferred measure(s)

A worked example is provided in Appendix F.

9.9 Public Communication and Stakeholder Consultation

Although a formal public and stakeholder consultation process is not required, it may be helpful to advise potentially affected users. The outcome from the evaluation of alternatives may be influenced by user input: for example, some industrial users may have concerns with the use of a silicate based inhibitor. Similarly, the implementation schedule may be affected by the impact on industrial users who may need to make modifications to their own equipment and processes to accommodate treated water adjusted for corrosion control.

Some corrosion control measures may require changes at the water treatment plant that could increase the occurrence of other regulated contaminants. Consultation with the local Medical Officer of Health may indicate the priorities suitable for a given system. For example, the addition of lime may increase aluminum levels in treated water. If sodium hydroxide is used as an alternative to lime, aluminum levels will not be affected, however sodium levels may increase, and guidance/direction from the local Medical Officer of Health regarding tradeoffs such as this may be of assistance to the Owner and Operating Authority in the evaluation of alternative measures for corrosion control.

Opportunities for customer notification include direct mailings, websites, and bill stuffers. A direct mailing limited to sensitive users or vulnerable populations may be considered. Topics for public education will be specific to each municipality, their system, and water quality, but may include a discussion on sources of lead, implications for hot water use, or the use of partial LSL replacement to address structural integrity issues. Coordination with the local Medical Officer of Health is recommended when preparing public education materials.

9.10 Monitoring Corrosion Control Effectiveness

The purpose of section 7 in the Corrosion Control Plan is to provide to MOE the details of the monitoring plan that will be used by the Owner and Operating Authority to assess the effectiveness of corrosion control and to confirm the operating conditions for the recommended corrosion control treatment methods (see Chapter 6 for background information on monitoring tools and interpretation).

This recommendation should include:

- Water quality sampling (parameter, number of locations, frequency)
- Provisions for customer feedback and complaint tracking
- Additional laboratory studies if warranted

Although the number of sampling locations in not prescribed, the Owner and Operating Authority are expected to identify the number and location of the sampling sites in their Corrosion Control Plan. A worked example is provided in Appendix F.

9.11 Corrosion Control Plan Implementation

The implementation schedule included with the Corrosion Control Plan may include the following:

- Identification of key tasks and sequencing
- Overview of each key task to described expected outcome upon completion
- Estimated timeline to complete each task

This can be presented as either a schedule (such as a GANTT chart) or a table with key tasks and dates identified. Three examples are provided in Appendix F.

In the plan, the Owner and Operating Authority will identify corrosion control operating conditions (e.g., pH 7.0 ± 0.2), the target for chemical dosing within the plant (e.g., lime dose from a minimum of 5 mg/L to a maximum of 20 mg/L), and the target for operating conditions or residual chemical concentrations within the distribution system (e.g., maintain residuals of at least 0.5 mg/L as P across the distribution system). As reviewed in Chapter 8, these will ultimately be identified in the CofA or DWWP/Licence. The Owner will also identify corrective measures to be taken when operating targets are not met. Operating outside the range of a parameter in the plan will not constitute an adverse test result for the purposes of Schedule 16 of O. Reg. 170/03, however, the need to maintain compliance with site specific CofA or DWWP/Licence conditions will require action to restore the parameter to the operating range within a reasonable time period.

10.0 Lead Reduction Strategies

The focus of the Guidance Document for Corrosion Control Planning is on treatment-based alternatives for corrosion control. There are other methods available to reduce the levels of lead in drinking water that do not involve altering water chemistry to reduce the potential for corrosion. These include the removal of lead sources in distribution and premise plumbing systems. Although lead service lines may represent the greatest contributor to lead measured at the tap, there are other sources that may also contribute to lead levels measured at the tap. Depending on the relative contribution from these different sources and water quality conditions, a LSL replacement program alone may not be adequate. For example, there are no LSLs in the Portland, Oregon system. However this soft water is sufficiently corrosive to cause lead to be released from brass fittings and as a result, corrosion control using pH/DIC adjustment is practiced. Ultimately, the preferred measure for corrosion control or lead reduction will be determined on a case-by-case basis in the context of each system’s features and water quality.

Removing lead from the system (e.g., the replacement of LSLs owned by the municipality) may be an on-going task that is part of annual water main maintenance programs. Of interest is the impact that this has on managing lead measured at the tap as part of an overall lead control strategy. Guidance to go beyond this level of effort to remove lead – and in particular if LSL replacement is the sole strategy for lead control – is not provided in this Guidance Document. Systems that would like to evaluate the effectiveness and implementation of non-treatment methods as an alternative to the submission of a Corrosion Control Plan should make a request for regulatory relief to the Director.

In support of a request for regulatory relief, it is recommended that the Drinking Water System Owner and Operating Authority review the following information:

- Summary of community lead sampling results
- Geographical occurrence of elevated lead levels
- Overview of Drinking Water System (including pH and alkalinity data), distribution system features and pipe age and materials
- Assessment of the source of lead that is contributing to lead levels measured at the tap
- Results from lead sampling at premise plumbing before and after lead service line replacement
    - Indicate whether or not the lead service line was partially or fully replaced

  - Identify the percentage of lead service line replaced relative to the total length of service line (municipal owned and privately owned), where a partial replacement was undertaken
  - Indicate the lapsed time between LSL replacement and sample collection

- Estimated number of lead services lines in the system, with distinction made for those owned by the municipality and those that are privately owned

- Summary of current lead reduction strategies, including:

  - Number of LSLs (private and municipal) replaced per year
  - Estimated years to replace all LSLs owned by the Drinking Water System Owner
  - Public outreach and customer acceptance
  - Programs to encourage homeowners to replace the private portion of the LSL

- Interim strategies to protect vulnerable populations from lead exposure and summary of how the vulnerable or sensitive populations will be identified

The Owner should be prepared to provide the Director with the rationale for why a treatment-based approach for corrosion control would not be feasible for their unique system. This rationale can include references to other municipalities with similar water quality and/or features.

If LSL replacement is granted as an alternative to corrosion control planning for lead control, and if results from subsequent regulatory sampling per Schedule 15.1-1 (4) indicate that more than 10 percent of samples in two of three sampling rounds are greater than 10 µg/L, it may be necessary to revisit the Corrosion Control Plan. It is well documented in the literature that lead levels following a partial LSL replacement may be lower than before replacement, may be no different than before replacement, or may be higher than before replacement. The magnitude of the benefits observed will depend on the relative portion of the service line owned by the municipality versus the homeowner, and whether or not lead is present in the soluble or particulate form. Replacement of lead services is complicated by the observation that it may elevate lead levels in the short term, likely due to physical and hydraulic disturbance of the pipe causing particulate lead to be released (Britton and Richards, 1981; Breach et al, 1991; Hulsmann, 1990; AwwaRF, 1990; Wysock et al, 1991; Wysock et al, 1992; Boyd et al, 2004, Swertfeger et al 2006). How long these elevated lead levels will persist is likely to be site specific, dependent on the materials and water quality at each site and the amount of disturbance during replacement. As a result, the Director may impose terms and conditions in the system's CofA or DWWP/Licence to address requirements for lead reduction and monitoring of performance.

A proposed schedule and sequence of tasks in support of seeking regulatory relief from Schedule 15.1 is presented in Table 10-1.

Table 10-1: Sequence of Components of an Implementation Plan

Tool	Application	Comment
Preparation for request for regulatory relief	Prepare background information in advance of meeting with MOE	
Desk-top study	Document features of lead reduction plan - estimated impact on lead release - proposed timelines for 100 percent replacement	
Field sampling	Document benefits of lead reduction strategy on lead levels measured at the tap	This may be conducted as part of preparation efforts
Public outreach	Describe public education campaign Identify vulnerable populations	
Implementation and contingency planning	Identify the potential risks of implementation and generate remedial or control measures, such as the provision of point-of-use filter devices to at risk users in consultation with the Health Department	
Post-implementation monitoring	Assess the effectiveness of the lead reduction strategy	Monitoring parameters and frequency may be included in the Owner's CofA or DWWP/Licence

Implications for approval are described in section 8.3.4. The mandatory forms and minimum requirements for the Corrosion Control Plan were described in Chapter 9. As the Notice of Submission (Appendix C-1) does not make reference to the approach for corrosion control, municipalities that are pursuing a lead reduction strategy can use this form without customizing it for lead reduction. The checklist (Appendix C-2) is specific to those systems that are using treatment-based corrosion control. A detailed example of the type of information that can be used in discussions with the Director is presented in Appendix F based on the experience of the City of Guelph. Consistent with previous discussions, those municipalities that want to pursue lead reduction should consult the Director to confirm information needs when seeking regulatory relief.

Glossary

Alkalinity – measure of a water's ability to neutralize acid; generally made up of bicarbonate, carbonate, and hydroxide ions

Anode – location(s) where metal corrodes and goes into solution

Buffer Intensity – resistance of a solution to pH change when a strong acid or strong base is added

Cathode – location(s) where metal deposition occurs

Corrosion – in the context of drinking water distribution, corrosion is the deterioration and leaching of corrosion by-products (e.g., lead, copper, zinc) from a pipe surface as a result of its reaction with the aquatic environment

Corrosion By-products – metals and metal complexes that are formed due to corrosion

Corrosion Cell – in order for corrosion to occur, an electrochemical corrosion cell must be present that contains the following components:

1. An anode
2. A cathode
3. An electrolyte solution (the water), which is in contact with both the anode and the cathode and provides a path for flow of ions (OH^-), and
4. An internal circuit (the pipe), which provides the electrical connection between the anode and the cathode, allowing electrons (e^-) to flow between them

Desk-top Studies – evaluations of corrosion control and lead release that use current and historical information on water quality, treatment, materials in distribution and premise piping systems, literature reviews, analogous systems, and customer input

Dissolved Inorganic Carbonate – estimate of the total carbonates in water in the form of carbon dioxide gas (CO_2, H_2CO_3), bicarbonate ion (HCO_3^-), and carbonate ion (CO_3^{2-})

Distribution Sample – water sample obtained from the Drinking Water System's distribution system or in plumbing that is connected to the Drinking Water System, from a point significantly beyond the point at which drinking water enters the distribution system or plumbing (per O. Reg. 170/03)

Erosion Corrosion – a type of corrosion that occurs due to high velocity flow or changes in flow direction in the distribution system

First Draw Sample (First Flush Sample) – the first flush of water sample is taken from the drinking water tap first thing in the morning before water has been used anywhere in the house (including flushing of toilets); under the US EPA's Lead and Copper Rule, the first draw sample is collected after a minimum stagnation period of six hours

Flushed Sample – a sample taken after prolonged flushing of the tap (at least three plumbing volumes)

Galvanic corrosion – type of corrosion which occurs when two different types of metal or alloys (such as lead and copper) contact each other and the elements of a corrosion cell are present. In this case, one of the metals serves as the anode and deteriorates, while the other serves as the cathode

Hardness – caused by multivalent cations such as calcium, magnesium, manganese, ferrous iron, and strontium and the anions associated with the metallic ions such as carbonate hardness and non-carbonate hardness (e.g., sulphate, chloride and nitrate)

Ionic Strength – a measure of the electrical potential of a solution used to represent the intensity of the "electric field" in a solution

Internal Corrosion – an electrochemical process to refer to corrosion on the inside of the pipe wall due to water chemistry conditions; also referred to as aqueous corrosion

Lead-Free – varies by jurisdiction, but typically refers to solder having less than 0.2 percent lead and pipe components having less than 8 percent lead

Non-Lead – varies by jurisdiction, but typically refers to components made of alloys with no lead added, i.e., containing less than 0.25 percent lead

Non-Residential Plumbing – plumbing that does not serve private residents

Particulate Lead – used to refer to lead available in the solid phase; total lead is the sum of soluble lead and particulate lead

pE – measure of available electrons in solution, calculated as the negative log of electron activity

pH – measure of the available protons in solution, calculated as the negative log of hydrogen ion concentration; a solution with pH from 0 to 7 is acidic, pH 7 is neutral, and from pH 7 to 14 is alkaline or basic

pH Stability – water in which pH fluctuation as it travels across the distribution system is maintained to within 0.5 pH units

Residential Plumbing – plumbing that serves private residents

Service Line – piping that connects the water main to premise plumbing

Soluble Lead – used to refer to lead available in the aqueous phase; total lead is the sum of soluble lead and particulate lead

Stagnation Period – time during which no water flows through the premise plumbing, allowing water to be in contact with the pipe wall for a set time period

Standing Sample – after prolonged flushing of the tap, water is allowed to stand in the plumbing system for a defined period (often 30 minutes), after which a sample is taken without flushing the pipe beforehand

Subsequent System – where a Drinking Water System receives potable water from another Drinking Water System

Tap Sample – water sample obtained from a tap (e.g., kitchen) within premise plumbing

Tuberculation – process in which corrosion by-products build up at the anode near the pit

Uniform Corrosion – corrosion that occurs when anodic and cathodic sites shift across the surface of the material, resulting in a relatively uniform rate of metal loss

Acronyms

AC	Asbestos Cement
AWWA	American Water Works Association
AwwaRF	American Water Works Association Research Foundation
BDL	Below Detection Limit
CofA	Certificate of Approval
CSMR	Chloride-to-Sulphate-Mass Ratio
DBP	Disinfection by-product
DIC	Dissolved Inorganic Carbon(ate)
DWWP	Drinking Water Works Permit
EDS	Energy Dispersion Spectroscopy
HAA	Haloacetic Acid
HPC	Heterotrophic Plate Count
ICP-MS	Inductively coupled plasma mass spectroscopy
LMRS	Large Municipal Residential System
LSI	Langelier Saturation Index
LSL	Lead Service Line
MAC	Maximum Acceptable Concentration
MIC	Microbiologically Induced Corrosion
MOE	Ministry of the Environment (Ontario)
MOH	Ministry of Health
MWRA	Massachusetts Water Resources Authority
ODWQS	Ontario Drinking Water Quality Standards

ORP	Oxidation Reduction Potential
PVC	Polyvinyl Chloride
RTW	Rothberg, Tamburini and Winsor
SDWA	Safe Drinking Water Act
TBD	To Be Determined
TDS	Total Dissolved Solids
THM	Trihalomethane
US EPA	United States of America Environmental Protection Agency
uPVC	Unplasticized Polyvinyl Chloride
VOC	Volatile Organic Compound
XRD	X-ray Diffraction

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6530e Flushing and Testing for Lead
6338e Flushing Your Plumbing
6339e Sampling for Lead
6966e Information for Property Owners about Lead Service Line Replacement
6610e Guide to Filling Out a Request for Regulatory Relief from Lead Sampling Requirements in Schedule 15.1 of Regulation 170/03, Safe Drinking Water Act
6560e Taking Samples for the Community Lead Testing Program

http://www.ontario.ca/ONT/portal51/drinkingwater/General?docId=177443&lang=en

Frequently Asked Questions: http://www.ontario.ca/drinkingwater/180526.pdf

Community Lead Testing Overview of Timing and Requirements:
http://www.ontario.ca/drinkingwater/250854.pdf

Tips for Recruiting Volunteer Households:
http://www.ontario.ca/drinkingwater/250855.pdf

What Municipalities Need to Know about Reducing Lead in Drinking Water Through Corrosion Control: http://www.ontario.ca/drinkingwater/254372.pdf and http://www.e-laws.gov.on.ca/html/regs/english/elaws_regs_030170_e.htm#BK151

Summary of ODWAC Drinking Water Control Measures and Lead: http://www.odwac.gov.on.ca/standards_review/corrosion_control.htm

TABLE OF CONTENTS

Introduction to Appendices

The following appendices provide information that can be used by municipalities in developing and submitting their Corrosion Control Plan. **Appendix A** contains tables to convert alkalinity to dissolved inorganic carbonate (DIC) and several diagrams based on the theory of lead solubility. These diagrams can be used when developing an understanding of water quality impacts on release of lead to water and selecting alternative measures for reducing lead levels. The intent was to provide this information in one location, however additional diagrams and graphs of these relationships can be found in the literature references which are provided at the end of this Guidance Document.

Appendix B contains treatment flow charts that have been adapted from the US EPA guidance document for the Lead and Copper Rule, titled "Revised Guidance Manual for Selecting Lead and Copper Control Strategies" (US EPA, 2003). They provide a tool for identifying treatment options for lead control based on water quality conditions.

Appendix C contains two of the required forms that must be submitted to the Ministry of Environment. Appendix C-1 contains the "**Notice of Submission of Corrosion Control Plan**", which must be submitted by all municipalities that are required to submit a Corrosion Control Plan. Appendix C-2 contains the "**Checklist for the Corrosion Control Plan**", which must be submitted by all municipalities that serve more than 1,000 people.

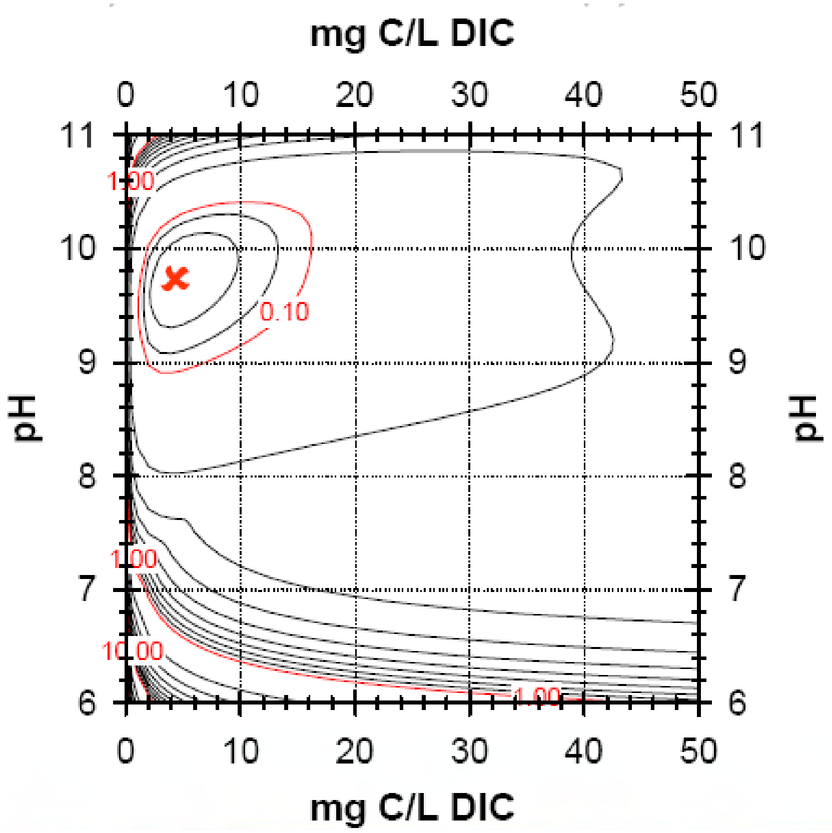
Appendix D contains the "**Corrosion Control Plan Treatment Recommendations Form for Systems Serving Less Than or Equal to 1,000 People**". This form should be submitted by all systems that serve less than or equal to 1,000 people that are required to submit a Corrosion Control Plan per Schedule 15.1, and can be submitted in lieu of a written Corrosion Control Plan.

Appendix E contains the suggested Table of Contents and format for Corrosion Control Plans for systems that serve more than 1,000 people and are required to submit a Corrosion Control Plan**.**

Appendix F provides several worked examples of the elements of the Corrosion Control Plan.

Appendix A: Diagrams and DIC Conversion Tables

Figure A-1: Theoretical Lead Solubility Curve Versus pH and DIC (M.R. Schock, 2005; provided by author)*



* Contour lines represent mg/L Pb in log scale. For example, from 1.00 to 0.10 in units of 0.1 (0.2, 0 .3, 0 .4 etc.), and from 10 to 1 in units of 1.0 (1.0, 2.0, 3.0, etc.). See section 3.2 of Guidance Document.

Figure A-2: Effect of DIC on Pb Assuming both Cerussite and Hydrocerussite (M.R. Schock, 2009; provided by author)

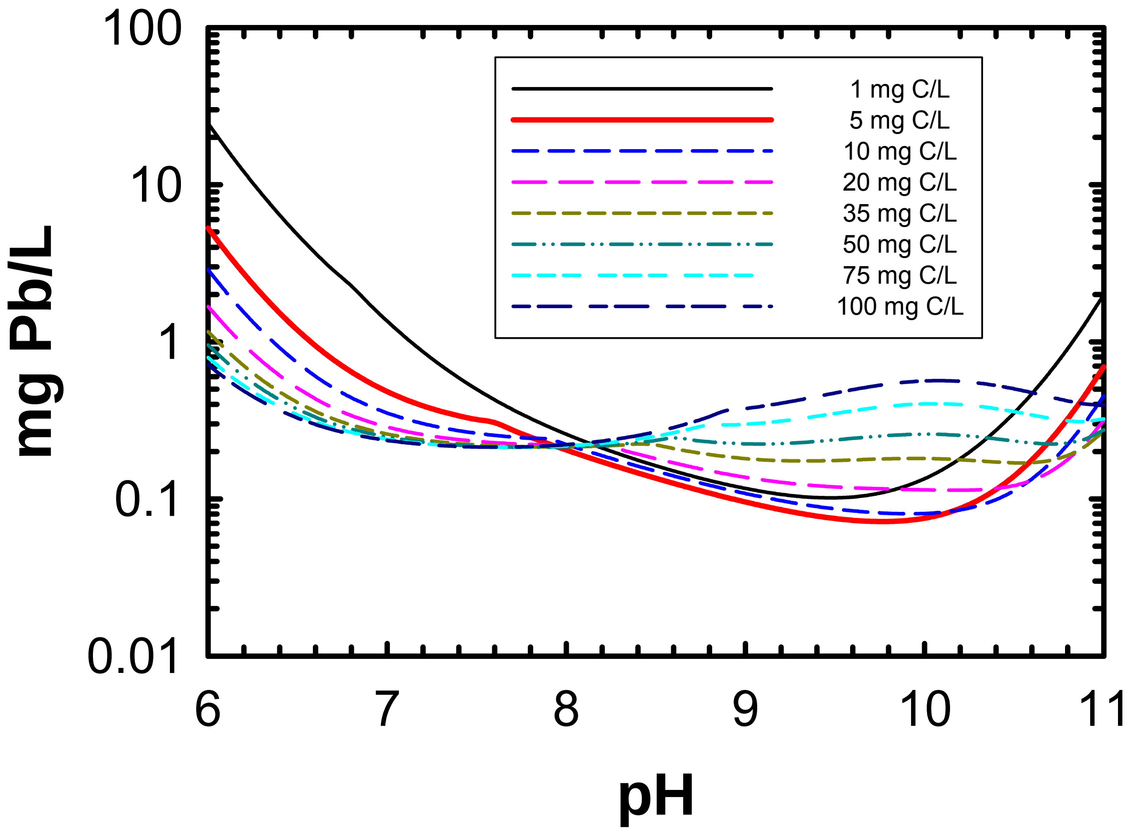
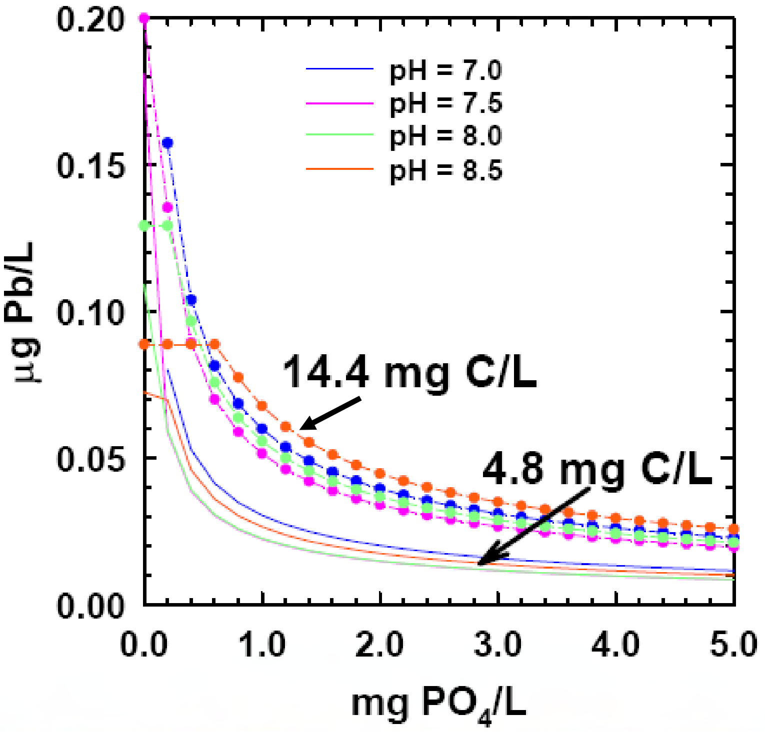
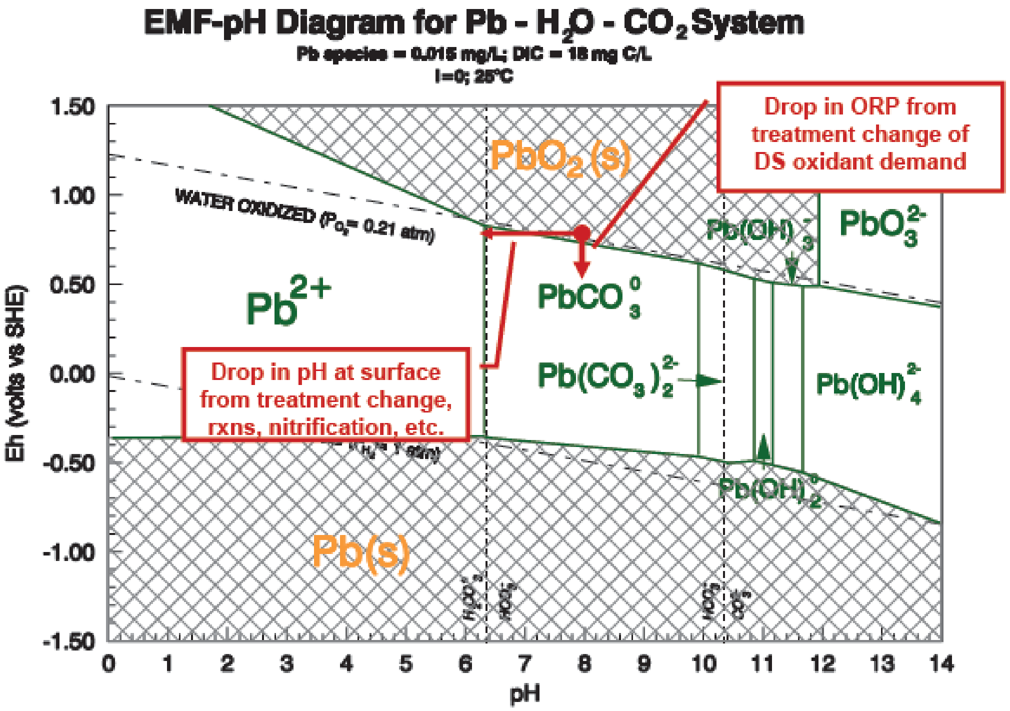


Figure A-3: Theoretical Lead Solubility versus Orthophosphate and pH (M.R. Schock, 2005; provided by author)*



* Dotted lines represent 14.4 mg C/L; smooth lines represent 4.8 mg C/L. See section 3.2 of Guidance Document.

Figure A-4: EMF/pH Diagram (M.R. Schock, 2007; provided by author)



* See sections 4.3 and 7.2 of the Guidance Document for explanation of the use of this diagram.

Table A-1: Estimated DIC as a Function of pH and Alkalinity (Adapted from US EPA, 2003)

Alkalinity	**pH**									
(as $CaCO_3$)	**6.8**	**7.0**	**7.2**	**7.6**	**7.8**	**8.0**	**8.4**	**8.8**	**9.0**	**9.2**
5	2	1	1	1	1	1	1	1	1	1
10	3	3	3	3	2	2	2	2	2	2
25	8	7	7	6	6	6	6	6	6	6
45	15	13	12	11	11	11	11	11	11	10
65	22	19	18	17	16	16	16	15	15	15
100	33	30	28	25	25	24	24	23	23	22
150	50	45	41	38	37	37	36	35	35	34
200	66	60	55	51	50	49	48	47	46	45
260	87	78	73	65	64	63	62	61	61	58
300	100	90	84	75	74	73	72	70	70	67
360	120	108	100	91	89	88	86	84	84	81
400	133	120	112	101	98	98	96	93	93	90

Appendix B: Flowcharts

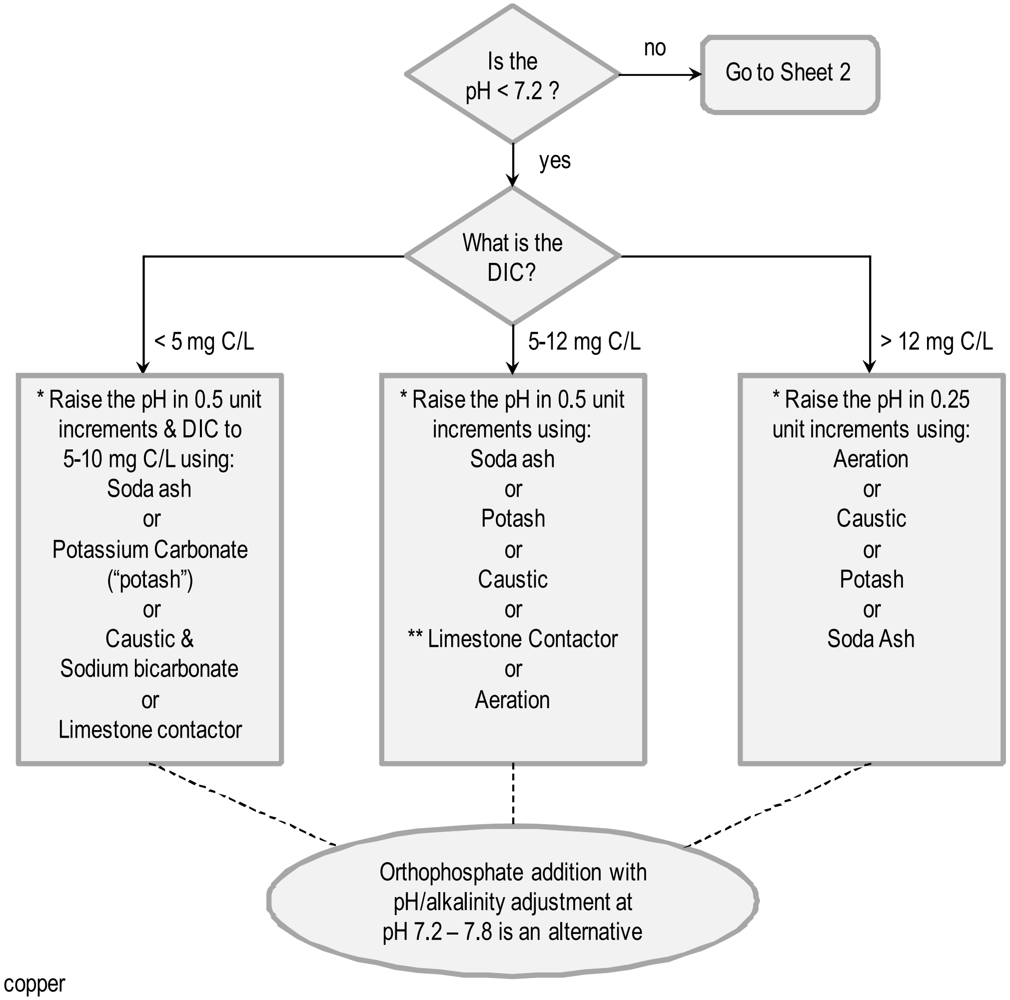
Figures B-1 – B-3: Flowcharts for Systems Exceeding Lead Levels per Schedule 15.1 Ontario Regulation 170/03

Figures B-4 – B-7: Flowcharts for Systems Exceeding Lead Levels per Schedule 15.1 Ontario Regulation 170/03 and Have Raw Water Iron or Manganese

Figure B-8: Flowchart for Limestone Contactor Feasibility Tree

Figure B-1: (Adapted from US EPA, 2003)

Sheet 1: Exceeded Lead Levels per Schedule 15.1: Ontario Regulation 170/03

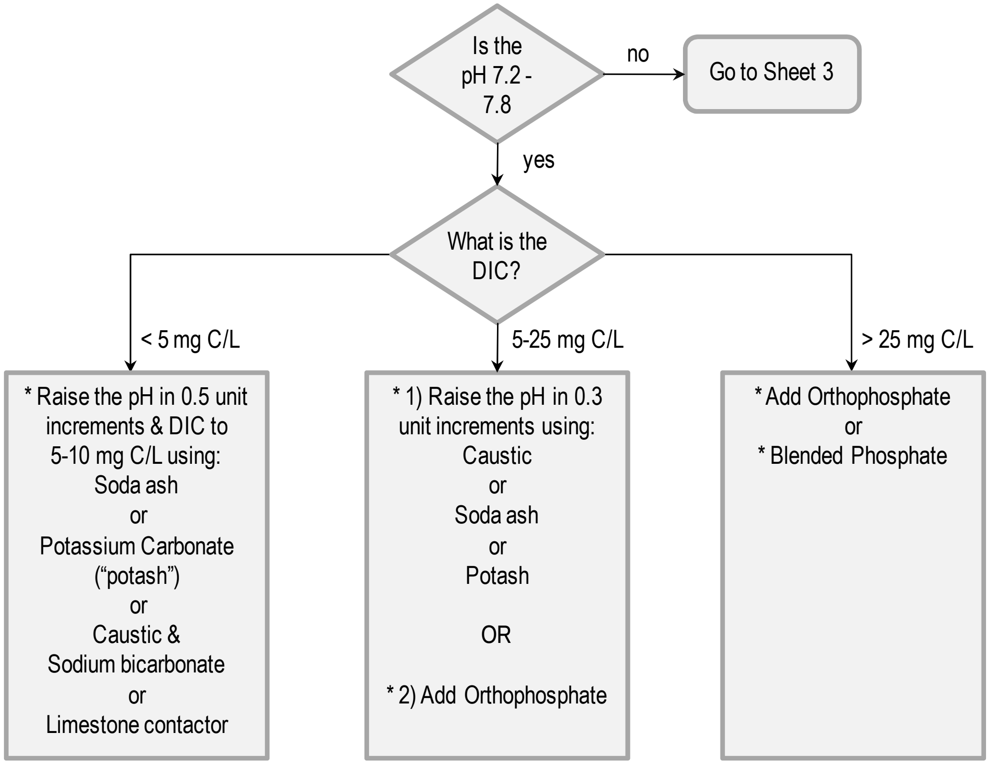


* Also beneficial for copper

** May be more appropriate if copper is not a problem (higher copper levels may result with higher DIC from use of limestone contactor)

Figure B-2: (Adapted from US EPA, 2003)

Sheet 2: Exceeded Lead Levels per Schedule 15.1: Ontario Regulation 170/03

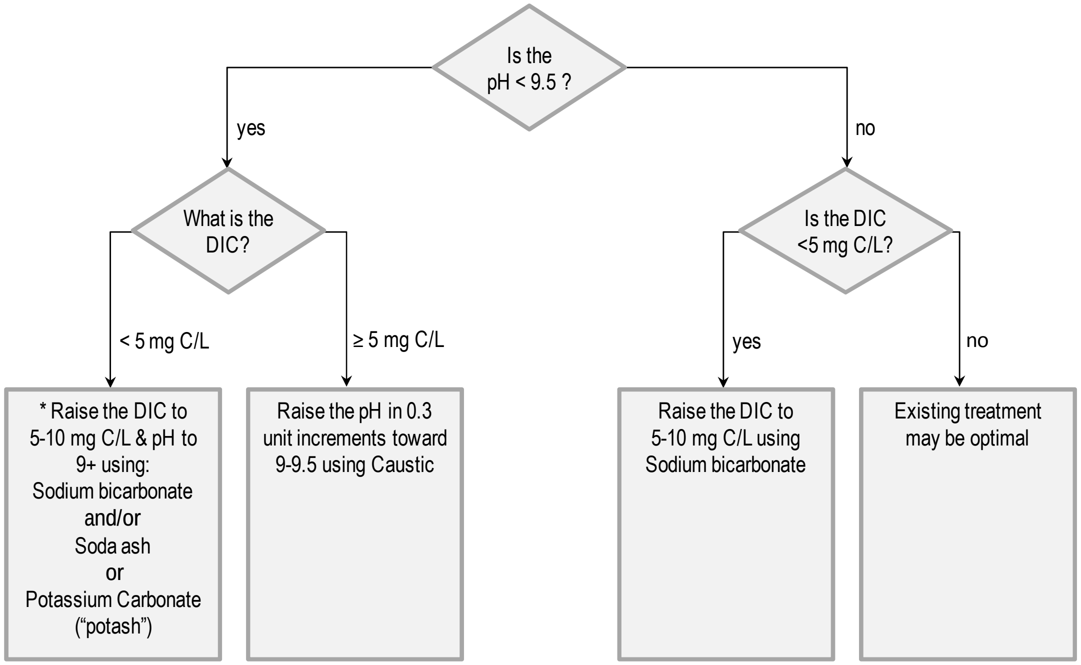


* Also beneficial for copper

** Initial dose should be > 0.5 mg/L orthophosphate as P either orthophosphate or blend

Figure B-3: (Adapted from US EPA, 2003)

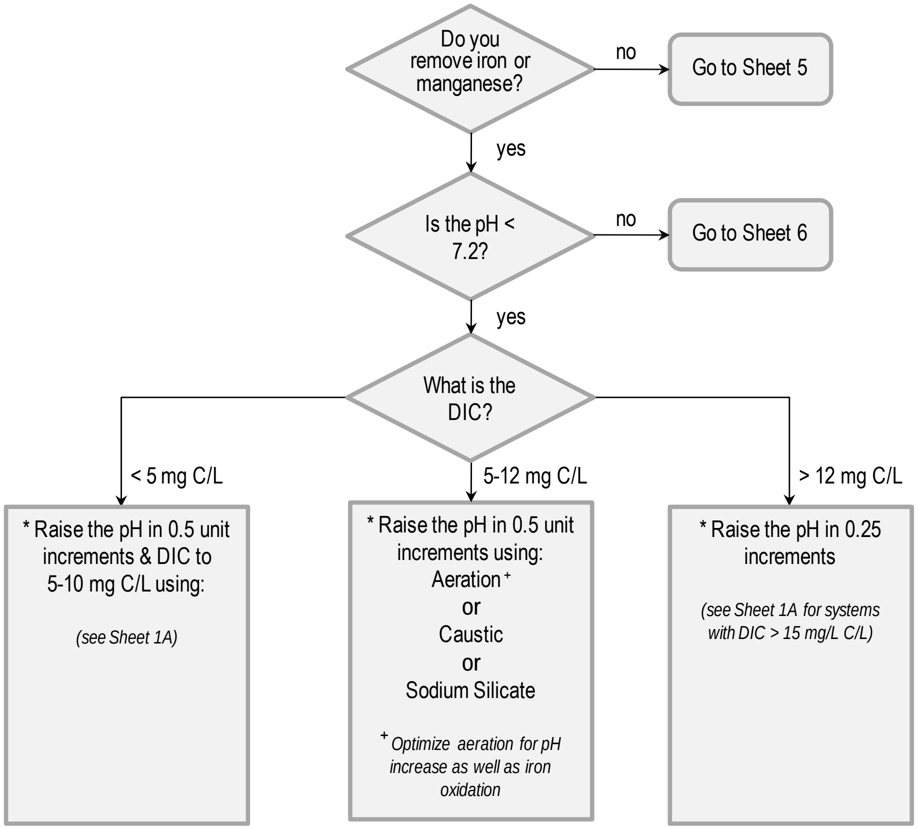
Sheet 3: Exceeded Lead Levels per Schedule 15.1: Ontario Regulation 170/03



* Also beneficial for copper

Figure B-4: (Adapted from US EPA, 2003)

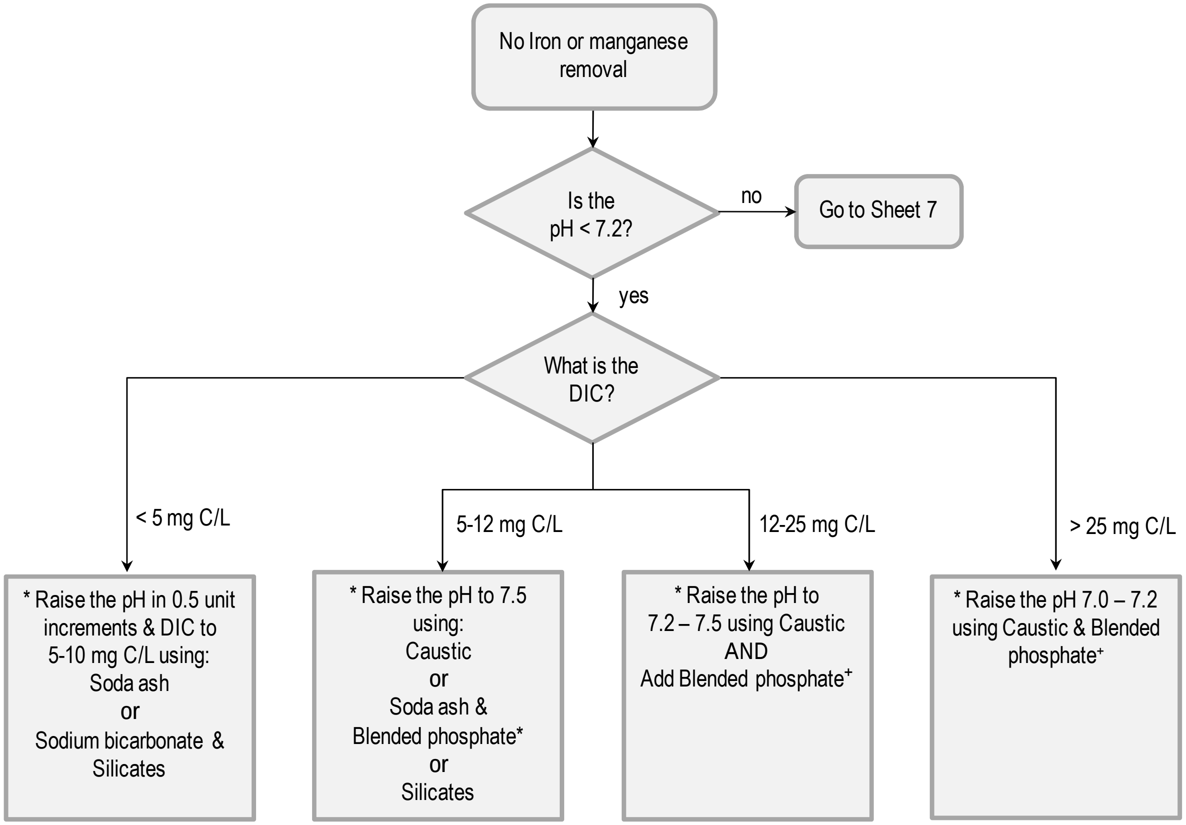
Sheet 4: Exceeded Lead Levels per Schedule 15.1: Ontario Regulation 170/03
and Have Raw Water Iron or Manganese



* Also beneficial for copper

Figure B-5: (Adapted from US EPA, 2003)

Sheet 5: Exceeded Lead Levels per Schedule 15.1: Ontario Regulation 170/03
and Have Raw Water Iron or Manganese

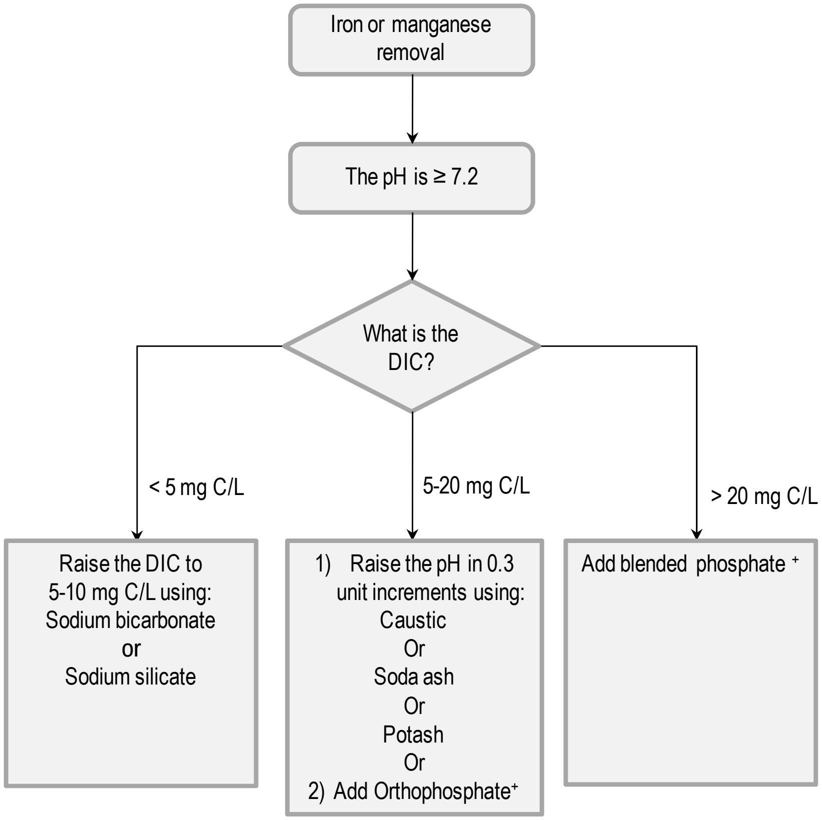


* Also beneficial for copper

⁺ The blend should provide a minimum of 0.5 mg/L orthophosphate as P.

Figure B-6: (Adapted from US EPA, 2003)

Sheet 6: Exceeded Lead Levels per Schedule 15.1: Ontario Regulation 170/03
and Have Raw Water Iron or Manganese

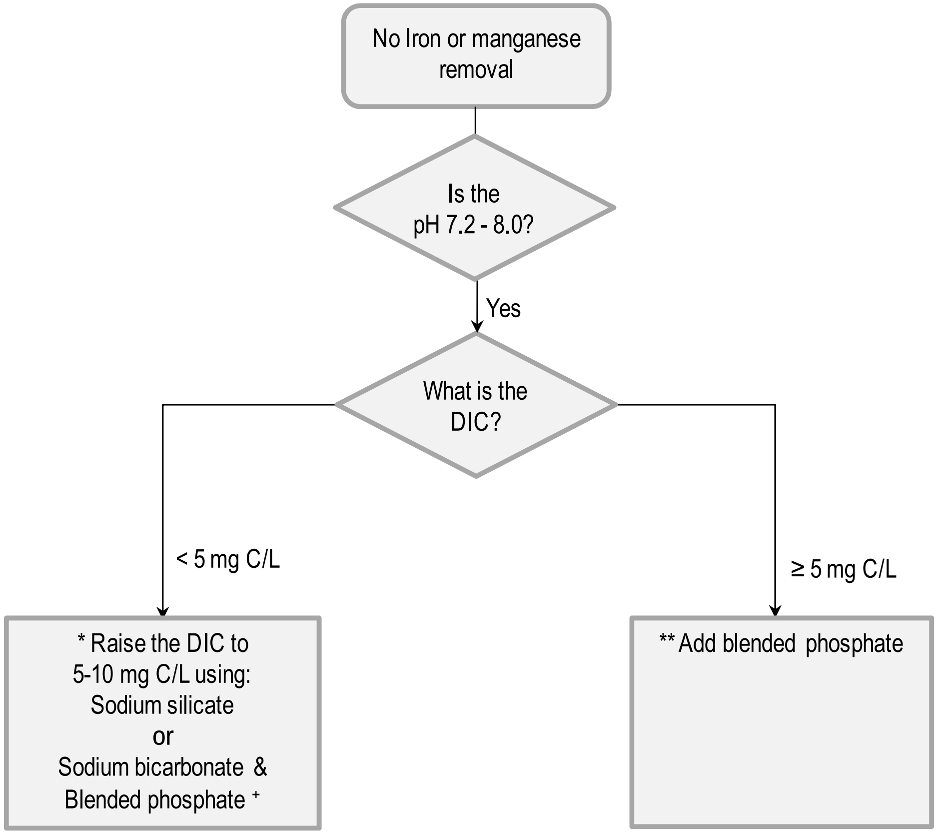


*Also beneficial for copper

+The blend should provide a minimum of 0.5 mg/L orthophosphate as P.

Figure B-7: (Adapted from US EPA, 2003)

Sheet 7: Exceeded Lead Levels per Schedule 15.1: Ontario Regulation 170/03 and Have Raw Water Iron or Manganese

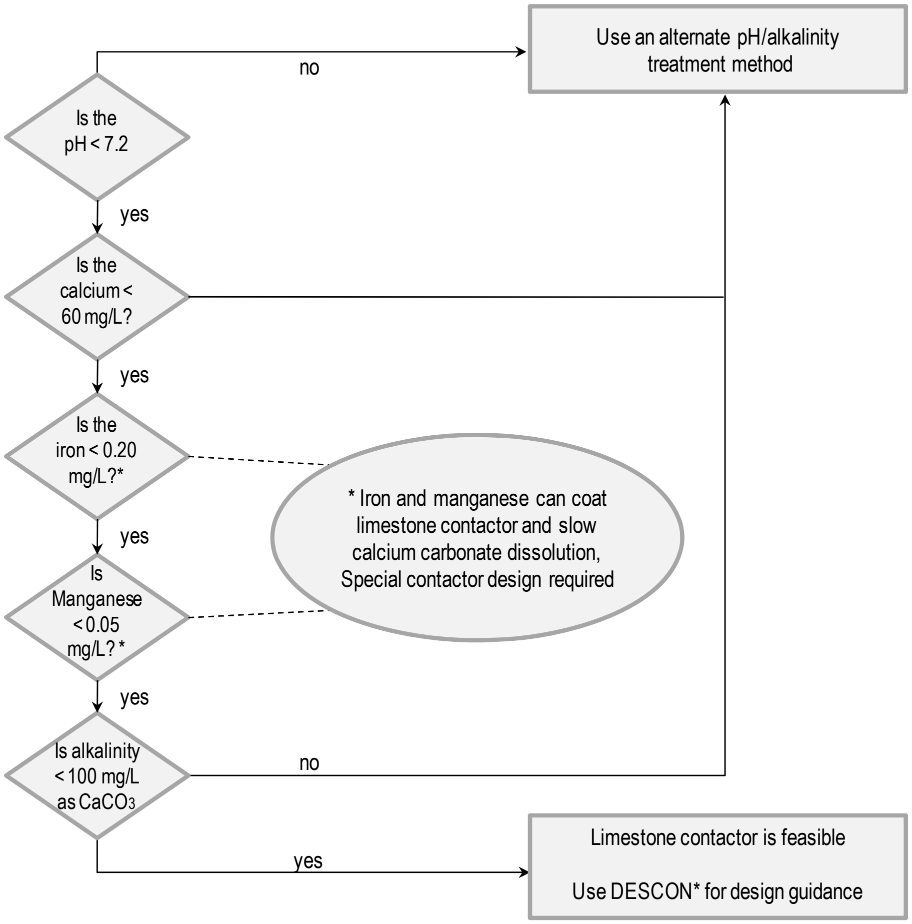


* Also beneficial for copper

** The blend should provide a minimum of 0.5 mg/L orthophosphate as P.

Figure B-8: (Adapted from US EPA, 2003)

Sheet 8: Limestone Contactor Feasibility Tree



***** Letterman, R.D. and Kothari, S (1995). "Instructions for using DESCON: A computer program for the design of limestone contactor". *Prepared as part of Cooperative Agreement No. 814926*

Appendix C: Notice of Submission of Corrosion Control Plans and Checklist for the Corrosion Control Plan

C-1: Notice of Submission of Corrosion Control Plan

C-2: Checklist for the Corrosion Control Plan (for Systems with More than 1,000 People)

The mandatory submission requirements were identified previously in Chapter 9 of the Guidance Document, and are repeated here to:

1. Clarify the mandatory submission requirements for Corrosion Control Plans, and

2. Identify the minimum content requirements for Corrosion Control Plans that are submitted.

The mandatory submission requirements are identified in Table C-1. All systems must submit the **Notice of Submission**, which is found in Appendix C-1. Systems that serve less than or equal to 1,000 people will submit the "**Corrosion Control Plan Treatment Recommendations Form for Systems with Less Than or Equal to 1,000 People**". Systems that serve more than 1,000 people will submit the "**Checklist for the Corrosion Control Plan**" (Appendix C-2) and a **Corrosion Control Plan**. The minimum requirements of the Corrosion Control Plan are described in Table C-2 consistent with the Regulation. These requirements are discussed in more detail below.

Table C-1: Overview of Mandatory Submission Requirements

Mandatory Submission Requirement	Systems with ≤ 1,000 People	Systems with > 1,000 People
Notice of Submission (Appendix C-1)	✓	✓
Checklist for the Corrosion Control Plan (Appendix C-2)	Not mandatory	✓
Corrosion Control Plan Treatment Recommendations Form for Systems with Less Than or Equal to 1,000 People (Appendix D)	✓	Optional
Corrosion Control Plan	Not mandatory	✓

The "**Notice of Submission"** (Appendix C-1) is a mandatory submission form that must be included in every Corrosion Control Plan. The Notice of Submission identifies the municipality's name and contact information. Where the Owner is not the Operating Authority of the Drinking Water System, both the Owner and the Operating Authority must sign the Notice of Submission. Where an Owner supplies a subsequent system or downstream user with water, and if that subsequent system is also required to submit a Corrosion Control Plan, both the Owner and the subsequent user must sign the Notice of Submission.

The "**Checklist for the Corrosion Control Plan**" (Appendix C-2) must be completed and submitted with the Corrosion Control Plan by systems serving more than 1,000 people. It is expected that the site specific needs of each municipality will result in each municipality following their own path to develop their Corrosion Control Plan, and equally expected that the outcome of the Corrosion Control Plan will be unique to each municipality. The purpose of the Checklist is two-fold:

1. It provides a road map to help municipalities develop their Corrosion Control Plan and the necessary content, and
2. It streamlines the review process undertaken by MOE to indicate what content is provided in each Corrosion Control Plan

For systems that serve less than or equal to 1,000 people, the "**Corrosion Control Plan Treatment Recommendations Form for Systems with Less Than or Equal to 1,000 People**" (Appendix D) can be submitted in lieu of the Checklist (Appendix C-2). The Corrosion Control Plan Treatment Recommendations Form for Systems with Less Than or Equal to 1,000 People provides a series of tables for the Owner to complete. The tables of Appendix D follow the requirements of the Checklist, and as a result, systems with less than or equal to 1,000 people need only submit Appendix D.

For systems serving more than 1,000 people, the Checklist can be used to identify the content required for the Corrosion Control Plan. At a minimum, all systems serving greater than 1,000 people must include a desk-top study as part of their Corrosion Control Plan. The following items must be included in the desk-top study:

- Notice of Submission
- Checklist
- Executive Summary
- Introduction and System Description
- Identification of Internal Corrosion Problems and Sources
- Assessment of the Significance of Contaminants and Sources
- Identification of Alternative Corrosion Control Measures and their Impacts (this is based on a review of analogous systems, literature reviews; this does not necessarily include pipe loop testing or other field work)
- Identification of Preferred Measure for Corrosion Control
- Public Notification and Stakeholder Consultation
- Monitoring Corrosion Control Effectiveness (this is the post-implementation monitoring plan)
- Corrosion Control Plan Implementation (this is the plan and schedule for implementation)

Voluntary field work and pipe loop testing are considered beyond the requirements of a desk-top study, and may in fact be a recommendation as part of the implementation plan. If a municipality has conducted a pipe loop study or voluntary field work either before or as part of the development of the Corrosion Control Plan, then these results should be included in the Corrosion Control Plan. There is a place on the Checklist to identify optional items completed or tasks undertaken (e.g., pipe loop testing) as part of corrosion control planning to alert the MOE reviewer.

The minimum requirements of the Corrosion Control Plan are described in Table C-2 consistent with the Regulation. Chapters 1 through 9 of the guidance document provide more explanation of the contents identified in Table C-2. Appendix E contains the suggested format for a Table of Contents for a Corrosion Control Plan that follows the sequence of content of the Checklist.

Where there is any conflict between the Corrosion Control Plan requirements in this Guidance Document and the requirements in Ontario Regulation 170/03: Drinking Water Systems, Schedule 15.1-11 Corrosion Control, the requirements in the Regulation will take precedence.

Table C-2: Summary of Minimum Requirements for Corrosion Control Plan

Corrosion Control Plan Chapter	Minimum Requirements	See…
Executive Summary	Overview of the Corrosion Control Plan and preferred measure for corrosion control.	This Document 9.2
Introduction and Drinking Water System description	The system description should be provided in adequate detail to select and justify the preferred corrosion control measure.	This Document 9.3
Identification of internal corrosion problems and sources of contamination	Provide details to identify the source and significance of corrosion and geographical extent of corrosion occurrence (map). Review water quality in source, treated, and distribution system water. Identify materials of construction used in the distribution system and premise plumbing.	This Document 9.4 Chapter 2 Regulation 15.1-11 (5) (a)
Assessment of the significance of contaminants and sources	Assess the significance of sources and contaminants and eliminate negligible ones from further analysis. The Corrosion Control Plan must provide an explanation of how it was determined that an amount of a contaminant is negligible. The source summary table is used to identify the potential corrosion by-products for which control is necessary and the sources of contamination should be identified. Establish baseline water quality conditions that will be used to develop alternatives measures for control.	This Document 9.5 Regulation 15.1-11 (5) (a)

Corrosion Control Plan Chapter	Minimum Requirements	See…
Identification of alternative corrosion control measures and their impacts	Identify alternative measures for corrosion control and the conditions for application. For each alternative measure for corrosion control, identify the treatment objectives, rationale for consideration, and expected performance. Describe the impacts of the alternative corrosion control measures in terms of reducing corrosion, secondary impacts, and life-cycle costs.	This Document 9.6, 9.7 Chapters 3, 4 Regulation 15.1-11 (5) (b)
Preferred measure(s) selected, with rationale	Identify the preferred measure(s) for corrosion control, including treatment objectives and operating procedures. Provide the rationale or justification of the selection of the preferred measure.	This Document 9.8 Chapter 5 Regulation 15.1-11 (5) (c)
Public notification and stakeholder consultation undertaken	Describe public notification and stakeholder consultation, including with industrial users and health care providers.	This Document 9.9
Monitoring corrosion control effectiveness	Provide details of the monitoring plan that will be used to assess the effectiveness of corrosion control and to confirm the operating procedures or conditions.	This Document 9.10 Chapter 6 Regulation 15.1-11 (5) (e)
Corrosion control plan implementation	Describe the features of the implementation schedule, including key tasks, timelines, and expected outcomes for each task. Include a review of risks of implementation and contingency planning.	This Document 9.11 Chapter 8 Regulation 15.1-11 (5) (d)
Appendices	Explanation of the identification of insignificant sources and contaminants, supporting calculations, and other associated materials.	This Document 9.12

C-1: Notice of Submission of Corrosion Control Plan

Owner Name: ______________________________

Address: ______________________________

System Name: ______________________ DWIS No: __________

The attached Corrosion Control Plan was prepared in accordance with the guidance in the MOE document "Guidance Document for Preparing Corrosion Control Plans for Drinking Water Systems" Final Draft dated December, 2009 and the minimum required information identified in the checklist has been submitted.

Owner Contact

Name:______________________________

Title:______________________________

Phone Number and E-mail Address:______________________________

Signature:______________________________

Date: ____________

Operating Authority (if different from Owner)

OA Name:______________________________

OA Contact:______________________________

Phone Number and E-mail Address:______________________________

Signature:______________________________

Date: ____________

Owner of Supplying System (if different from receiving system)

Name:____

Contact:____

Phone Number and E-mail Address:______________________________

Signature:____

Date: ________________________

Project Technical Contact

Name:____

Title:____

Phone Number and E-mail Address:______________________________

Signature:____

Date: __________________________

LIST OF ATTACHMENTS

Notice of Submission (Appendix C-1)	☐
Checklist for the Corrosion Control Plan (Appendix C-2)	☐
Corrosion Control Plan Treatment Recommendations Form for Systems with Less Than or Equal to 1,000 People (Appendix D)	☐
Corrosion Control Plan	☐

C-2: Check-List for the Corrosion Control Plan

			Check if Included in Corrosion Control Plan	**Minimum Requirements**	**Explanation/ Reference**
	Notice of Submission of Corrosion Control Plan		☐	X	
	Executive Summary				
	ES.1	Overview of System and Basis for Which Plan is Prepared	☐	X	
	ES.2	Source Summary Table	☐	X	
	ES.3	Potential for Lead Leaching	☐	X	
	ES.4	Measure(s) Identified to Reduce the Potential for Lead Leaching	☐	X	
	ES.5	Preferred Measure(s)	☐	X	
	ES.5	Summary of Implementation Schedule	☐	X	
1.0 Introduction and Drinking Water System Description					
	1.1	Source Water Supply Information and Characteristics	☐	X	Water source(s), flow, source water quality characteristics
	1.2	Treatment Facility Information and Characteristics	☐	X	Flow, unit processes, block flow drawing
	1.3	Distribution System Information and Characteristics	☐	X	Remote station locations, and areas served by each treatment plant/supply
	1.4	Summary of Lead Service Line Replacement Program (if applicable)	☐		Phasing, budget, number of full and partial lead service lines, number of replacements per year, dedicated program or as part of water main replacement
2.0 Identification of Internal Corrosion Problems and Sources of Contamination					
	2.1	Evaluation of Water Quality Parameter Monitoring Data	☐	X (Regulatory monitoring results at a minimum)	Parameters that describe corrosion and factors that affect corrosion (baseline data, regulatory data,

			Check if Included in Corrosion Control Plan	Minimum Requirements	Explanation/ Reference
					special studies)
		2.1.1 Raw Water	☐		
		2.1.2 Treated Water	☐		
		2.1.3 Distribution System	☐	(Schedule 15.1)	
		2.1.4 Premise Plumbing	☐	(Schedule 15.1)	
	2.2	Materials Survey Completed	☐	X	Distribution and service materials and extent
	2.3	Identification of Source and Extent of Lead Problem	☐	X	Geographical identification of lead use (map)
3.0 Assessment of the Significance of Contaminants and Sources					
	3.1	Source Summary Table	☐	X	Magnitude and Extent of Lead Release (see Chapter 3 of worked example in Appendix F)
	3.2	Establish Baseline Water Quality Conditions and Treatment Objectives	☐		Define pH, alkalinity, DIC in treated water and seasonal impacts. Identify treatment objectives (reductions in lead release)
	3.3	Identification of Source and Extent of Other Corrosion Problems	☐		Identify target compound(s) for corrosion control
4.0 Corrosion Control Measures and Their Impacts					
	4.1	Similar Systems Evaluated	☐	X	See list of references, conduct lit review, discussions with similar systems, etc.
	4.2	Use of Solubility Relationships to Estimate Potential Lead Release	☐	X	Appendix A solubility charts
	4.3	Flow Chart of Treatment Options	☐	X	Appendix B flow charts (adapted from US EPA, 2003)
	4.4	Summary of Laboratory or Field Testing Conducted	☐		

			Check if Included in Corrosion Control Plan	Minimum Requirements	Explanation/ Reference
		4.4.1 Profile Sampling	☐		
		4.4.2 Scale and Solids Analysis	☐		
		4.4.3 Pipe Loop Testing Profile Sampling	☐		
		4.4.4 Partial System Testing	☐		
		4.4.5 Other	☐		
	4.4	Evaluation and Identification of Corrosion Control/Metal Release Measures	☐	X	Identify corrosion control/ lead release alternatives that are being considered
	4.5	Discussion of Secondary Impacts	☐	X	
	4.6	Implementation Issues	☐		Identify your evaluation factors (Chapter 5) and secondary impacts (section 4.3)
	4.7	Operations and Maintenance Issues Identified	☐		
		4.7.1 Identification and evaluation of chemical choices for each preferred measure	☐		
	4.8	Life cycle Costs	☐		
5.0 Identification of Preferred Measure for Corrosion Control					
	5.1	Evaluation process and ranking provided	☐	X	Evaluation of preferred alternatives from Chapter 6
	5.2	Identification of preferred measure and rationale	☐		
6.0 Public Notification and Stakeholder Consultation Undertaken					
	6.1	Description of notification and consultation included	☐		Also consider subsequent systems (cases where Owner and Operating Authority are two parties, etc).

			Check if Included in Corrosion Control Plan	Minimum Requirements	Explanation/ Reference
7.0 Monitoring Corrosion Control Effectiveness					
	7.1	Identification of operating procedures and conditions	☐	X	For inclusion in the CofA or DWWP/License
	7.2	Description of monitoring plan to assess effectiveness	☐	X	Table 6-1, 6-4, in worked example (Appendix F)
8.0 Corrosion Control Plan Implementation					
	8.1	Implementation Plan	☐	X	Background in Chapter 8; Show components such as key tasks, sequence, outcome, timeline for each task See Table 8-1 and worked example in Appendix F
Appendices **(Provide supporting information as needed and fill in description of each appendix included with the Corrosion Control Plan)**					
	A		☐		
	B		☐		
	C		☐		
	D		☐		

Appendix D: Corrosion Control Plan Treatment Recommendations Form for Systems Serving Less Than or Equal to 1,000 People

Corrosion Control Plan Treatment Recommendations Form for Systems Serving Less Than or Equal to 1,000 People

The following form provides a template for systems that serve less than or equal to 1,000 people. Not all municipalities will have all the data and documentation available to fully complete this form. Where data are available but are incomplete, please provide the data that are available and the time period when the data were collected. Where data are not available, please indicate this in the table as appropriate.

1.0 INTRODUCTION AND DRINKING WATER SYSTEM DESCRIPTION (Information on source water, treatment, and distribution system materials)

Source Water

Provide typical source water quality characteristics for your system. If you have more than one source, such as multiple wells, please provide typical information for each. If source water changes seasonally, you can copy this page and provide typical information for each season as appropriate.

				Source Water Quality Characteristics							
Source Water Supply	**Name**	**Surface/ Ground**	**% of Supply**	**pH**	**Alkalinity (mg/L as $CaCO_3$)**	**TDS (mg/L)**	**Conductivity (umho/cm)**	**Ca (mg/L)**	**Hardness (mg/L as $CaCO_3$)**	**Chloride (mg/L)**	**Sulphate (mg/L)**
Source #1											
Source #2											
Source #3											
Source #4											

Date Source Water Quality Parameters were collected:____

Use space below to provide any comments about source water characteristics:

Treatment

Provide typical treated water quality characteristics for your system. If you have more than one treatment facility, please provide typical information for each.

Treatment Facilities – Production					
Treatment Facilities	Name	Source (from table above)	Rated Capacity (m^3/d)	Flow (m^3/d)	
				Avg.	Max.
Facility #1					
Facility #2					
Facility #3					
Facility #4					

Treatment Facilities – Processes (please provide a block flow diagram)										
Facility	Coagulant Used			Disinfectant Used			pH Adjustment			Other Information
	Type	Dose (and Basis)	Target pH	Type	Free or Combined	Target Residual	Chemical	Dose	Target pH	
Facility #1										
Facility #2										
Facility #3										
Facility #4										

Distribution System

Use space below to provide any comments about distribution system characteristics, such as remote station locations, areas served by each treatment facility or source water supply (attach a map if available):

Indicate information on lead service line replacement programs (if applicable) below:

Lead Service Line Replacement Program (if applicable)		
No. of Lead Service Lines in Place	**No. Partially Replaced Annually**	**No. Fully Replaced Annually**

2.0 IDENTIFICATION OF INTERNAL CORROSION PROBLEMS AND SOURCES OF CONTAMINATION (Information on source, treated, and distribution system water quality characteristics related to corrosion)

Monitoring Results

Provide monitoring results of source water quality metals levels for your system. If you have more than two raw water sources, please copy this table and provide typical information for each.

Raw Water

	Raw Water Source #1			Raw Water Source #2		
	Concentration	**Units**	**Sample Date**	**Concentration**	**Units**	**Sample Date**
Lead						
Copper						
Iron						
Manganese						

Treated Water

Provide typical treated water quality characteristics for your system from each treatment facility or point-of-entry to the distribution system. If you have more than two facilities or points of entry to the distribution system, you can copy this page and provide typical information for each, as appropriate.

	Facility #1 or 1st Point-of-entry to Distribution System		**Facility #2 or 2nd Point-of-entry to Distribution System**	
	Value	**Date**	**Value**	**Date**
pH				
Alkalinity, mg/L as $CaCO_3$				
Temperature, ^oC				
Chlorine Residual, mg/L				
Conductivity, µmhos/cm				
TDS, mg/L				
Dissolved Oxygen, mg/L				
Chloride, mg/L				
Sulphate, mg/L as SO_3				
Phosphate, mg/L as PO_4				
Silicates, mg/L as SiO_2				
Nitrite, mg/L				
Nitrate, mg/L				
Free Ammonia, mg/L				

Distribution System – Flushed Samples

Provide water quality monitoring data results from fully flushed samples collected in the distribution system. Provide the date the sample was collected. If you have more than five distribution system locations, you can copy this page and provide information for each, as appropriate.

Parameter	Location (please provide a map showing locations)									
	1		2		3		4		5	
	Value	Date	Value	Date	Value	Date	Value	Date	Value	Date
Lead, µg/L										
Copper, mg/L										
Iron, mg/L										
Manganese, mg/L										
pH										
Alkalinity, mg/L as $CaCO_3$										
Temperature, ^oC										
Chlorine residual, mg/L										
Conductivity, µmhos/cm										
Nitrite, mg/L										
Nitrate, mg/L										
Free Ammonia, mg/L										

Premise Piping – May 2007 Director's Order, if Available

Provide water quality monitoring data results from flushed samples at customer's taps in response to the May 2007 Director's Order, if available.

Flushed Samples at Customers' Taps (in response to the May 2007 Director's Order, if Available)							
Parameter	**Location (please provide a map showing locations)**						
	No. Sites	**Average**	**Min**	**Max**	**Number Above 10 µg/L**	**Analytical Method**	**Detection Limit**
Lead, µg/L	20						
pH					N/A		
Alkalinity, mg/L as $CaCO_3$					N/A		

Premise Piping – Schedule 15.1-7, O. Reg. 170/03
Provide results from flushed and standing samples collected at residential and non-residential plumbing sites per Schedule 15.1-7. Please provide map showing locations.

Flushed and Standing Samples at Residential and Non-Residential Plumbing Samples (per Schedule 15.1-7)								
Parameter			**Round 1**	**Round 2**	**Round 3**	**Round 4**	**Analytical Method**	**Detection Limit**
Flushed Tap[1]	Lead, µg/L	No. Sites						
		Average						
		Minimum						
		Maximum						
		Number Above 10 ug/L						
	pH	Average						
		Minimum						
		Maximum						
Standing Tap[2]	Lead, µg/L	No. Sites						
		Average						
		Minimum						
		Maximum						
		Number Above 10 ug/L						
	pH	Average						
		Minimum						
		Maximum						

Flushed and Standing Samples at Residential and Non-Residential Plumbing Samples (per Schedule 15.1-7)								
Parameter			**Round 1**	**Round 2**	**Round 3**	**Round 4**	**Analytical Method**	**Detection Limit**
	Alkalinity[3], mg/L as $CaCO_3$	Average						
		Minimum						
		Maximum						

Notes:

1. If available. Flushed samples measured at the tap are not required under Schedule 15.1-7. However, if a municipality has collected flushed samples at the tap (e.g., collect one sample at the tap after the five minute flush and before the 30 minute stagnation period), please record the results in this table.
2. Please provide summary data for residential and non-residential plumbing samples.
3. Measuring alkalinity at the tap is not required under Schedule 15.1-7. However, please record results if available.

Distribution System Samples – Schedule 15.1-7, O. Reg. 170/03

Provide water quality monitoring data results from flushed samples at distribution system sites, per Schedule 15.1-7. Provide map showing location.

Flushed Samples at Distribution System Sites (per Schedule 15.1-7)								
Parameter			Round 1	Round 2	Round 3	Round 4	Analytical Method	Detection Limit
Flushed Distribution System	Lead	No. Sites						
		Average						
		Minimum						
		Maximum						
	pH	Average						
		Minimum						
		Maximum						
	Alkalinity	Average						
		Minimum						
		Maximum						

Voluntary Sampling

Provide water quality monitoring data results from other voluntary sampling programs that have been completed. Please provide map showing sampling locations.

Other Samples (as Applicable)									
Sampling Program	**Parameter**	**No. Sites**	**Average**	**Min**	**Max**	**Percentage of Samples Above 10 µg/L**	**Analytical Method**	**Detection Limit**	**Sample Period**

Materials Survey

Provide the total kilometers of distribution system piping and the total number of service connections.

Total Kilometers of Distribution System Water Mains		
Size	**Material[1]**	**Kilometers**

1. Steel, concrete, ductile iron, lined or unlined, etc.

Total Number of Service Connections	
Material[1]	**Number**

1. Lead, copper, galvanized, plastic, etc.

3.0 ASSESSMENT OF SIGNIFICANCE OF CONTAMINANTS AND SOURCES

Source Summary Table

Contaminant	**Source**	**Location**	**Extent/Results**					**Significant (Y/N)**
			Number of Samples	**Average**	**Percentage > 10 µg/L**	**Min**	**Max**	

Notes for Table:

i) Source can be either water main; service line; premise plumbing

ii) Contaminant of concern: lead (primary), copper, iron (secondary)

iii) Location: identify part of service area

iv) Extent/results: summarize typical levels of contaminant measured

v) Significance: identify whether levels are considered of significance for control (lead based on regulatory levels per Schedule 15.1-7; DWSP; voluntary program)

vi) Significance: copper, iron based on aesthetic objectives and system specific considerations

4.0 IDENTIFICATION OF ALTERNATIVE CORROSION CONTROL MEASURES AND THEIR IMPACTS

Identify Corrosion Control/Metal Release Measures

Checkmarks can be placed in the appropriate row/column to indicate results of evaluation of alternative corrosion control/metal release measures. Evaluation should be based on an understanding of historical data from your system (materials, water quality, regulatory lead levels), similar systems experiences, solubility diagrams and theory. Secondary tables can be completed for other corrosion parameters of concern such as copper and/or iron.

Lead Control

Metal Release Measure	Very good	Good	Poor	Adverse
pH adjustment	☐	☐	☐	☐
pH/alkalinity adjustment	☐	☐	☐	☐
Phosphate inhibitor	☐	☐	☐	☐
Silicate inhibitor	☐	☐	☐	☐

Use space below to provide a quantified definition for the assessment above (e.g., expressed as a percent lead reduction compared with the baseline condition):

Very good	
Good	
Poor	
Adverse	

Identify Factors that Affect Corrosion and Corrosion Control in the System

Provide a description of the factors associated with each alternative corrosion control/metal release measures listed as ‘very good’ or ‘good’ in previous table:

	Evaluation Criteria				
Preferred Corrosion Control Measure(s)	**Performance**	**Implementation**	**Secondary Impacts**	**O&M**	**Life Cycle Costs**

5.0 IDENTIFICATION OF PREFERRED MEASURE FOR CORROSION CONTROL

Evaluation of Preferred Measures

Rank the alternative corrosion control/metal release measures as part of the process used to identify the preferred approach. Provide relative ranking numbers in the appropriate row/column to indicate results (please see example in Appendix F for how to use this table).

Corrosion Control Measures	**Evaluation Criteria**				
	Performance	**Implementation**	**Secondary Impact**	**O&M**	**Life Cycle Costs**

Use space below to indicate ranking procedure (for example, rankings are from 1-10 with 10 being the most effective, or the least impact):

Recommendations:

Indicate the recommended corrosion control treatment method.

Method	Check Box	Target pH	Target Alkalinity mg/L as $CaCO_3$	Chemical(s) Used for Adjustment
pH/Alkalinity Adjustment	☐			
		Target dose, mg/L (indicate as P, PO_4, SiO_2 or other)	**Target residual, mg/L (indicate as P, PO_4, SIO_2 or other)**	**Brand Name of Chemical**
Phosphate Inhibitor	☐			
Silicate Inhibitor	☐			

Use space below to provide additional explanation:

6.0 MONITORING CORROSION CONTROL EFFECTIVENESS

Provide recommendations for monitoring the effectiveness of the preferred measure or measures (attach a monitoring plan).

7.0 CORROSION CONTROL PLAN IMPLEMENTATION

Provide the schedule for implementation (attach).

APPENDIX E: Suggested Format for Corrosion Control Plan – Table of Contents

SUGGESTED TABLE OF CONTENTS FOR A CORROSION CONTROL PLAN

Executive Summary

1.0 Introduction and System Description

2.0 Identification of Internal Corrosion Problems and Sources of Contaminants

3.0 Assessment of Significance of Contaminants and Sources

4.0 Identification of Alternative Corrosion Control Measures and Their Impacts

5.0 Identification of Preferred Measure for Corrosion Control

6.0 Public Notification and Stakeholder Consultation

7.0 Monitoring Corrosion Control Effectiveness

8.0 Corrosion Control Plan Implementation

Appendices……………………………………………………………………………….
Materials Survey
Lead Service Line Information
Supporting Solubility Diagram Evaluations
Supporting Treatment Flow Chart Evaluations

List of Tables……………………………………………………………………………..
Water Quality Parameter Monitoring Data Summaries
Source Summary Table

List of Figures…………………………………………………………………………….
Treatment Facility Schematic
Distribution System Map – materials/ages of water mains
Distribution System Map – lead service line locations (if applicable)
Distribution System Map – areas served by each treatment plant/supply
Implementation Plan Schedule Schematic
Appropriate schematics for preferred corrosion control measure (as needed)

Notes:…………………………………………………………………………………………………..

APPENDIX F: Worked Example

CAUTION: This appendix contains worked examples of the various sections of a Corrosion Control Plan. These examples are fictitious and represent information from a number of systems with different water quality, treatment, and distribution system features and data are not carried forward from example to example. Therefore, each section must be reviewed and customized by the Municipality in the preparation of their Corrosion Control Plan.

EXECUTIVE SUMMARY

The purpose of the Executive Summary in the Corrosion Control Plan is to provide an overview of the Drinking Water System, the corrosion control challenges of the System, the recommended measure for corrosion control, and implementation schedule to reduce the potential for lead leaching.

Key features to address in this section include:

- *Overview of System and the basis for which the Corrosion Control Plan is prepared*
- *Source Summary Table*
- *Potential for lead leaching*
- *Measure(s) identified to reduce the potential for lead leaching*
- *Preferred measure(s)*
- *Summary of implementation schedule*

Example:

The Municipality treats the Ontario River at 50,000 m^3/day Municipality Water Treatment Plant using conventional treatment with free chlorine for both primary disinfection and residual maintenance in the distribution system. The treated water is characterized as a soft water (alkalinity less than 10 mg/L as $CaCO_3$), the pH of treated water is on average 7.5, and water temperature varies from 1ºC in the winter to 18ºC in the summer. The distribution system consists of predominantly unlined cast iron pipe. The Municipality does not purchase water from another system, nor does the Municipality sell water to another system. The Municipality is both the Owner and the Operating Authority for the Drinking Water System.

Using results from sampling collected per Schedule 15.1-4, it was determined that more than 10 percent of samples exceeded 10 µg/L in rounds 1 and 2 and therefore the Municipality is required to submit a Corrosion Control Plan (see source summary table below).

Table ES-1: Source Summary Table

Contaminant	**Source**	**Location**	**Extent/Results**					**Significant (Y/N)**
			Number of Samples	**Average**	**% > 10 µg/L**	**Min**	**Max**	
Lead, ug/L	Town Lake	Tap	4 rounds with 110 samples per round	8	14	BDL	23	Y

Contaminant	Source	Location	Extent/Results					Significant (Y/N)
			Number of Samples	Average	% > 10 µg/L	Min	Max	
	City Lake	Tap	4 rounds with 80 samples per round	7	23	BDL	31	
Copper, mg/L	City Lake	Tap	10	0.02	N/A	BDL	0.07	N
Iron, mg/L	City Lake	Distribution system	10	0.3	N/A	BDL	1.2	Y
Zinc, mg/L	City Lake	Distribution system	10		N/A	BDL	BDL	N

The Municipality has 12,000 service connections and estimates that there are 3,000 Municipally-owned lead services lines. The number of privately-owned lead service lines is unknown. The municipality replaces approximately 120 LSLs per year as part of routine water main rehabilitation and repair work.

Based on a review of historical water quality data for treated water and distribution system sampling and results from the regulated community lead sampling program, corrosion by-products that require management or control include lead, copper, and iron. Lead release occurs across the distribution system.

Using lead solubility curves, flow charts from the MOE Corrosion Control Planning Guidance Document, and the experience of municipalities with similar water quality conditions, the following measures for corrosion control were evaluated as part of this study:

- pH and alkalinity adjustment to pH 9.0 and alkalinity greater than or equal to 40 mg/L as $CacO_3$
- phosphate-based inhibitors at ambient pH
- silicate based inhibitors

Each alternative measure was evaluated based on expected performance (lead control), secondary impacts, feasibility of implementation, and life-cycle cost. The preferred measure for corrosion control is pH and alkalinity adjustment with lime and carbon dioxide. Using performance results from other municipalities treating the Ontario River, the Municipality intends to proceed to design and construction of new chemical feed and metering systems in December 2010, with commissioning planned for September 2011.

1.0 INTRODUCTION AND DRINKING WATER SYSTEM DESCRIPTION

1.1 Source Water Supply Information and Characteristics

The Municipal WTP treats water from two sources: Town Lake and City Lake. Both sources are used year round in a 75:25 ratio. An overview of source water characteristics as a function of each source is presented in Table 1-1.

Table 1-1: Source Water Characteristics

Characteristic	Source 1	Source 2
Name	Town Lake	City Lake
Surface/Groundwater	Surface	Surface
Percentage of Supply	75%	25%
pH	7.4	7.8
Alkalinity (mg/L as $CaCO_3$)	60	75
Conductivity (µmho/cm)		
Hardness (mg/L as $CaCO_3$)	55	55
Chloride (mg/L)	3	7
Sulphate (mg/L)	0.3	0.7

1.2 Treatment Facility Information and Characteristics

Typical flow rates, process units, and chemicals systems used at the Municipality WTP are listed in Tables 1-2 and 1-3. A block flow drawing for the plant is shown in Figure 1-1. The Municipality WTP is operated 24 hours a day, seven days a week.

Table 1-2: Overview of Treatment Capacity

Treatment Facility	Source (from table above)	Rated Capacity (m^3/d)	Flow (m^3/d)	
			Avg.	Max.
Municipality WTP	Town Lake City Lake	85,000	56,000	80,000

Table 1-3: Overview of Treatment Facilities

Facility	**Coagulant Used**			**Disinfectant Used**		**pH Adjustment**		
	Type	**Dose (as Al)**	**Target pH**	**Free or Combined**	**Target Residual in Treated Water**	**Chemical**	**Dose**	**Target pH**
Municipality WTP	Alum	10 mg/L	7.0	Free Chlorine	1.2 mg/L	None	N/A	N/A

Treated water characteristics related to lead release and lead control are summarized in Table 1-4. The pH of treated water entering the distribution system varies.

Table 1-4: Overview of Treated Water Quality

Parameter	**Facility #1 or 1st Point-of-entry to Distribution System**		**Facility #2 or 2nd Point-of-entry to Distribution System**	
	Average	**Minimum to Maximum**	**Average**	**Minimum to Maximum**
pH	7.4	6.8 to 7.6	N/A	N/A
Alkalinity, mg/L as $CaCO_3$	55	50 to 60	N/A	N/A
Temperature, ^{o}C	7	1 to 20	N/A	N/A
Chlorine Residual, mg/L	1.2	0.9 to 1.4	N/A	N/A
Conductivity, µmhos/cm	N/A		N/A	N/A
TDS, mg/L	30	18 to 40	N/A	N/A
Dissolved Oxygen, mg/L	N/A		N/A	N/A
Chloride, mg/L	10	8 to 15	N/A	N/A
Sulphate mg/L as SO_3	N/A		N/A	N/A
Phosphate, mg/L as PO_4	N/A		N/A	N/A
Silicates, mg/L as SiO_2	N/A		N/A	N/A
Nitrite, mg/L	N/A		N/A	N/A
Nitrate, mg/L	N/A		N/A	N/A
Free Ammonia, mg/L	N/A		N/A	N/A

* N/A = data not available or not applicable (free chlorine is used for residual maintenance)

1.3 Distribution System Information and Characteristics

One treatment facility (Municipality WTP) supplies treated water to the distribution system. The distribution system covers an area of approximately 100 km^2 and operates with two pressure zones. There are three remote sites, each with a reservoir and pump station.

Concrete pressure pipe is predominantly used for the water mains in the distribution system. PVC is used in approximately 15 percent of the water mains.

A summary of water quality data for the distribution system (as measured at hydrants) is presented in Table 1-5. Data for pH measured at distribution system sampling sites for 2005 to 2009 are presented in Figure 1-2. The pH can vary across the system by more than 2 pH units.

Table 1-5: Overview of Distribution System Water Quality

Parameter	**Location (please provide a map showing locations)**					
	1		**2**		**3**	
	Value	**Date**	**Value**	**Date**	**Value**	**Date**
Lead, µg/L	0.5	Jan 2, 09	0.3	Apr 14, 09	0.4	Oct 7, 09
Copper, mg/L	0.8		0.9		0.2	
Iron, mg/L	0.25		0.29		0.27	
Manganese, mg/L	< 0.002		< 0.002		< 0.002	
pH	7.2		7.4		7.4	
Alkalinity, mg/L as CaCO$_3$	55		55		55	
Temperature, °C	3		12		4	
Chlorine residual, mg/L	0.7		0.6		0.4	
Conductivity, µmhos/cm	N/A		N/A		N/A	
Nitrite, mg/L	N/A		N/A		N/A	
Nitrate, mg/L	N/A		N/A		N/A	
Free Ammonia, mg/L	N/A		N/A		N/A	

* N/A = data not available or not applicable (free chlorine is used for residual maintenance)

1.4 Summary of Lead Service Line Replacement Program

The Municipality has 80,000 service connections and estimates that there are 20,000 Municipally-owned lead services lines. The number of privately-owned lead service lines is estimated at 40,000. The municipality replaces approximately 1,000 LSLs per year as part of routine water main rehabilitation and repair work or in response to customer requests when the homeowner replaces their portion of the LSL. At this rate, it will take approximately 20 years to replace all LSLs owned by the Municipality.

The Municipality encourages the homeowner to replace their LSL:

- Bill stuffers on lead in drinking water and the costs and benefits of LSL replacement were distributed to all users in June 2008 and June 2009
- Information is provided on the Municipality's website
- Door stuffers on lead in drinking water and the costs and benefits of LSL replacement are distributed two months in advance of water main rehabilitation and repair work and again two weeks before work commences

2.0 IDENTIFICATION OF INTERNAL CORROSION PROBLEMS AND SOURCES OF CONTAMINATION

2.1 Evaluation of Water Quality Parameter Monitoring Data

Premise Piping - May 2007 Director's Order Results from lead sampling conducted in response to the Director's Order are presented in Table 2-1. These samples represent lead levels measured at the tap after a five minute flush.

Table 2-1: Lead Results, Flushed Samples at Customer's Tap, May 2007 Director's Order

Parameter	No. Sites	Average	Min	Max	Number Above 10 ug/L	Analytical Method	Detection Limit
Lead, ug/L	20	7	BDL	37	5		0.5
pH	20	7.5	7.2	7.9	N/A		0.5
Alkalinity	20	40	35	45	N/A		0.5

Premise Piping – Schedule 15.1-7 Results from standing samples collected at residential and non-residential plumbing samples per Schedule 15.1-7 are summarized in Table 2-2. Flushed samples were not collected at the sites. Lead results are plotted in Figure 2-1 to show and compare the variability in lead levels measured during all four sampling rounds.

Table 2-2: Residential and Non-Residential Samples, Community Lead Sampling Program

Parameter		Round 1	Round 2	Round 3	Round 4	Analytical Method	Detection Limit
Lead, ug/L	No. Sites	116	112	110	110		N/A
	Average	5	7	3	9		0.5
	Minimum	BDL	BDL	BDL	BDL		0.5
	Maximum	62	78	45	68		0.5
	Number Above 10 ug/L	26	37	18	42		
pH	Average	7.4	7.3	7.6	7.5		N/A
	Minimum	7.2	7.1	7.2	7.1		N/A
	Maximum	7.7	7.7	7.8	7.8		N/A

Distribution System Samples – Schedule 15.1-7 A summary of water quality monitoring data results from flushed samples at distribution system sites, per Schedule 15.1-7, is presented in Table 2-3.

Table 2-3: Flushed Samples at Distribution System Sites (per Schedule 15.1-7)

Parameter			Round 1	Round 2	Round 3	Round 4	Method	Detection Limit
Flushed Distribution System	Lead, ug/L	No. Sites	21	22	20	20		N/A
		Average	2	2	2	2		0.5
		Minimum	BDL	BDL	BDL	BDL		0.5
		Maximum	4	2	2	3		0.5
	pH	Average	7.3	7.3	7.5	7.4		N/A
		Minimum	7.2	7.1	7.2	7.1		N/A
		Maximum	7.6	7.6	7.7	7.7		N/A
	Alkalinity, mg/L as $CaCO_3$	Average	32	36	36	37		1
		Minimum	28	31	28	31		1
		Maximum	36	50	48	50		1

The Municipality has not conducted lead monitoring beyond what is required from Schedule 15.1

2.2 Materials Survey

A map showing geographical extent of different ages and materials of water mains available in the distribution system is presented in Figure 2-2. There is approximately 30 km of concrete pressure pipe, 20 km of ductile iron pipe, and 10 km of unlined cast iron that will be replaced by 2015.

A map showing geographical extent of suspected and confirmed lead service line use is shown in Figure 2-3.

2.3 Identification of Source and Extent of Lead Problems

Both regulated and non-regulated lead sampling results were plotted on a map of the distribution system to demonstrate lead occurrence across the Municipality's distribution system. As expected, elevated lead levels were measured predominantly in the older portions of the Municipality, is areas with homes typically constructed before 1955 (see Figure 2-4).

3.0 ASSESSMENT OF THE SIGNIFICANCE OF CONTAMINANTS AND SOURCES

3.1 Source Summary Table

The Source Summary Table is presented in Table 3-1.

Table 3-1: Source Summary Table

Contaminant	Source	Location	Extent/Results					Significant (Y/N)
			Number of Samples	Average	% > 10 µg/L	Min	Max	
Lead, ug/L	Town Lake	Tap	4 rounds with 110 samples per round	8	14	BDL	23	Y
	City Lake	Tap	4 rounds with 110 samples per round	7	23	BDL	31	
Copper, mg/L	City Lake	Tap	12	0.02	N/A	BDL	0.07	N
Iron, mg/L	City Lake	Distribution system	12	0.05	N/A	BDL	0.15	N

3.2 Establish Baseline Water Quality Conditions and Treatment Objectives

The target corrosion by-product in the Municipality's system is lead. The treatment objective for corrosion control in the Municipality's water is based on reducing lead levels as low as possible. Baseline water quality conditions for the purpose of developing and evaluating alternative measures for lead control include pH in treated water of 7.4 ± 0.2 and alkalinity of 90 ± 5 mg/L as $CaCO_3$.

3.3 Identification of Source and Extent of Other Corrosion Problems

Based on the review of historical water quality data and data generated as part of studies undertaken in support of this Corrosion Control Plan, corrosion control is not required for corrosion by-products other than lead.

4.0 IDENTIFICATION OF ALTERNATIVE CORROSION CONTROL MEASURES AND THEIR IMPACTS

This purpose of the inclusion of section 4 of the Corrosion Control Plan is to identify and evaluate alternative corrosion control measures and their impacts. An estimate or assessment of performance in terms of lead release should be based on corrosion and lead control theory, results from case studies in the literature, data from similar systems, or when available, results from pipe loop testing and partial system testing. Information provided in Chapters 2 and 3 in the Guidance Document provide detailed information on corrosion and metal release control theory which can be used to identify suitable alternatives and to assess their impact on controlling metal release.

An assessment of implementation issues, secondary impacts, operations and maintenance issues, and life-cycle costs should also be included. Suggested factors to consider are identified in Chapters 5, 6, 7 and 8 of the Guidance Document, and an additional example is included in section 5.4 of the Guidance Document.

EXAMPLE:

4.1 Introduction

Based on MOE's "Guidance Document for Preparing Corrosion Control Plans for Drinking Water Systems", the Municipality evaluated the following corrosion control treatment alternatives:

pH and/or Alkalinity Adjustment
Orthophosphate Corrosion Inhibitors

Silicates were not evaluated based on the lack of similar system information and chemical availability and cost. The alternatives were reviewed and applied to the Municipality's water. Current treated water pH and alkalinity are 7.0 and 20 mg/L as $CaCO_3$ respectively. Using the alkalinity/DIC conversion tables in Appendix A of the MOE Guidance Document, the DIC is estimated to be 5 mg C/L.

4.2 Performance

The alternative measures were evaluated based on expected performance (lead control) using lead solubility curves, treatment flow charts from the MOE Corrosion Control Planning Guidance Document, and the experience of municipalities with similar water quality conditions. These evaluations are described below.

4.2.1 Theoretical Lead Solubility and Treatment Flow Charts

Table 4.1 shows the theoretical decrease in lead solubility as pH increases for the Municipality's water quality, or orthophosphates are added at 1.0 mg/L as P or 1.5

mg/L as P in the 7.2 to 7.5 pH range. Accompanying solubility diagrams are provided in Appendix B. Treatment flow charts were also used to identify appropriate alternatives for our system (see Appendix B for treatment flow chart). These charts indicate that raising the pH in 0.5 pH unit increments or adding orthophosphate at a pH range of 7.2 to 7.5 are preferred alternatives for reducing lead levels.

Table 4.1: Theoretical Decrease in Lead (by pH and Phosphate Dose)

	pH adjustment		Phosphate Addition at 3.0 mg/L as PO_4	
pH	Estimate of Lead (mg/L)	Percent Reduction	Estimate of Lead (mg/L)	Percent Reduction
7.0	0.40	0% (ambient)	0.012	97%
7.5	0.30	25%		
8.0	0.20	50%		
8.5	0.15	62.5%		
9.0	0.10	75%	Na	Na

4.2.2 Similar Systems

(Provide a description of similar systems)

4.2.3 Evaluation of Alternatives Based on Performance

Table 4.2 presents an evaluation of the alternatives for control of lead, based on solubility relationships, treatment flow charts, and similar systems. An evaluation of these alternatives with respect to other metals (copper, iron) was not completed, as these metals were not identified as a problem in our system.

Table 4.2: Evaluation of Alternatives Based on Performance

Lead Release Measure	**Very good**	**Good**	**Fair**	**Poor**	**Adverse**
pH adjustment = 7.5				X	
pH adjustment = 8.0			X		
pH adjustment $\geq$ 8.5		X (62.5%)			
pH adjustment >-9.0		X (75%)			
Phosphate inhibitor	X				

This assessment was based on the following criteria:

Rating	Percent Reductions Estimated for Lead Levels based on Solubility Relationships
Very good	>75% - 100%
Good	>50% - 75%
Fair	>25% - 50%
Poor	>0% - 25%
Adverse	<0%

4.2.4 Summary of Evaluation of Impacts

The table below provides a summary and description of the factors associated with each alternative corrosion control/metal release measures listed as ‘very good’ or ‘good’ with respect to lead control performance in Table 4.2. **(Each Municipality will need to develop specific evaluation factors for their system to assess their alternative measures.)**

Table 4-3: Example Summary of Evaluation of Alternatives and Their Impacts

General Factor Category	**Evaluation Factor**	**pH Adjustment to 9.0**	**Phosphate Inhibitor at 3.0 mg/L as PO_4**	**Basis of Application**
Corrosion control performance	Controls lead	Good	Very Good	Estimated based on results from analogous system
	Controls iron	Good	Fair	Estimated based on results from analogous system
Implementation	Requires pilot testing prior to full-scale implementation	No	Yes	
	Affects industrial users potentially	Yes	Yes	Industrial users identified include a brewery, chip maker, and research facilities

General Factor Category	Evaluation Factor	pH Adjustment to 9.0	Phosphate Inhibitor at 3.0 mg/L as PO_4	Basis of Application
Secondary impacts	Compromises primary disinfection	No	No	Corrosion chemicals will be applied after CT is achieved
	Increases phosphorus loading at wastewater treatment plant impacts	No	No	Based on calculated P loading
	Aggravates copper release	No	No	Estimated based on results from analogous system
Operation and maintenance	Increases dependence/number of instruments used for process control	Yes	Yes	Calculate based on proposed process control approach
	Increases the number of chemical systems – and types of chemicals – requiring maintenance	Yes	Yes	Calculate based on design criteria
	Requires the use of a proprietary chemical	No	Possibly	Review availability of local chemical suppliers
Customer acceptance	Imparts a “new” taste to the water	No	No	Based on flavour profile analyses
	Requires (some) industry users to modify water prior to use	Yes	Yes	Based on consultation with industry
Cost	Incurs a capital cost of $TBD			Calculate
	Incurs costs for chemical consumption of $TBD/year			Calculate

4.2.5 Implementation Issues

(Provide a discussion of implementation issues. See section 8.2 in the Guidance Document.)

4.2.6 Secondary Impacts

(Provide a discussion of secondary impacts. See section 4.3 in the Guidance Document.)

4.2.7 Operations and Maintenance Issues

(Provide a discussion of O&M issues. See section 5.5.3 in the Guidance Document.)

4.2.8 Life Cycle Costs

(Provide a discussion of O&M issues. See section 5.5.5 in the Guidance Document.)

5.0 IDENTIFICATION OF PREFERRED MEASURE FOR CORROSION CONTROL

The purpose of section 5 in the Corrosion Control Plan is to identify the preferred measure(s) for corrosion control, including treatment objectives and operating procedures, and provide the rationale or justification of the selection of the preferred measure. The examples included here are based on assessments using different evaluation factors. Each Owner will need to assess these factors based on their unique situation. Therefore, this example does not provide a text example of the evaluation, but presents some example formats for ranking the preferred alternatives.

In Example Format 1, a matrix was developed to assess the importance of each of the factors as they relate to one specific corrosion control/metals release measure. This type of information can be used to weight the various factors, or information in the matrix can be used directly to develop a recommendation, with associated explanatory text in the Corrosion Control Plan.

In Example Format 2, relative ranking numbers have been placed in the appropriate row/column to indicate results from desk-top/laboratory/field testing of various metal release measures. Each factor has been assigned a weight, based on the Municipalities assessment of its level of importance. Again, each evaluation and ranking procedure will be unique, and this is provided as way of example only.

The assessment of the ranking values in the table indicates that phosphoric acid was the preferred treatment measure. A note indicating the Owner’s ranking procedure and other pertinent information should be provided in the text, or as a footnote (for example rankings from 1-10 with 10 being the best). Different evaluation factors may be weighted differently. In Example Format 2, performance has been assigned a greater weight than other factors (2 versus 1). Accompanying text should also be provided that indicates what the assessment was based on (desk-top study/solubility diagrams; laboratory testing; field testing; or some combination).

EXAMPLE:

EXAMPLE FORMAT 1 – Matrix of Evaluation Factors

General Factor Category	High Importance	Medium Importance	Low Importance
Corrosion and metal release control performance	Lead control		
Implementation		Time to implement Need for pipe loop testing	
Secondary impacts	Disinfection	Disinfection by-products	Sodium in treated water
Operations and maintenance	Ability to use existing chemical	Requires use of a proprietary chemical[1]	
Customer acceptance			Industrial users may need to modify process
Life-cycle cost	*Cost items should be addressed separately*		

1. If this has a cost impact rather than an impact for purchasing (e.g., sole source material contract), then address this in the life-cycle cost.

EXAMPLE FORMAT 2 – Summary of Factors to Evaluate the Choice of Corrosion and Metal Release Control Measure

Treatment	Evaluation Criteria (Weight)						Weighted
	Performance (2)	Implementation (1)	Secondary Impact (1)	O&M (1)	Customer Acceptance (1)	Life Cycle Cost (1)	
Phosphoric Acid	10	10	8	8	4	10	60
Zinc Orthophosphate	7	10	8	10	4	8	54
pH 8.0	4	5	7	4	10	5	39
pH 9.0	8	2	5	2	8	2	35

Legend: Weighting factors in parentheses ( )
Ranking numbers: 10 = best, 1 = worst
Weighted value is calculated as the product of factor criteria and weight

6.0 Public Notification and Stakeholder Consultation

No example provided; this section is intended to describe and summarize notification and consultation undertaken by the municipality.

7.0 MONITORING CORROSION CONTROL EFFECTIVENESS

The purpose of section 7 in the Corrosion Control Plan is to provide the details of the monitoring plan that will be used to assess the effectiveness of corrosion control and to confirm the operating conditions for the recommended corrosion control treatment methods (see Chapter 6 of the Guidance Document). This recommendation should include:

- *Water quality sampling (parameter, number of locations, frequency)*
- *Provisions for customer feedback and complaint tracking*
- *Additional laboratory studies if warranted*

Although the number of sampling locations in not described in this example, the Owner and Operating Authority are expected to identify the number and location of sampling sites in their Corrosion Control Plan.

EXAMPLE:

Corrosion control using a phosphate-based inhibitor and pH adjustment to maintain the pH within the optimum range of performance has been identified as the preferred measure for lead control. The proposed framework for the post-implementation monitoring plan is described in Tables 7-1 and 7-2.

Table 7-1: Recommended Parameters and Locations for Post-Implementation Monitoring

Parameters	Point -of- Entry	Distribution System	Residential and Non-Residential Taps	Distribution System Dead Ends and Areas of Low Chlorine Residual
Lead	X	X	X	X
Alkalinity, pH	X	X	X	X
Orthophosphate inhibitor	X	X	X	X
Temperature*, TDS*	X	X	X	X
Dissolved oxygen*		X		
Iron		X		X
Chloride*, sulphate*		X		X
Turbidity*, colour		X		X
Microbiological parameters (coliform, HPC)*		X		X

* Collected as part of the existing monitoring program.

Table 7-2: Recommended Monitoring Programs and Sampling Frequency for Post-Implementation Monitoring

Monitoring Program (1)				
Point-of-Entry Sampling	**Distribution System Flushed Samples**	**Residential and Non-Residential Stagnation Samples**	**Supplemental Tap Sampling**	**Other**
Daily or continuous pH Weekly alkalinity, inhibitor levels	Number of sites as specified in Regulation Frequency of 1/month	Number of sites as specified in Regulation Frequency of 1/month	Additional tap sampling in response to customer requests Profile sampling at 10 homes	Track customer complaints Continue operations of pipe loop

The monitoring proposed to confirm that the operating conditions are achieved listed below:

- pH in treated water (maintain between 7.4 to 7.8)
- pH across the distribution system (maintain within ± 0.2 units)
- Phosphate residuals at the end of the distribution system (as measured at Elm Street, Birch Street, Pine Street, Aspen Street, and Butternut Street)

8.0 CORROSION CONTROL PLAN IMPLEMENTATION

The implementation schedule included with the Corrosion Control Plan may include the following:

- *Identification of key tasks and sequencing*
- *Overview of each key task to described expected outcome upon completion*
- *Estimated timeline to complete each task*

This can be presented as either a schedule (such as a GANTT chart) or a table with key tasks and dates identified. The example included here is based on the provision of new chemical feed and metering systems.

EXAMPLE:

Table 8-1: Implementation Schedule

Task	Description	Schedule
Bench-scale testing	Perform bench-scale tests to identify design criteria with respect to chemical dosing Data generated from testing are limited to chemical dosing and some secondary water quality impacts (such as chlorine decay as a function of pH, pH-dose response curves, and aluminum levels as a function of lime dose)	4Q2010 (predesign)
Pipe loop testing	To assess lead reduction, secondary impacts, and establish design and operating criteria	1Q2011 to 3Q2011 (9 months)
Consultation with industry users and other stakeholders; notify public	Consult local Medical Officer of Health Consult industrial users and research institutions Notify public of changes to water treatment	Before pilot testing After pilot testing Six months before commissioning
Design and construction	Per the requirements of the municipality, if applicable; includes tender and award	4Q2011 to 3Q2012
Implementation and contingency planning	Identify the potential risks of implementation and generate remedial or control measures, such as adding temporary chemical feed systems, enhanced flushing, or modifying the schedule of phased implementation	

Task	Description	Schedule
Post-implementation monitoring		Ongoing once new treatment system is commissioned

Figure 8-1: Preliminary Schedule for Implementation of Chemical Treatment for Corrosion Control

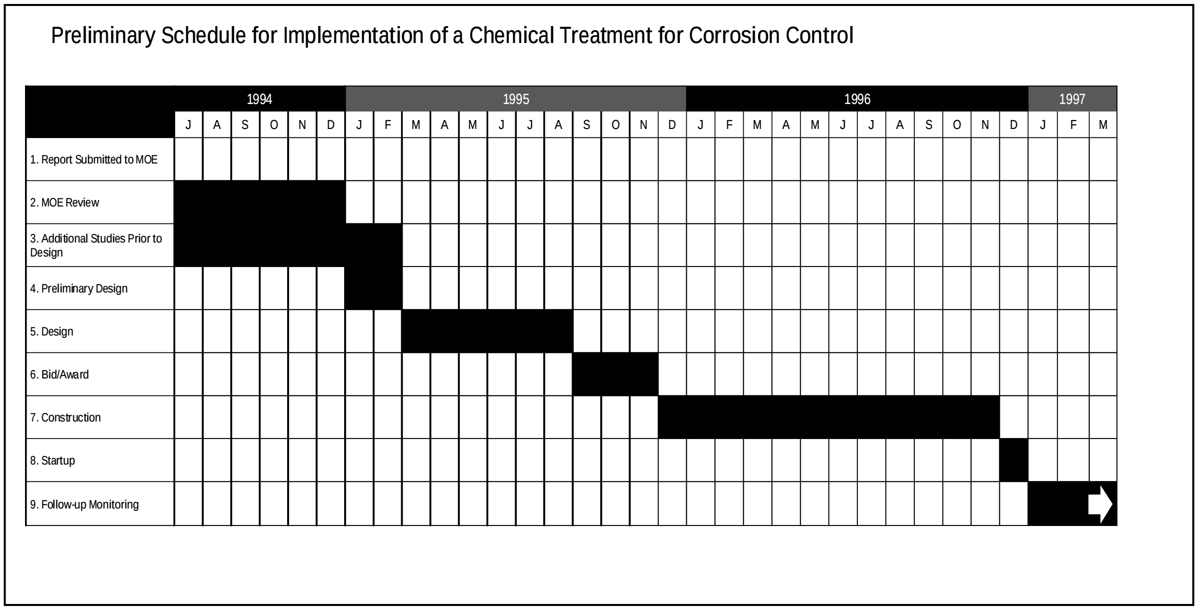
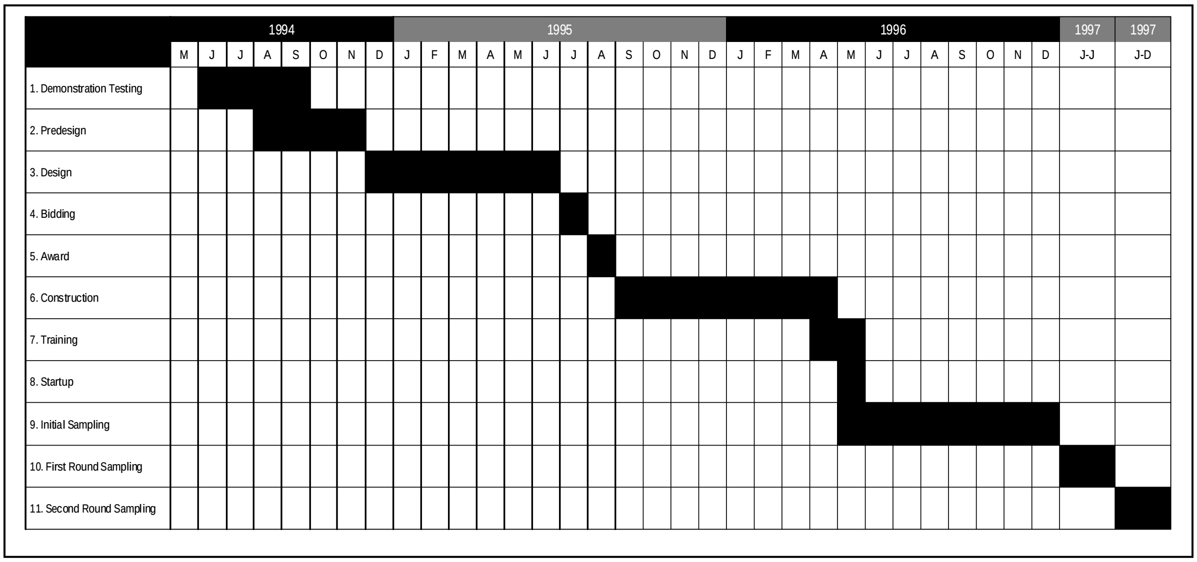


Figure 8-2: Example Implementation Schedule



EXAMPLE: LEAD REDUCTION STRATEGY INFORMATION NEEDS

The following list of information needs was prepared by the City of Guelph and provides an example of the type of information that may be gathered when seeking regulatory relief to support a non-treatment based approach to lead control. The discussions with the Director to seek regulatory relief from Schedule 15.1 will be conducted on a case-by-case basis; discussions between the City of Guelph and the Director were initiated but not concluded during the preparation of this Guidance Document.

- Results from the voluntary lead sampling program – Summer 2007

- Results from the legislated community lead sampling program (Rounds 1 to 4)

- Results from the Lead Profiling Study (2008 to 2009) to assess the source of lead that is contributing to lead levels measured at the tap

- Overview of Drinking Water System: source water quality (lead, pH, alkalinity)

- Review of distribution system features, pipe age and materials to assess the geographical occurrence of known and suspected LSLs (based on the age of homes, historical water main and service line records)

    - Assessment of estimated number of LSLs in the system, on the City side and the private side
    - Water Service Verification Program – additional sampling provided at no cost to residents in homes built before mid-1950's in order to identify lead services (2008-present)

- Summary of geographical occurrence of elevated lead levels based on results from the legislated community lead sampling program and additional verification sampling

- Lead Service Line (LSL) Replacement Program:

    - LSLs replaced in City of Guelph in the past as part of rehabilitation/ reconstruction projects
    - Replacement program accelerated as of 2007 to present, as results of testing indicated elevated lead levels in homes with LSLs
    - 2009 – Coordinated efforts with Engineering Department street renewal projects during which the City replaces encountered lead service lines on the City and private side

- Assessment of lead results from lead sampling at premise plumbing before and after LSL replacement:

  - Following LSL replacement, samples are collected at 6, 12, 18 months following replacement
  - Partial vs. full replacement statistics are maintained

- Summary of current lead reduction strategies including:

  - Number of LSLs (private and municipal) replaced per year
  - Estimated years to replace all LSLs in the City
  - Public outreach and customer acceptance to encourage the public to request water tests:

    - 2007-2008 Frequent ads in newspaper, radio, Open House for the public (2007)
    - 2009 increased outreach efforts to encourage more residents to request water tests, this included:

      - Frequent ads in the local newspaper, community guides
      - Website updates, revision of information packages given out to customers with LSLs, creation of new brochures
      - Lead information booth at numerous community events throughout the summer and fall and at the Waterworks/City Hall Open House
      - Updated community outreach literature, distribution of posters/brochures in daycares, some doctor’s offices, some City facilities (i.e. community centres etc.), downtown area businesses, website for New Moms in Guelph
      - Joint letter from Public Health Unit and Waterworks targeted to homes where service type is unknown in records
      - Ads on bus shelters and mobile signs throughout the zone with potential lead services

- Coordinated efforts with the Health Unit: meetings in 2008 and 2009. Plans for 2010 to increase joint advertising and outreach efforts

- Programs to encourage homeowners to replace the private portion of the LSL:

  - Private side replacement is strongly encouraged at the time of every City side service replacement
  - As of Spring 2009 where possible, Waterworks has started to assist private property owners with the replacement of the private side and/or coordinated the City side replacement with private side replacement, effectively reducing costs to the customers
  - Spring 2010 – Grant Program launched to encourage private homeowners to replace the private side of the service

- Interim strategies to protect sensitive populations from lead exposure and summary of how the vulnerable or sensitive populations will be identified:

    - When booking lead sampling appointments information is collected from the customer to determine if they are part of the Risk Group (children under the age of 6, pregnancy/planned pregnancy in the home)
    - It is anticipated that a Filter Program for the High Risk Groups will be implemented in 2009 (details to be determined)

- The Lead Reduction Plan will include a rationale for why a treatment-based approach for corrosion control would not be feasible

    - Multiple groundwater sources, blending of water in the distribution system
    - Number of potential lead services and the localized nature of LSL occurrence
    - A review of similar systems (similar water quality and similar features)

- Post implementation monitoring

    - Lead sampling at homes where an LSL has been replaced, to monitor for the presence of a lead spike
    - Reduced legislated lead sampling
    - Additional parameters and frequency of sampling will be determined at the final report preparation stage