FINAL REPORT

Lead Reduction Plan for the City of Sarnia

Prepared for

City of Sarnia

May 2018

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Executive Summary

Introduction. The City of Sarnia (City) services a population of approximately 72,000 with purchased treated drinking water from the Lambton Area Water Supply System (LAWSS). As required under Schedule 15.1 of O. Reg. 170/03 under the *Safe Drinking Water Act, 2002*, the City participated in the legislated community lead testing program between 2008 and 2010.

After exceeding the Ontario Drinking Water Quality Standard (ODWQS) for lead of 0.01 mg/L (10 µg/L) in more than ten percent of samples from two out of three consecutive sampling rounds, the City sought regulatory relief in 2010 from a) conducting residential sampling as part of the legislated community lead testing program, and b) preparing a Corrosion Control Plan (CCP) under Schedule 15.1, on the basis that the City's existing practice of replacing publicly-owned lead service lines (LSLs) as encountered would be maintained as a means to remove lead from the Sarnia Water Distribution System, thus controlling lead measured at the tap.

The MOECC requested in 2016 that the City submit a Lead Reduction Plan, per Section 10.0 of the MOECC's *Guidance Document for Preparing Corrosion Control Plans for Drinking Water Systems (Guidance Document)*, through Conditions 1.10 and 1.11 of Schedule D, as outlined in the City of Sarnia's Municipal Drinking Water Licence (MDWL) for the Sarnia Water Distribution System (Licence Number 037-101, Issue Number 5, dated June 1, 2017). This LRP was prepared in response to these conditions. As a measure of due diligence, the City has chosen to assess and evaluate both chemical treatment alternatives and lead source reduction alternatives within this Plan.

Background. The Sarnia Water Distribution System receives water from the LAWSS water treatment plant (WTP) which is situated in the City of Sarnia on the southern tip of Lake Huron at the headwaters of the St. Clair River. The LAWSS WTP draws its source water from Lake Huron via the St. Clair River.

The LAWSS WTP uses chemically assisted direct filtration with disinfection. The facility consists of an intake system, a low lift pumping system, a treatment system, and distribution pumping system that supplies water to seven drinking water systems (DWSs), including the City of Sarnia, the Township of St. Clair, the Town of Plympton/Wyoming, the Village of Point Edward, the Township of Warwick, and the Municipality of Lambton Shores. The Sarnia Water Distribution System (SWDS) is considered to be a "flow-through" system, in that water from the LAWSS WTP must first pass through the Sarnia system before reaching LAWSS's other municipal customers.

Approximately 57% of the watermains in Sarnia are iron-based, including cast and ductile iron. Sarnia's oldest watermains date from pre-1900, and the age of watermains generally decreases moving east from the older portion of the City. The City has developed a preliminary, conservative estimate for the number of LSLs in the SWDS, based on the age of watermains. Of the City's 25,000 service connections, the City estimates that there could be:

- 4,483 known or suspected **public LSLs**
- 8,643 known or suspected **private LSLs**

The potential geographic extent of known or suspected LSLs is consistent with the area bound by Front St., Exmouth St., Murphy Rd., and Campbell St.

Sarnia has embarked on a long-term capital replacement program targeting aged infrastructure over the next decade and beyond. For the past several years, focus has been placed on sewer separation (which includes replacement of all utilities in City-owned right-of-ways). As lead services became a concern following the Schedule 15.1 lead testing program, greater emphasis has been placed on targeting areas with LSLs, in addition to the City's other considerations.

Taking advantage of the excavation of the road and replacement of the entire watermain, replacement of multiple public LSLs can be carried out efficiently during these projects. The City estimates a cost of approximately $4,000 per replacement (for the public portion of the LSL) when carried out during these capital replacement projects. Outside of capital replacement projects, the City replaces public LSLs as encountered during distribution system repairs and related activities or when requested by the homeowner. The City estimates a cost of approximately $10,000 per replacement (for the public portion of the LSL) when carried out as a single replacement outside of capital replacement projects.

Water quality review. A detailed review of LAWSS's raw and treated water quality, water quality in the SWDS, and water quality at the tap was carried out. A summary of baseline water quality conditions is presented in Table ES-1. The origin of target corrosion by-products and their sources are presented in Table ES-2 and Table ES-3, respectively.

Table ES-1. Summary of Baseline Conditions for Corrosion Control

Facility	Flow Rates (ML/d)	pH	Alkalinity (mg/L as $CaCO_3$)	Other Considerations Average (Range)
Lambton Area Water Supply System WTP	Rated: 181.8 2012-2016 Average: 53.8	Average: 7.56 Typical range: 7.3 to 7.8 Absolute range: 6.75 to 8.10	Average: 72 Range: 65 to 78	DIC, mg/L: 18.5 (17.1 to 20.1) *Tr.* Lead, µg/L: 2.7 (<0.02 to 94) *Tap* Iron, µg/L: 1.3 (0 to 10) *Tr.*; 488 (17 to 1,120) *DSS* Manganese, µg/L: 0.7 (0.1 to 7.8) *Tr.*; 25 (0.4 to 59) *DSS* Aluminum, µg/L: 92 (7 to 2,380) *Tr.*; 555 (191 to 1,530) *DSS* Calcium, mg/L: 27 (26 to 28) *Tr.*; 29 (28 to 32) *DSS* Sodium, mg/L: 6.3 (5.7 to 6.6) *Tr.*

Note: Tr. – Treated water; Tap – Tap water; DSS – Distribution system, pipe scale

Table ES-2. Summary of Origin of Target Corrosion By-Products for Corrosion Control

Parameter	Source Water	Treated Water	Distribution System	Premise Plumbing
Primary corrosion by-products				
Lead	Negligible	Negligible	Negligible	Present
Copper	Negligible	Negligible	Not measured	Not measured
Iron	Present (Measured up to 33% of the AO)	Negligible	Present in watermain scale	Not measured
Other parameters for consideration (secondary impacts)				
Aluminum	Present (Measured up to 69% of the OG)	Present (Regularly exceeds the AO during the summer)	Present in watermain scale	Not measured*
Calcium	Present	Present	Present in watermain scale	Not measured*
Sodium	Present	Present	Not measured; no change expected from treated water	Not measured*
Manganese	Present (Measured up to 16% of the AO)	Present (Measured up to 16% of the AO)	Present in watermain scale	Not measured*

*No change expected from distribution system

Table ES-3. Source Summary Table

Contaminant	Source	Location	Extent/Results				
			No. of Samples	**Avg**	**Min**	**Max**	**Significant (Y/N)**
Lead, µg/L	Director's Order, 2007	Tap	21	5.7	0.06	32.4	**Y**
	Schedule 15.1 (5 rounds)		445	2.7	0.04	46.2	
	Summer 2017 sampling (3 homes)		5	63.0	0.44	94.1	
	Director's Order, 2007	Distribution System (bulk water)	3	0.43	0.21	0.65	N
	Schedule 15.1 (15 rounds)		160	0.16	<0.01	1.34	
	Summer 2017 sampling (hydrants)		12	0.19	<0.01	0.47	
Iron, µg/L	Summer 2017 sampling (hydrants)	Distribution System (pipe scale)	10	488	17	1,120	Bulk water: N Scale: Y

From this review, the following key observations are relevant in the context of lead release and corrosion control.

- The variability in treated water is high (-0.81/+0.35 pH units though typically within ±0.25 pH units). Tighter control of treated water pH (i.e., ±0.1 pH units) is usually preferred for control corrosion.
- Treated water is not a significant source of the corrosion-related metals, lead, copper, and iron.
- Treated water from the LAWSS WTP seasonally exceeds the operational guideline (OG) for aluminum. Aluminum was present (predominantly in the particulate form) in watermain scale at high concentrations. If a phosphate-based corrosion control approach is implemented, a unidirectional flushing program will be required to remove this accumulation of aluminum, which will otherwise react with phosphate.
- Under typical water quality conditions observed in the Sarnia Distribution System, the alkalinity is such that it does not cause the CCPP to exceed 7 mg/L as $CaCO_3$, meaning that excessive precipitation of calcium carbonate is not expected under existing conditions in this system.
- The distribution system is not considered to be a source of lead measured at the tap.
- Though high levels of iron (predominantly in the particulate form) were present in the scale from cast iron watermains, the City has not typically received discoloured water complaints. It is likely that iron is present in the scale formed over decades on LSLs and premise plumbing, which has implications for the sorption of lead and its subsequent release.
- Manganese was present in the watermain scale at appreciable concentrations considering the trace level of manganese typically observed in the treated water. If treatment-based corrosion control is implemented, watermain scales may destabilize during the acclimation period, which could potentially result in the release of manganese (potentially above the AO of 50 µg/L).
- The geographic extent of lead exceedances observed during residential Schedule 15.1 sampling was limited to the City's estimated lead zone.
- Results from residential sampling suggest that both premise plumbing and the service lines are contributing to lead measured at the tap, however additional studies such as lead profile testing and plumbing surveys at individual homes would be required to confirm this.

- The highest lead result observed during Schedule 15.1 sampling was 46.2 µg/L, which was identified as a post-LSL-replacement lead spike. The majority (86%) of sites sampled had lead levels at or below 5 µg/L.
- Lead spikes above the MAC (19.3 and 46.2 µg/L) were observed in two of seven homes sampled three to eight months following LSL replacement. Lead spikes following LSL replacement are typically associated with particulate lead release. The occurrence of post-replacement lead spikes in the Sarnia system demonstrates that a lead management strategy based on LSL replacement will require measures to mitigate the impact from post-replacement lead spikes, to protect vulnerable populations.
- Post-replacement tap water lead levels were well below the MAC in five of seven homes sampled following LSL replacement. Post-replacement lead levels in these homes were low, ranging from 0.12 to 1.83 µg/L, demonstrating the benefit of LSL replacement.
- At one of these homes, a pre-replacement lead sample had been collected. Removal of the LSL (not known whether full or partial) at this location resulted in a 90% reduction in lead compared to the pre-replacement level (18.4 µg/L prior to replacement and 1.83 µg/L post-replacement). A summer sample was collected from this home in 2017 (approximately 9 years following replacement); the lead level measured at the tap was low (0.33 µg/L), demonstrating long-term reduction.
- Additional sampling was carried out in summer 2017 at two homes where a partial (City-side) LSL replacement had occurred 40 years previously, in 1977. Lead measured at these houses was high; in one case, lead was measured at more than nine times the MAC. Lead levels of this magnitude suggest that further data need to be collected to demonstrate the merits of partial LSL replacement, and confirms that partial LSL replacement may not be suitable or effective in all circumstances.

Identification of lead reduction alternatives. Based on the treated water pH and dissolved organic carbonate (DIC), two potential *treatment* options for the Sarnia system were identified as follows:

1. Raise the pH in 0.3 unit increments using caustic or soda ash or potash, or
2. Add orthophosphate

Corrosion control based on upward pH adjustment in this water may be bound by the following limitations:

- Upper limit around 8.6 based on managing excessive calcium carbonate precipitation under summer temperature conditions.
- A greater degree of pH instability can be expected in the range of 8.0 to 8.5 (due to lower buffer intensity); this may be manageable through other water quality adjustments (e.g., increasing alkalinity and DIC).

A desktop assessment of theoretical lead solubility suggested that:

- **pH adjustment:** Below pH 8.3, only marginal reductions in lead solubility would be expected, whereas a larger reduction in lead solubility would be expected if the pH is increased beyond 8.6. However as previously noted, caution should be taken in increasing the pH above 8.6 in this water to avoid excessive calcium carbonate precipitation.
- **Orthophosphate:** Lead solubility (due to uniform corrosion) would be expected to decrease by approximately 85% at an orthophosphate dosage of 2 mg/L as PO_4. This reduction is significantly higher than that which would be expected from increasing the pH to 8.6.

The desktop assessment does not address lead release from mechanisms other than uniform corrosion (e.g., lead scale dissolution and particulate release) and cannot be used to predict treatment conditions that would be needed to achieve compliance, which must be assessed through a pipe loop study.

In addition to treatment-based lead reduction approaches (pH adjustment and phosphate-based inhibition), a non-treatment approach consisting of LSL replacement was also considered.

Identification of potential impacts. Based on the review of system characteristics, the water quality assessment, and a review of analogous systems, potential secondary impacts and implementation issues associated with the implementation of pH adjustment, phosphate-based inhibition, and LSL replacement were identified, as well as potential mitigation measures to address these impacts and issues. These are summarized in Table ES-4.

Development of alternatives. Based on the assessment of secondary impacts and implementation issues, seven lead management alternatives were developed for Sarnia. These alternatives were based on the three approaches previously identified: LSL replacement; phosphate-based treatment; and treatment based on pH adjustment. A fourth approach based on LSL replacement with a focus on interim investigation was included as an "interim alternative". The alternatives consisted of the following:

- **LSL-based alternatives:**
    - Option A: Accelerated LSL replacement over 15 years
    - *Option B: Accelerated LSL replacement over 25 years*
        - *Screened out because the LSL replacement period was too long*
- **Treatment-based alternatives:**
    - Option C: Treatment with phosphate (indefinite) with LSL replacement over 50 years
    - *Option D: Treatment with pH adjustment (indefinite) with LSL replacement over 50 years*
        - *Screened out because not expected to provide adequate lead reduction*
    - Option E: Treatment with pH adjustment (indefinite) with accelerated LSL replacement over 40 years
- **Alternatives based on LSL replacement with interim investigations:**
    - Option F: Interim data collection period (3 years) focused on verification sampling and treatment investigations, with full homeowner support, followed by re-evaluation of alternatives
    - *Option G: Interim data collection period (3 years) focused on verification sampling and treatment investigations, with minor homeowner support, followed by re-evaluation of alternatives*
        - *Screened out because it does not provide an adequate level of interim protection*

The program components for these alternatives were defined based on the need for mitigation measures as identified in Table ES-4. Figure ES-1 provides an overview of the program components included with the four options (A, C, E, and F) that were carried forward for further consideration.

Table ES-4. Potential Secondary Impacts, Implementation Issues, and Related Mitigation Measures for Sarnia

Secondary Impact	Mitigation	LSL Replacement	Phosphate	pH Adjustment
Particulate lead spikes	• Provide POU filters • Post-replacement monitoring	●	●	●
Ability to reduce lead levels measured at the tap	• Combine treatment with accelerated LSL replacement to achieve compliance • Encourage full LSL replacement through tailored public outreach program • Homeowner support program (loan/grant) • Post-replacement monitoring	●	●	●
Low homeowner participation	• Tailored public outreach program • Homeowner support program (loan/grant) • Provide POU filters	●	●	●
Lead release from sources other than LSLs	• Tailored public outreach program	●		
Interim exposure to lead	• Tailored public outreach program • Verification sampling • Provide POU filters	●	●	●
Implementation in a Two-Tier System	• Investigate these concerns prior to implementing treatment		●	●
Reaction of phosphate with other constituents (Al, Fe, Ca)	• Coagulation optimization to reduce treated water aluminum • Pre-filter orthophosphate dosing • Unidirectional flushing to manage accumulation of precipitate		●	
Increased bacteria	• Distribution system monitoring • Unidirectional flushing		●	●
Wastewater impacts	• Increase chemical use at WWTP to meet phosphorus discharge limit		●	
Storm sewer impacts	• Maintain phosphate residual below the storm sewer discharge limit		●	
Calcium carbonate precipitation	• Maintain pH at or below 8.6			● *(summer)*
Iron corrosion	• Manage through UDF	● *(existing)*	● *(existing)*	*Improvement relative to current conditions*
Release of pipe scale constituents	• Manage through UDF		●	●
Increased DBPs	• Distribution system monitoring			●

	Option A *Replace LSLs*	Option C *Phosphate*	Option E *pH*	Option F *Investigation*
Verification sampling	590 /yr	180 /yr	220 /yr	1,200 /yr
Replace public LSLs	150 /yr	40 /yr *(current practice)*	60 /yr	85 /yr
Private LSL loan	50 /yr			50 /yr
POU filters	250 /yr	140 /yr	160 /yr	185 /yr
Public outreach	✓	✓	✓	✓
Monitoring	Residential	Residential Dist. System	Residential Dist. System	Residential
Municipal impact study		✓	✓	✓
Treatment trial		✓	✓	✓
Design & construction		✓	✓	
Watermain flushing	✓ *(current practice)*	✓ *(increased)*	✓ *(increased)*	✓ *(current practice)*
Re-evaluate				✓

Figure ES-1. Summary of Program Components for Options A, C, E, and F

Rationale for preferred alternative. There is currently limited information about the actual number of LSLs in the City of Sarnia. In 2017, an estimate was developed using very conservative assumptions. This 2017 estimate of the number of LSLs in the Sarnia Distribution System is therefore likely much larger than the actual number of LSLs in the system. The City cannot make a defensible decision or financial commitment to carry out accelerated LSL replacements at the rate dictated by the 2017 estimate of LSLs. Further, LAWSS cannot defensibly justify implementing corrosion control treatment to its members without sufficiently identifying and quantifying impacts on the latter, particularly when the LSL replacement alternative is poorly defined due to the conservative estimate of the number of LSLs.

Based on these circumstances, "Option F" describes the first three years of a lead management strategy which is based on eliminating all suspected LSLs within 15 years, either by confirming non-leaded material via available information or, where LSLs are present, actually replacing the LSL. During this three-year period, focus is placed on developing required programs, accelerated LSL verification, and investigating treatment options, with LSL replacement continuing at slightly higher than current rates. This rate of replacement however is lower than that which would be required to replace all LSLs in 15 years, based on the 2017 estimated number of LSLs in the Sarnia Distribution System.

As shown in Figure ES-2, the objective of this interim plan is to collect the information that is needed for the City and LAWSS to defensibly commit to a lead management program for the City of Sarnia, namely:

- Refining the LSL estimate to a more realistic number upon which to build a financially sound plan.
- Confirming the level of homeowner participation in conducting private LSL replacements.
- Confirming the level of public health protection provided by LSL replacement in combination with interim protection measures such as filters (i.e., through reductions in lead measured at the tap).

- Assessing the feasibility of implementing corrosion control treatment at the LAWSS WTP, in terms of:
  - Understanding the impacts of corrosion control treatment on the LAWSS member municipalities.
  - The ability of different corrosion control treatment alternatives to control lead measured at the tap, within the Sarnia Distribution System.
  - The ability to minimize interference with existing water treatment processes at the LAWSS WTP (specifically, coagulation due to seasonally elevated aluminum residuals).

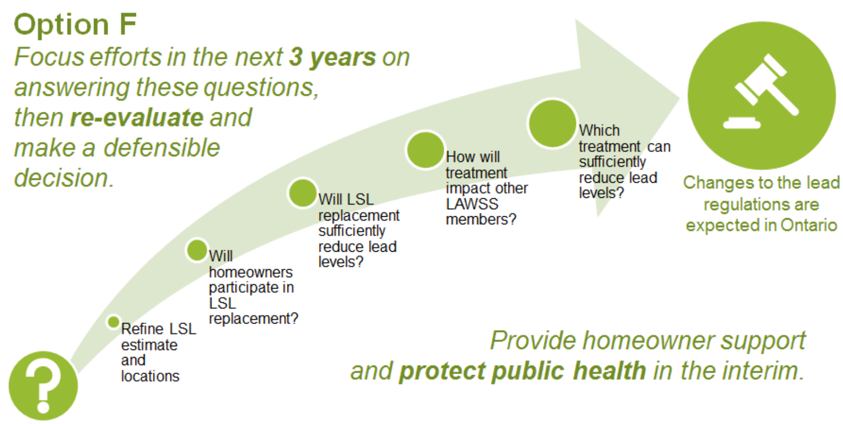

Figure ES-2. Rationale for selecting Option F

As shown in Figure ES-3, the commitment to replace all LSLs in 15 years (by 2034) will be re-evaluated at the conclusion of the three-year interim period, based on the totality of information collected over the course of this three-year interim plan. If, based on this re-evaluation, it is determined that the remaining LSLs cannot be removed by 2034 (12 years starting in 2022) and/or that LSL replacement on its own does not provide a sufficient level of public health protection, a course correction can be made and corrosion control treatment will be negotiated with the LAWSS Board. Alternatively, if replacement of the remaining LSLs by 2034 is determined to be feasible, the City can develop a realistic, fiscally sound plan to replace the remaining LSLs in 12 years.

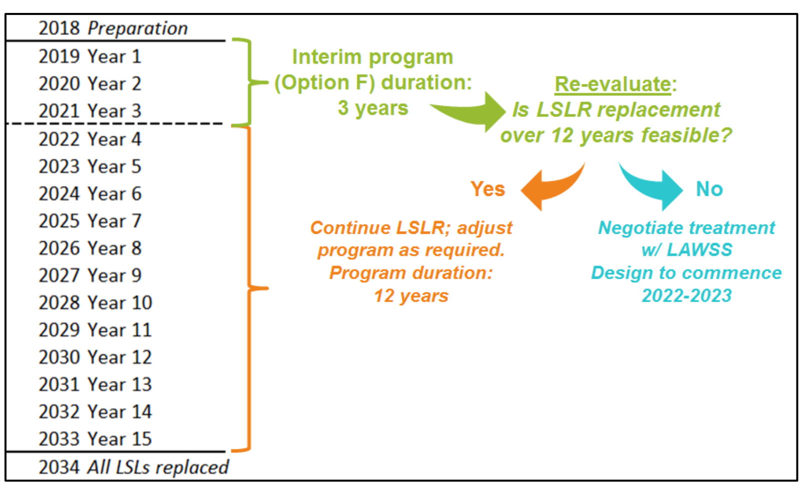

Figure ES-3. Overview of Option F (interim three-year plan)

Advantages of “Option F” include:

- **Protection of vulnerable populations.** By kick-starting the multiple programs that are required in support of lead management, such as public outreach and education, homeowner assistance (loan for private LSL replacement), interim/temporary lead reduction measures (filters), and monitoring, “Option F” provides protection of vulnerable populations during this interim period. These programs would be required regardless of whether the City moves forward with an LSL replacement approach or a treatment approach.
- **Planning for potential future corrosion control treatment.** “Option F” includes background studies in support of a corrosion control treatment approach. Corrosion control treatment can therefore be implemented in 2022-2023 (moving into the design phase) should it be deemed necessary at the end of the three-year period. In other words, “Option F” does not delay the possible implementation of corrosion control treatment relative to what would be possible if a decision was made *today* to implement corrosion control treatment.
- **Adaptable.** By allowing for a course correction (if needed) in 2022, “Option F” provides the City and LAWSS with the flexibility to adapt to upcoming changes to Ontario’s regulatory framework related to lead.
- **Fact-based decision-making.** By focusing on LSL replacement and the collection of required information while protecting vulnerable populations over an interim period, “Option F” sets the City and LAWSS on track to make a defensible decision at the end of the interim period.

Phased implementation plan. Since key program components require a considerable amount of time and effort to develop and implement, the three-year interim plan will commence in 2019 (Year 1), and will conclude at the end of 2021 (Year 3). The (previously allocated) lead management budget for 2018 will be used for 2018 program development activities in support of implementing the three-year plan in 2019. The following is a high-level overview of the plan’s implementation:

1. **LSL verification program**
    - Verification sampling (starting in 2019) will aim to verify 1,200 homes annually. Pre-construction verification sampling will occur in summer 2018.
    - Records review to refine the LSL database will commence summer 2018, and will continue on an ongoing basis.
2. **LSL replacement program**
    - Because the City cannot control how many LSLs will be encountered during sewer separation / watermain replacement projects and operations projects, nor the level of homeowner participation for private LSL replacement, the number of annual LSL replacements is expected to vary from year to year. It is estimated that between 75 to 85 public LSLs, and approximately 60 private LSLs will be replaced annually during the three-year program, starting in 2019.
3. **Treatment and distribution system maintenance**
    - The City will negotiate with LAWSS for the completion of a member municipality impact study in 2019, to determine whether corrosion control treatment is feasible in the LAWSS system by assessing and quantifying potential impacts to the member municipalities of LAWSS.
    - If treatment is determined to be feasible, a pipe loop study will be commenced in 2020 to investigate the ability of the treatment alternatives to control lead in the Sarnia Distribution

System. A coagulation optimization study may also be conducted if phosphate-based inhibition is identified, through the pipe loop study, as the preferred approach.

- The interim lead management strategy will be re-evaluated in 2021 based on the information gathered during the three-year period.

4. Homeowner support program

- A loan program for private LSL replacement will be developed in 2018 for rollout in 2019. It is estimated that 50 loans will be offered per year, at a maximum cost of $2,000 per loan.
- A point-of-use filter program will be developed in 2018 for rollout in 2019. This will consist of a filter rebate program (estimated at 100 filter rebates for $40 each) that will be offered annually to households with vulnerable populations following the detection of lead through verification sampling. Additionally, filters will be provided to homeowners for free for a period of six months following any public LSL replacement, to reduce exposure to “lead spikes”.

5. Public outreach program

- Communication materials to meet immediate needs will be updated in 2018.
- A communications plan will be developed in 2018, for rollout in 2019. This plan will document target audiences, key messaging, communication formats and mediums, the timing of communications, communications protocols and lines of communication, and internal training needs. Additional communication materials for the public outreach program (as defined in the communications plan) will be developed.
- An initial public outreach campaign will be rolled out in 2019. This will include communication with community partners.
- A communication blast will occur annually to solicit participation in the verification sampling program and LSL replacement program.

6. Monitoring for effectiveness

- Residential post-replacement sampling will use the Schedule 15.1 sampling protocol at approximately 6 and 12 months following replacement. Samples will be analysed for total lead and total iron.

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Acronyms and Abbreviations

ANSI	American National Standards Institute
AO	aesthetic objective
AWWA	American Water Works Association
BLL	blood lead level
$CaCO_3$	calcium carbonate
CCP	Corrosion Control Plan, per O. Reg. 170/03, Schedule 15.1
CCPP	calcium carbonate precipitation potential
CDC	United States Centres for Disease Control and Prevention
CH2M	CH2M HILL Canada Limited
City	City of Sarnia
CSMR	chloride-to-sulphate mass ratio
DBP	disinfection by-product
DIC	dissolved inorganic carbonate
DWS	drinking water system
DWSP	Drinking Water Surveillance Program
FTE	full-time equivalent
Guidance Document	*Guidance Document for Preparing Corrosion Control Plans for Drinking Water Systems*
HAA	haloacetic acid
HDPE	high-density polyethylene
ICP-MS	inductively coupled plasma mass spectrometry
LAWSS	Lambton Area Water Supply System
LCR	Lead and Copper Rule
LRP	Lead Reduction Plan, per O. Reg. 170/03, Schedule 15.1
LSL	lead service line
MAC	maximum acceptable concentration
MDWL	Municipal Drinking Water Licence
µg/L	micrograms per litre
mg/L	milligrams per litre
ML/d	million litres per day
MOE	Ontario Ministry of the Environment
MOECC	Ontario Ministry of Environment and Climate Change
NDWAC	National Drinking Water Advisory Committee

NSF	National Sanitation Foundation
OCWA	Ontario Clean Water Agency
ODWQS	Ontario Drinking Water Quality Standard
OG	operational guideline
O&M	operations and maintenance
ORP	oxidation-reduction potential
PAC	powdered activated carbon
PO_4	phosphate
POU	point-of-use
PVC	polyvinyl chloride
SAB	USEPA's Science Advisory Board
SCADA	supervisory control and data acquisition
Schedule 15.1	Schedule 15.1 of O. Reg. 170/03 under the *Safe Drinking Water Act, 2002*
SWDS	Sarnia Water Distribution System
THM	trihalomethane
UDF	unidirectional flushing
USEPA	United States Environmental Protection Agency
WTP	water treatment plant

Introduction and Drinking Water System Description

The City of Sarnia (City) services a population of approximately 72,000 with purchased treated drinking water from the Lambton Area Water Supply System (LAWSS). As required under Schedule 15.1 of O. Reg. 170/03 under the *Safe Drinking Water Act, 2002*, the City participated in the legislated community lead testing program between 2008 and 2010.

After exceeding the Ontario Drinking Water Quality Standard (ODWQS) for lead of 0.01 mg/L (10 µg/L) in more than ten percent of samples from two out of three consecutive sampling rounds, the City sought regulatory relief in 2010 from a) conducting residential sampling as part of the legislated community lead testing program, and b) preparing a Corrosion Control Plan (CCP) under Schedule 15.1, on the basis that the City's existing practice of replacing publicly-owned lead service lines (LSLs) as encountered would be maintained as a means to remove lead from the Sarnia Water Distribution System, thus controlling lead measured at the tap. The Ontario Ministry of the Environment and Climate Change (MOECC) granted the City regulatory relief from the sampling requirements however regulatory relief from the requirement to prepare a CCP was never received.

In August of 2016, the MOECC requested that the City of Sarnia provide a status update on the City's LSL replacement program. At this time, it became clear that the MOECC had understood the City's 2010 request for relief to be a Lead Replacement Plan (LRP), while the City had understood that by not requiring the City to prepare a formal LRP or CCP, the MOECC had approved, in concept, of the City's approach of replacing lead services as encountered.

With this misunderstanding clarified, the MOECC requested in 2016 that the City submit a detailed plan for LSL replacement. In December 2016, the City submitted to the MOECC a proposed outline for a LSL replacement program. The MOECC formalized the requirement for the City to prepare a LRP, per Section 10.0 of the MOECC's *Guidance Document for Preparing Corrosion Control Plans for Drinking Water Systems (Guidance Document)*, through Conditions 1.10 and 1.11 of Schedule D, as outlined in the City of Sarnia's Municipal Drinking Water Licence (MDWL) for the Sarnia Water Distribution System (Licence Number 037-101, Issue Number 5, dated June 1, 2017).

This LRP was prepared in response to Conditions 1.10 and 1.11 of Schedule D, of the City's MDWL. As a measure of due diligence, the City has chosen to assess and evaluate both chemical treatment alternatives and lead source reduction alternatives within this Plan.

Since both treatment-based and lead source reduction alternatives are being considered, this LRP was structured using the outline for a CCP, provided in the MOECC's *Guidance Document*, with modifications as follows:

- ***Section 1*** provides descriptions of the source water, the LAWSS treatment system, the LAWSS and Sarnia distribution systems, and the occurrence of LSLs in the Sarnia distribution system.
- ***Section 2*** summarizes the historical quality of raw water, treated water, water within the distribution system, and water delivered at the tap, to identify the source and extent of corrosion in the Sarnia Water Distribution System.
- ***Section 3*** presents the findings from the assessment of corrosion sources, identifies those which require control, and establishes baseline water quality conditions that will be used to develop alternatives.

- ***Section 4*** identifies and describes alternative corrosion control measures (including treatment-based alternatives and lead source reduction alternatives) and their potential impacts. The rationale for the preferred approach is also presented in this section.
- ***Section 5*** outlines the implementation plan for the preferred approach, including key tasks, schedule, resource requirements, and costs.

1.1 Source Water Supply Information and Characteristics

The Sarnia Water Distribution System receives water from the LAWSS water treatment plant (WTP) which is situated in the City of Sarnia on the southern tip of Lake Huron at the headwaters of the St. Clair River. The LAWSS WTP draws its source water from Lake Huron via the St. Clair River. An overview of the source water characteristics is presented in Table 1-1.

Table 1-1. Source Water Characteristics

Name	Lake Huron, via the St. Clair River
Type of water source	Surface water
Average pH	8.2
Average alkalinity (mg/L as $CaCO_3$)	82
Average conductivity (µS/cm)	214
Average hardness (mg/L as $CaCO_3$)	98
Average chloride (mg/L)	7.3
Average sulphate (mg/L)	16.6

Source: DWSP data, 2012 to 2016

1.2 Treatment Facility Information and Characteristics

The City of Sarnia is supplied by the LAWSS WTP (DWS Number 210000906). An emergency connection allows servicing of the Sarnia Water Distribution System by the Petrolia WTP in Bright's Grove (which also obtains its water from Lake Huron) however this emergency connection has not been utilized since installed, to staff's knowledge.

Overview. The LAWSS WTP uses chemically assisted direct filtration with disinfection. The facility consists of an intake system, a low lift pumping system, a treatment system, and distribution pumping system that supplies water to seven drinking water systems (DWSs), including the City of Sarnia's. A process flow diagram of the facility is provided in Figure 1-1, and further details are summarized in the following paragraphs.

Capacity and flows. The LAWSS WTP's rated capacity is 181,844 m^3/day. Table 1-2 provides a summary of the LAWSS WTP flows between 2012 and 2016.

Table 1-2. LAWSS WTP Treated Water Flow Summary, 2012 to 2016

Treatment Facility	Source	Rated Capacity (m^3/d)	Monthly Treated Water Flow (m^3/d)		
			Average	Max	Min
Lambton Area WTP	Lake Huron (via St. Clair River)	181,844	53,772	111,245	34,264

Source: LAWSS WTP treated water flow data, 2012 to 2016

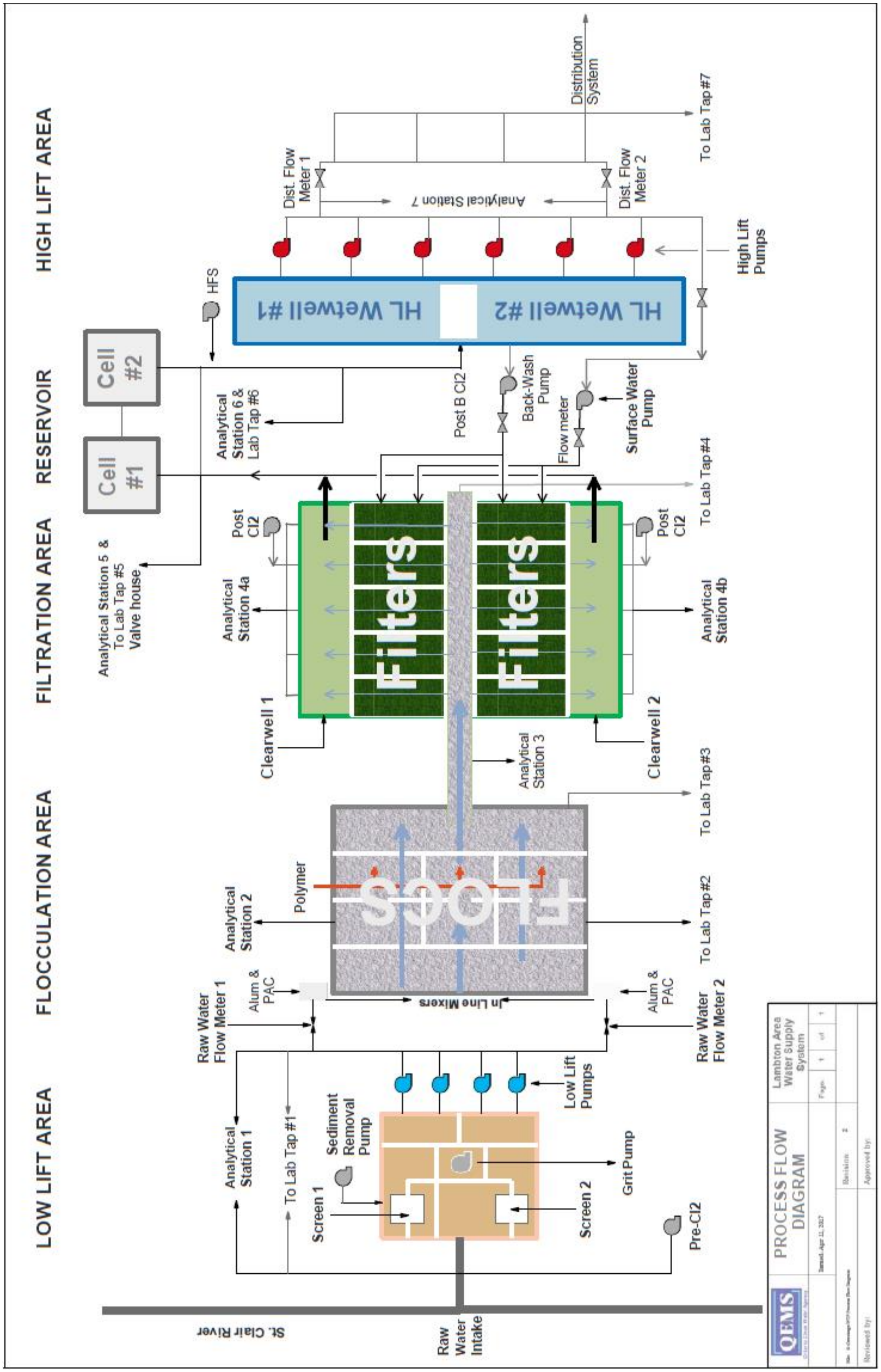

Figure 1-1. LAWSS WTP Process Flow Diagram

Intake and low lift pumping. Water is drawn into the plant via a 1,675 mm diameter intake pipe extending approximately 177 m into the St. Clair River at a depth of 15 m. A zebra mussel control system (sodium hypochlorite) is available at the intake when needed. Screening occurs at the surge wells where pre-disinfection is utilized. Water flows to the low lift pump wet wells where four vertical turbine pumps (1 duty, 3 standby) are located and used as needed to pump to a common discharge header.

Pre-treatment. Acidified liquid aluminum sulphate (coagulant) is added at an average dosage of 23 mg/L as product (8 mg/L as Al_2O_3) and flash mixed. Powdered activated carbon (PAC) is also applied at this location when needed for taste and odour control. The water is then flocculated; polymer is added to the flocculation trains when needed.

Treatment. Flocculated water is then filtered by ten dual media (anthracite/sand) gravity-fed filters. The filtered water is combined then distributed between two clearwells where sodium hypochlorite is injected for residual maintenance with a target free chlorine residual of 1.5 mg/L at the distribution system point-of-entry. To maximize the chlorine contact time, the treated water is diverted to two baffled reservoirs in series, with a total capacity of 67,460 m^3. Naturally occurring fluoride is present in the source water at approximately 0.1 to 0.2 mg/L; this natural level is augmented using hydrofluosilicic acid as the treated water exits the reservoirs to achieve a target residual of 0.7 mg/L. No chemicals are used in the treated water for pH correction or corrosion control. Refer to Table 1-3 for a list of treatment chemicals used at the LAWSS WTP.

Table 1-3. LAWSS WTP Treatment Chemical Summary

Chemical	Purpose
Sodium hypochlorite	Pre-chlorination and disinfection
Powdered activated carbon (PAC)	Seasonal taste and odour control
Clar+Ion A7 (acidified aluminum sulphate)	Coagulation
Polymer 8103+	Seasonal filter/coagulant aid
Hydrofluorosilicic acid	Fluoridation
Polymer Zetag 4120	Residual Management System (coagulation)
Sodium Bisulphite	Residual Management System (dechlorination)

Residue management. Backwash from the dual media filters is treated using a high rate clarification process (Actiflo). The clarified water is dechlorinated then discharged to the St. Clair River. Settled solids are sent to the Sarnia Water Pollution Control Plant for final treatment and disposal.

Distribution pumping and control. Six vertical turbine pumps are available for supplying water to the distribution system. The water treatment process and distribution components are controlled by a dedicated supervisory control and data acquisition (SCADA) computer system and are monitored by a certified operator, 24 hours per day. Emergency diesel generators are available at the WTP to keep the plant in operation in the event of a power failure.

1.3 Distribution System Information and Characteristics

1.3.1 Lambton Area Water Supply System (DWS Number 210000906)

Overview. LAWSS is jointly owned by the member municipalities represented by the Lambton Area Water Supply Joint Management Board, whose municipal members include the City of Sarnia, the Township of St. Clair, the Town of Plympton/Wyoming, the Village of Point Edward, the Township of

Warwick, and the Municipality of Lambton Shores. LAWSS is operated by the Ontario Clean Water Agency (OCWA). Refer to Figure 1-2 for an overview of LAWSS.

Description. Servicing a large portion of Lambton County, LAWSS is comprised of the following:

- Approximately 250 km of transmission mains ranging in size between 200 and 900 mm in diameter. Materials include cast iron, ductile iron, Hyprotec-lined ductile iron, concrete pressure pipe, asbestos cement, high density polyethylene (HDPE), and polyvinyl chloride (PVC).
- Three standpipes (Forest, Port Lambton, and Watford)
- One elevated tower (Indian Road)
- Two booster pumping and rechlorination stations (free chlorine), which are controlled and monitored from the WTP via the SCADA system:
    - The East Lambton Reservoir and Pumping Station; water storage capacity of 9,000 m^3
    - The West Lambton Reservoir and Pumping Station; water storage capacity of 90,000 m^3

The following standpipes are not operated by LAWSS but receive water from LAWSS:

- Wyoming Standpipe: Owned and operated by the Township of Plympton/Wyoming. Pressure is monitored and alarmed from the distribution inlet chamber that is part of LAWSS, and data are recorded by SCADA at the LAWSS control room. Response to these alarms are initiated by OCWA, but may be directed to the Municipality and their water department.
- Brigden Standpipe: Owned and operated by the Township of St. Clair. OCWA does not monitor or receive alarms for this system.
- Alvinston Standpipe: Owned by the Township of Brooke-Alvinston and operated by OCWA under a separate contract.

Connections. Refer to Table 1-4 for a list of DWSs which receive water from LAWSS.

Table 1-4. Drinking Water Systems Supplied by LAWSS

Drinking Water System Name	Drinking Water System Number
Sarnia Distribution System	260003136
Village of Point Edward Distribution System	210000924
St. Clair Distribution System	260006464
Plympton-Wyoming Distribution System	260006594
Township of Warwick Distribution System	260001799
Alvinston Distribution System	260040170
Corporation of the Municipality of Lambton Shores Distribution System **Receives only some of their water from LAWSS*	260006581

Emergency connections exist between LAWSS and the following DWSs to provide water to either system in case of emergencies:

- Chatham-Kent: Connection at Whitebread Line and Highway 40
- Petrolia: Connection at Confederation Line and Ploughing Match Road
- Lambton Shores: Connection at Lakeshore Road and the northwest corner of Ravenswood Road

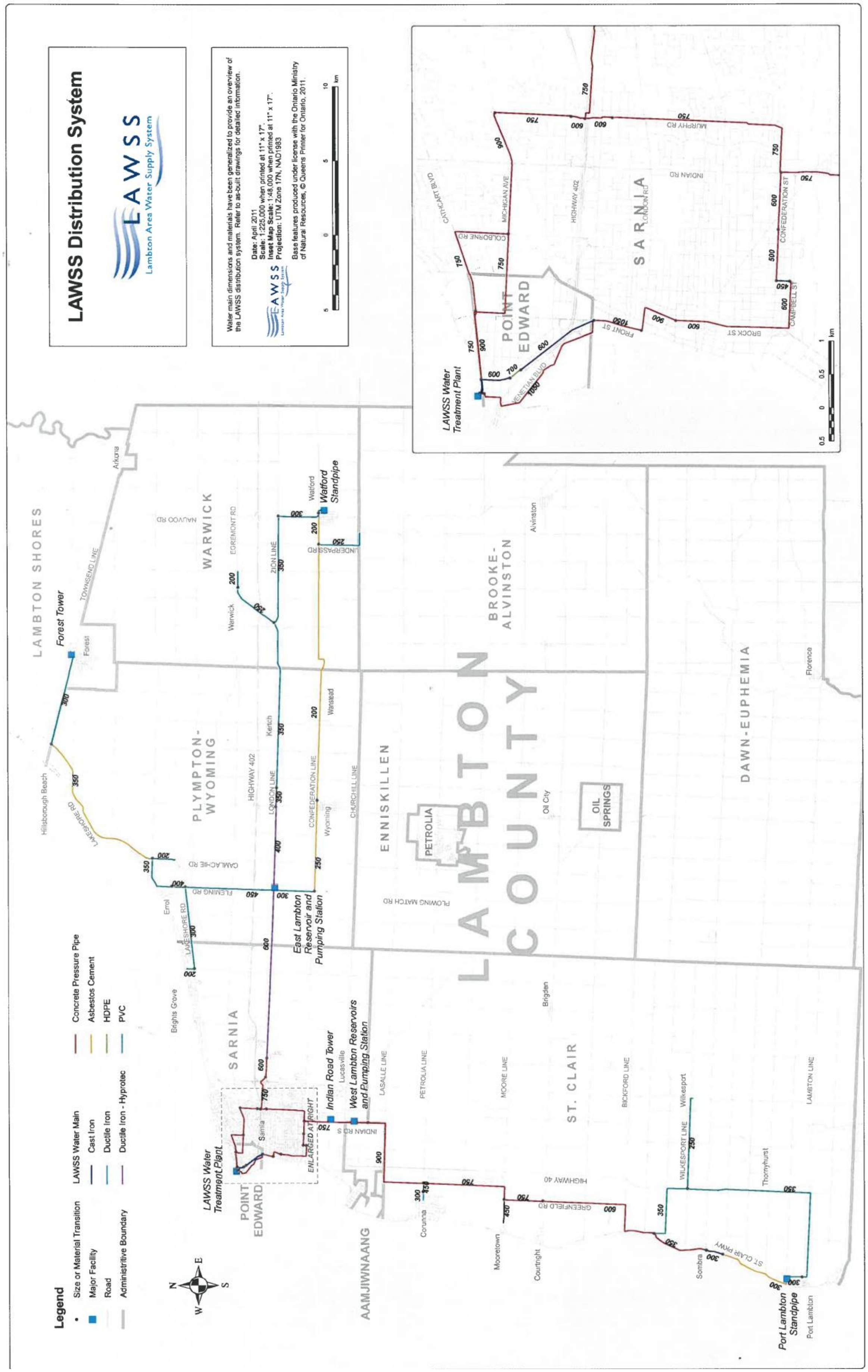

Figure 1-2. LAWSS Transmission and Water Storage System

1.3.2 Sarnia Water Distribution System (DWS Number 260003136)

Overview. The City of Sarnia is located on the south shore of Lake Huron, across the St. Clair River from Eastern Michigan. The Sarnia Water Distribution System (SWDS) services a population of approximately 72,000 through 25,000 service connections. The City's Public Works Division is the operating authority of the SWDS; however, OCWA is contracted to provide operators for distribution system sampling.

Description. The Sarnia Water Distribution System is comprised of the following:

- Approximately 500 km of watermains ranging in diameter from 50 to 600 mm. Materials include PVC, cast iron, ductile iron, concrete, and a small portion of other materials such as galvanized iron, asbestos, and HDPE. The oldest watermains date from pre-1900; the age of watermains generally decreases moving east from the older portion of the City. Refer to Table 1-5, Figure 1-3, and Figure 1-4 for additional information on the watermain materials, sizes, and age.
- Approximately 2,700 hydrants and five automatic flushers.
- There are no storage or booster pumps within the SWDS.
- The SWDS consists of a single pressure zone. Pressure within the system is regulated by water facilities owned and operated by LAWSS. Operating pressures within the SWDS range from 480 kPa (70 psi) to 415 kPa (60 psi) with typical pressure at approximately 448 kPa (65 psi).
- The secondary disinfectant is free chlorine.

Table 1-5. Summary of Watermain Materials in the Sarnia Water Distribution System

Material	**2017**	
	Length, km	**Percentage**
Total iron-based pipe	286.5	57%
Cast iron	*196.2*	*39%*
Ductile iron	*89.9*	*18%*
Galvanized iron	*0.4*	*0.07%*
Concrete	20.0	4%
Asbestos	0.2	0.05%
HDPE	2.2	0.4%
Total PVC pipe	190.7	38%
PVC (type unspecified)	*180.2*	*36%*
PVC (Fusible)	*1.0*	*0.2%*
PVC (Thin wall)	*9.5*	*1.9%*
Total	**499.5**	-

Flow-through system. Water from the LAWSS WTP must pass through the Sarnia system before reaching neighbouring municipalities. Sarnia distribution mains are connected at various points to the LAWSS transmission mains that continue onward to customers which include the Aamjiwnaang First Nation, the Township of St. Clair, the Town of Plympton-Wyoming, the Municipality of Lambton Shores, and the Township of Warwick. Water supplied to major water users flows through backflow preventers to protect the SWDS from downstream activities. Water quality within the system is sampled, tested, and monitored in accordance with LAWSS's sampling, testing, and monitoring procedure.

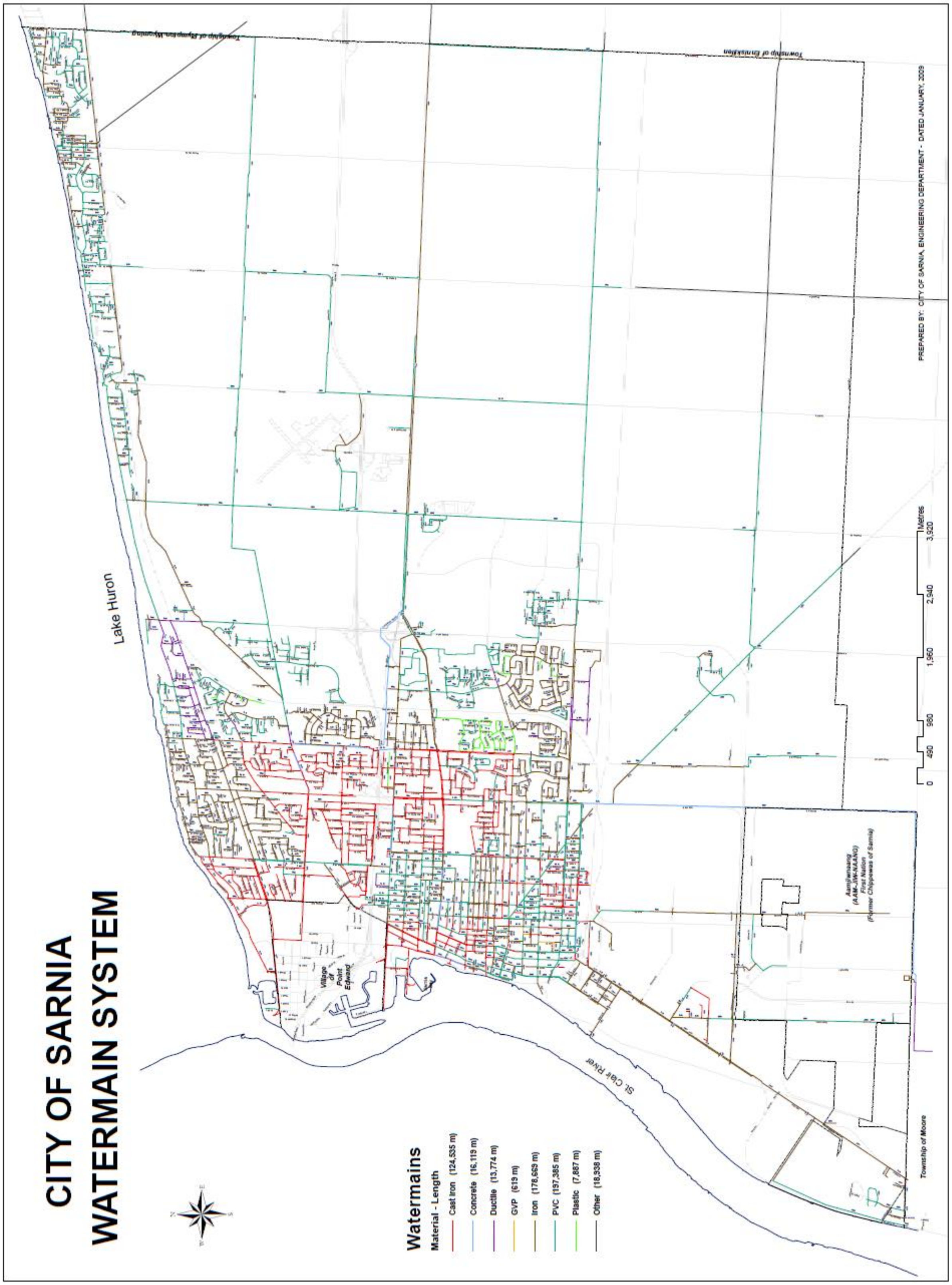

Figure 1-3. Sarnia Water Distribution System Watermain Materials and Size

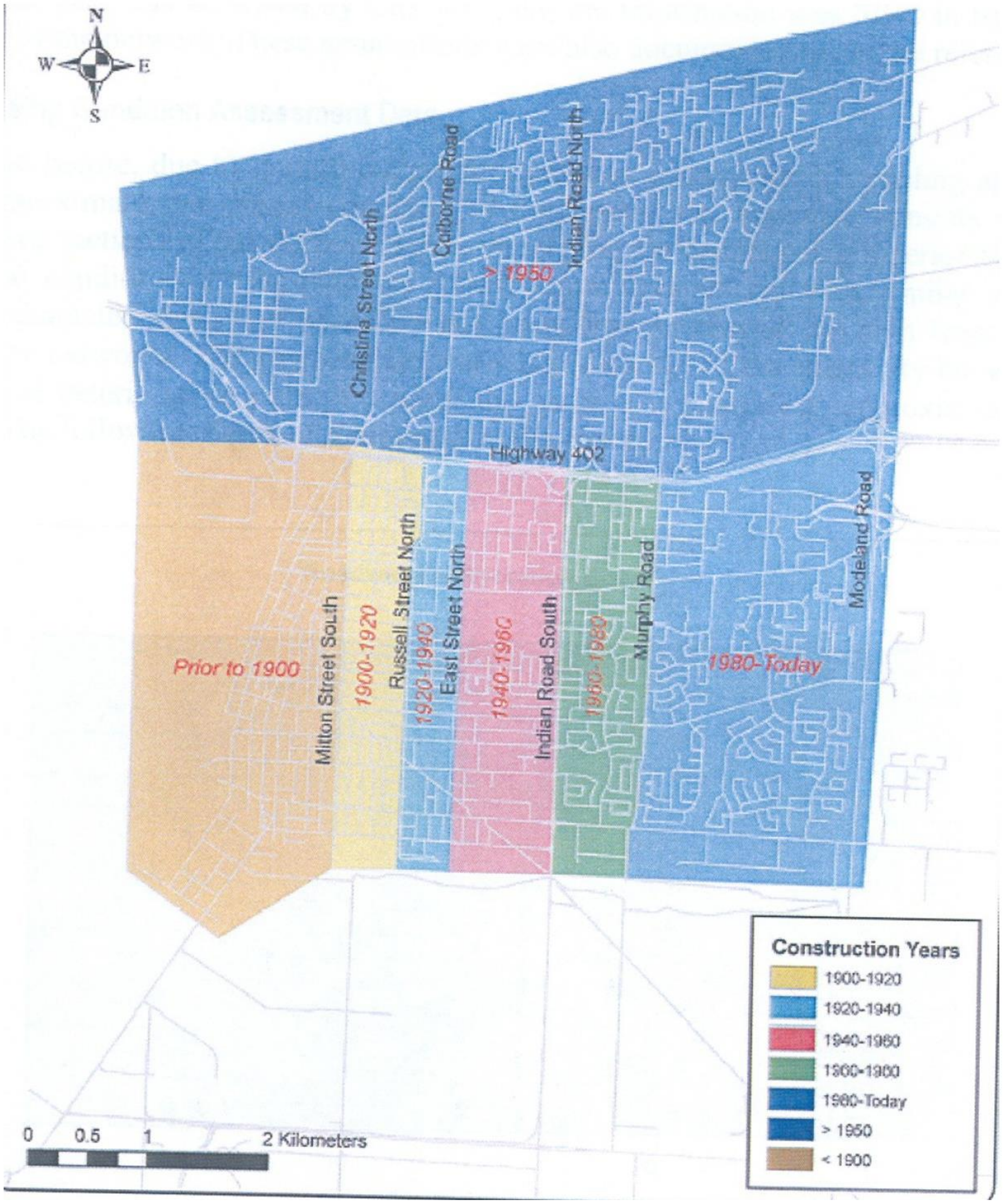

Figure 1-4. Approximate Geographic Extent for the Year of Original Watermain Installation

Flows and metering. Flows entering the SWDS, and all other systems supplied by LAWSS, are metered. Similarly, all residential, commercial, and industrial water users within the SWDS are metered. The City's water losses are estimated by subtracting the City's metered usage and estimated non-metered usage (i.e., fire protection, main breaks, etc.) and the amount of water supplied to all other municipalities (with an assumed allowance for their losses) from the total amount of water pumped from the LAWSS WTP. A summary of the annual metered and unmetered usage in the SWDS is presented in Table 1-6.

Table 1-6. Average Metered (and Unmetered) Water Use in the Sarnia Water Distribution System, 2012 to 2016

System	Source	Average Flow (m^3/d)	Average Percentage of LAWSS WTP Flow
Sarnia Water Distribution System	LAWSS	28,779	59%

Source: LAWSS annual flow summaries, 2012 to 2016

Connections. Figure 1-5 shows the connections between the SWDS, the municipalities supplied by LAWSS, and those supplied by the Petrolia WTP. These are summarized as follows:

- The SWDS is connected to the Town of Petrolia Water Distribution System and the Enniskillen Township Water Distribution System. The Town of Petrolia supplies both systems from the Petrolia WTP. These interconnections are through valves which are normally closed and can be manually opened in the case of an emergency.
- The SWDS supplies water to approximately fifteen homes in the adjacent Township of St. Clair. These homes are not connected to the St. Clair distribution system.
- Connections also exist between the Plympton-Wyoming Water Distribution System, the Point Edward Distribution System, and the St. Clair Water Distribution System. These three systems share LAWSS as their source of water supply. These inter-connections are through valves that are normally closed and are opened only in the case of an emergency.

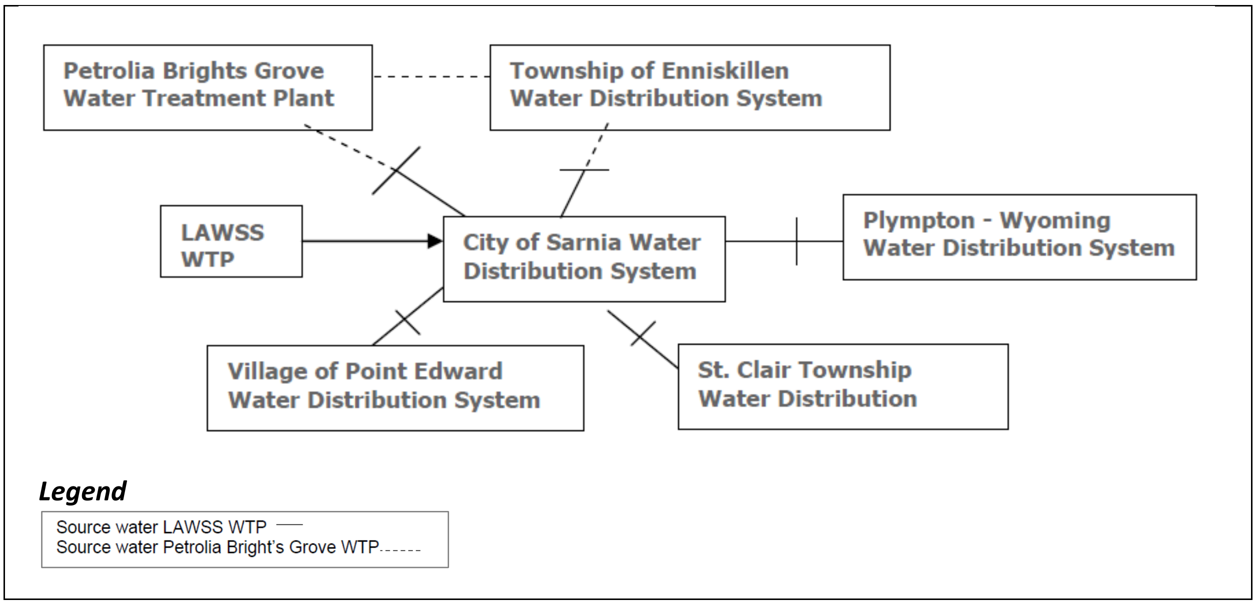

Figure 1-5. Connection Between the Sarnia Water Distribution System and Other DWSs

Operation and maintenance. The City has distribution operation and maintenance programs as follows:

- Hydrant inspection and watermain flushing program: All hydrants are operated and maintained annually, from early April to December. All watermains in the SWDS are flushed annually as part of this program. The flushing program consists of a quasi-UDF approach, in that watermains are flushed systematically from a clean source, however watermains are not isolated through closed valves during the flush and therefore UDF flush velocities may or may not be achieved. Hydrants are painted with a colour-coding system according to their achievable flow range. The City also has five auto flushers to aid in distribution system flushing maintenance in dead-end or low flow areas.
- Valve inspection and exercising program: A valve location/identification, operation, and maintenance program for all valves in the SWDS commenced in 2009. When valves are located, the valve's GPS location is recorded, and the valve is assigned an asset number. Valve GIS data, including location and maintenance data, are added to the GIS mapping system. When the valve inventory exercise is complete, the City plans to exercise approximately 2,600 valves per year, which is roughly 25% of the total number of valves in the system. Each valve will therefore be exercised once every four years.

1.4 Lead Service Lines in the Sarnia Water Distribution System

There are approximately 25,000 service connections in the SWDS. Prior to this LRP, the City did not maintain records of service line materials. Ongoing endeavours related to LSL replacement and the identification of LSLs within the City are discussed in the following paragraphs.

Capital replacement projects. Sarnia has embarked on a long-term capital replacement program targeting aged infrastructure over the next decade and beyond. As lead services became a concern following the Schedule 15.1 lead testing program, Sarnia expanded infrastructure replacement to include service connections.

Water distribution system capital projects are assessed based on multiple factors, as outlined below:

- ***Age and material.*** "Age and Material" is the most significant assessment criterion. As a watermain ages its condition deteriorates by a combination of increased calcium deposits, low flows, low pressure, rusting, and breakage. The type of material significantly affects the rate at which deterioration occurs.
- ***Watermain breaks per 100 metres.*** The number of watermain breaks provides an accurate measure of operational decline due to pipe deterioration. Watermains that have a history of breakage are a significant burden on the operational budget.
- ***Fire flow.*** Several areas within the City experience very low water flows. Such low flow areas are both an operational and safety concern. Low flows are also directly related to increased water ages within the affected pipes.
- ***Pipe diameter.*** Large diameter pipes are often transmission lines that supply significant quantities of water to large areas within the City. Problems with larger diameter pipes are considered to have high associated social and economic risks. Smaller diameter pipes (<150 mm) are also a priority as they often have low pressures and/or lead services.
- ***Lead services.*** Lead services need to be removed as they have significant detrimental effects on water quality. Areas with known or suspected lead services are prioritized for replacement. When lead services are encountered during these projects, the public portion of the lead service is replaced at the same time as the watermain.

For the past several years, focus has been placed on sewer separation (which includes replacement of all utilities in City-owned right-of-ways), with additional consideration given to low-flow areas and areas with LSLs. These projects are issued for tender and awarded to qualified contractors. Refer to Table 1-7 for a list of capital replacement projects carried out between 2008 and 2017.

Between 2008 and 2016, the City has conducted between 2 and 7 capital replacement projects per year. These have varied in scope (sewer separation, watermain replacement, road reconstruction, etc.) and in the extent of the area included in project, ranging between 80 and 1,100 m though typically in the range of 500 to 700 m. Annual expenditures for these projects have varied from $0.7M to $7.7M. LSL replacement represents only a small portion of this expenditure, and in some cases, projects were carried out in areas where LSLs were not present.

Taking advantage of the excavation of the road and replacement of the entire watermain, replacement of multiple public LSLs can be carried out efficiently during these projects. The City estimates a cost of approximately $4,000 per replacement (for the public portion of the LSL) when carried out during these capital replacement projects.

Table 1-7. List of Capital Replacement Projects (Watermains), 2008 to 2017

Year	Contract	Description	Addn'l Information
2008	1	Exmouth St reconstruction; Phase III	All water services in the right-of-way were replaced with copper (small dia. services) or PVC (large dia. services).
	2	Christina St reconstruction; Wellington St to George St	
	5	Talfourd St reconstruction; Russell St to Proctor St Harkness St reconstruction; Talfourd St to Ontario St	
	7	Mitton St reconstruction; Campbell St To Devine St	
2009	1	Harkness St / Sheppard St / Conrad St reconstruction; Talfourd St to Devine St	$2,015,498
	2	Mitton St reconstruction; Devine St to Wellington St Ontario St reconstruction; Talfourd St to Wellington St	$1,755,171
	5	Devine St reconstruction; Christina St to Margaret St	$1,260,265
	7	Elprado St / Buena Ventura St / Brigden Rd watermain replacement	$1,026,336
	9	Blackwell Sideroad watermain replacement; Confederation St to Church Rd	$561,652
	16	Wellington St east of Hwy 40	$740,000
	17	Wellington St reconstruction; Finch Dr to Hwy 40	$363,000
2010	1	East St watermain replacement; Devine St to south of Wellington St Devine St. watermain replacement; east of Ontario St to East St.	$859,743
	2	Wellington St. watermain replacement; Murphy Rd to Finch Dr	$1,196,554
	6	Quinn Dr watermain replacement; Lambton Mall Rd to Barclay Dr	$306,639
	16	Wellington St watermain replacement; Hwy 40 to London Line	$579,441
	17	Wellington St watermain replacement; east of Finch Dr to Hwy 40	$931,605
2011	1	East St reconstruction Phase 2; East St: Wellington St to London Rd (2011); George St to London Rd (2012) London Rd: Cecil St to East St (2011)	$4,739,288 (2011) $1,445,695 (2012)
	2	Devine St reconstruction Phase 2; Margaret St to Proctor St	$2,167,146
	5	Lochiel St reconstruction; Front St to Christina St	$160,006
	7	Dagan St and McGregor Rd watermain reconstruction	$421,592
	8	Jean St (Bright's Grove) storm reconstruction; First St to Second St	$294,348
2012	1	Lincoln Park Ave and Oxford St reconstruction; Lincoln Park Ave: Cecil St to Rayburne Ave Oxford St: London Rd to Maxwell St	$1,062,691
	2	Devine St reconstruction Phase 3; Proctor St to pump station	$2,691,101
2013	1	Temple St reconstruction	$663,610
	2	Colborne Rd reconstruction	$1,871,423
	3	Michigan Ave to Mathews Ave watermain	$696,405
	5	Brock St and Tashmoo; reconstruction and water meter chamber	$297,143
	9	Penhuron Ln watermain	$127,000
2014	1	East St reconstruction	$929,293
	2	Capel St / Lydia St / Maxwell St / Nelson St reconstruction	$2,361,901
2015	2	Coronation Ln / Modeland Rd / Old Post Rd watermain replacement	$501,741
	3	Bruce St watermain replacement	$286,082
2016		Talfourd St area sewer separation and reconstruction	$1,383,625
		Savoy St reconstruction	$1,015,874
2017	1	Talfourd and side streets reconstruction	$4,101,222
	2	Old Lakeshore Road watermain	$501,724
	5	London Road gate valve & watermain	$173,740
	6	Jamieson Lane watermain	$162,514

Table 1-8 summarizes the number and length of public LSLs removed during capital replacement projects carried out between 2009 and 2017. In 2009, 2014, and 2017, there were 32, 36, and 34 public LSLs encountered and removed, respectively. In the other years, no LSLs were encountered. In some cases, the projects may have occurred outside of the lead zone. However in other cases, no LSLs were found, even when the projects occurred within the lead zone. For example, none of the 28 services encountered during the 2016 projects (which were located within the lead zone) contained lead on the public side, and only one had lead on the private side.

Where lead was encountered on the public side, it occurred in approximately 19% of the services in 2009, and 34% of the services in 2017. The percentage of services with lead present on the private side was significantly lower, ranging from 0 to 11%. The average length of public LSL removed per address in 2009, 2014, and 2017 was approximately 10 m.

Table 1-8. Documented Public LSL Removal During Capital Replacement Projects

Year	Streets	Number of Services on Affected Watermain	Number of PUBLIC LSLs Encountered and Replaced	Number of PUBLIC LSLs Encountered and Not Replaced	Total Length of PUBLIC LSL Removed	Number of PRIVATE LSLs Encountered
2009	Conrad Street Talfourd Street Ontario Street Harkness Street Christina Street Mitton Street	**Total: 170 (est.)**	13 6 6 2 3 2 **Total: 32**	Unknown	117 m 78 m 68 m 20 m 42 m 28 m **Total: 353 m**	Unknown
2010	*Refer to Table 1-7*	Unknown	Total: 0	Total: 0	Total: -	Total: 0
2011	*Refer to Table 1-7*	Unknown	Total: 0	Total: 0	Total: -	Total: 1
2012	*Refer to Table 1-7*	Unknown	Total: 0	Total: 0	Total: -	Total: 0
2013	*Refer to Table 1-7*	Unknown	Total: 0	Total: 0	Total: -	Total: 1
2014	Capel Street Nelson Street Lydia Street Maxwell Street East Street	Unknown	9 1 9 7 10 **Total: 36**	Unknown	96 m 6 m 106.5 m 57.5 m 30 m **Total: 296 m**	2 0 1 1 0 **Total: 4**
2016	Queen Street Devine Street Talfourd Street Christina Street	15 1 11 1 **Total: 28**	0 0 0 0 **Total: 0**	0 0 0 0 **Total: 0**	- - - - **Total: -**	0 0 1 0 **Total: 1**
2017	Vidal Street Talfourd Street Brock Street Proctor Street Margaret Street Devine Street Emma Street Richard Street Stuart Street	2 40 3 1 17 4 15 3 16 **Total: 101**	2 17 1 0 13 0 1 0 0 **Total: 34**	0 0 0 0 1 0 0 0 0 **Total: 1**	12 m 214 m 6 m - 118 m - 14 m - - **Total: 364 m**	0 0 0 0 0 0 0 0 0 **Total: 0**

LSL replacements during repair operations. Outside of capital replacement projects, the City replaces public LSLs as encountered during distribution system repairs and related activities. These activities are typically carried out by a City crew of 5 people.

As summarized in Table 1-9, the City has replaced 103 public LSLs during repair and operation activities, between 2005 and 2016. In these instances, LSL replacement is localized to the pit or trench excavated to conduct the repair activity, therefore these projects usually result in only one LSL being replaced at a time. The City estimates a cost of approximately $10,000 per replacement (for the public portion of the LSL) when carried out during repair operations.

Shut-off valve relocation. Sarnia embarked on a program to move shut-off valves (curb stops) from within municipal property to the property line, as part of sidewalk installations. This consisted of moving the shut-off valve and replacing the length of service line between the old shut-off valve and new one with a new copper service line. In some instances, a portion of LSL may remain between the old shut-off valve location and the watermain, however records of this were not maintained. It is noted that this may impact future searches for LSLs via digging a pit to examine the service box through visual inspection, since a portion of the service line adjacent to the watermain might still be lead. The geographic extent and timeframe over which this program was carried out are currently unknown, however this is being explored through a review of historical documentation.

Table 1-9. Public LSLs Replaced Annually During Repair Operations, 2005 to 2016

Year	Public LSLs Replaced	Private LSL Remaining Following Public LSL Replacement		
	Total	Non-Lead	Lead	Unknown
2005	1			1
2006	3			3
2007	3			3
2008	12			12
2009	10	1		9
2010	5			5
2011	4	2	1	1
2012	17	13	3	1
2013	13	7	4	2
2014	11	7	2	2
2015	14		1	13
2016	10	7	1	2
2017	0	Unknown	Unknown	Unknown
Total	103	37	12	54

Note: These totals do not include public LSL replacements conducted as part of capital replacement projects.

Private LSL replacement. To date, the City has focused efforts on public LSL replacement. When lead has been detected above the ODWQS as part of the Schedule 15.1 lead testing program, information packages have been provided to homeowners by the City and the County of Lambton Public Health Unit, communicating the benefits of private LSL replacement. The City has documented some instances of private LSL replacement, where the private LSL was replaced in response to lead testing results; however, the City does not have complete documentation of private LSL replacements. Refer to

Section 2.4 for more information about residential lead testing, communication with homeowners, and water quality following partial LSL replacement.

Development of a LSL database. As part of the development of this LRP, the City has conducted a preliminary records review to establish a "lead zone" within the City. To this end, the City created a georeferenced database of service line materials using the following procedure:

- It was assumed that the practice of installing lead services ceased around 1957. Using GIS, a preliminary list of addresses was developed based on watermains that were originally installed in 1957 or earlier. Addresses on this list were populated with "suspected lead" for the material of both the public and private service lines.
- The City has replaced publicly-owned LSLs as encountered when conducting capital replacement projects and other works. On the streets where capital replacement projects had occurred, and/or where public LSL replacements were carried out unrelated to a capital replacement project, the publicly-owned portion of the service line was updated to "non-lead" (or the actual material, if documented) in the database. If the private service line material had been documented during public LSL replacement, the database was updated accordingly.
- Results from the Schedule 15.1 lead testing program were entered into the database, and will be used, along with future verification sampling, to further refine the number of known and suspected LSLs in the City. Refer to Sections 4.6.1.1 for more information on this approach.

Delineation of lead zone. After developing the LSL database, a preliminary "lead zone" was delineated. The potential geographic extent of known or suspected LSLs is consistent with the area bound by Front St., Exmouth St., Murphy Rd., and Campbell St.

As expected, the potential lead zone is primarily located within the older portion of the City, consistent with the approximate watermain age shown in Figure 1-4. The number of known or suspected LSLs within the "lead zone" is summarized in Table 1-10.

Table 1-10. Summary of Known or Suspected LSLs in the Lead Zone As Of June 2017

Description	Number of Known or Suspected LSLs
Total number of addresses in the "lead zone"	8,787
Number of addresses with known or suspected **public** LSLs	4,483
Number of addresses with known or suspected **private** LSLs	8,643

The following observations can be made from a review of the database:

- The majority of addresses in the lead zone are **suspected** to have a LSL on the **private** side; out of the 8,643, only 18 private services lines are confirmed to be lead, and 24 private service lines are confirmed to be galvanized iron.
- Just over half of the addresses in the lead zone are **suspected** to have a LSL on the **public** side; out of 4,483, only 6 public service lines are **confirmed** to be lead.

Based on the process followed to develop the database and the large number of suspected (as opposed to confirmed) LSLs, this can be taken to represent a conservative estimate. Moving forward, the City intends to refine these numbers through additional records review and verification sampling (refer to Section 4.6.1.1 for more information in this regard).

Summary of expenditures related to LSL replacement. Annual expenditures for capital replacement programs and for lead service line replacement from 2009 to 2016 are summarized in Table 1-11. For reference, the approximate expenditures associated with sampling for the Schedule 15.1 lead testing program are also shown. This information will serve as a baseline for the development of program costs, in Section 4.6.

Table 1-11. Summary of Approximate Expenditures Associated with Public LSL Replacement and Sampling, 2009 to 2017

Year	**Capital Replacement Projects** [1]		**Repair Operations** [1]		**Schedule 15.1 Lead Testing Program Cost** *(Contracted to OCWA)*	**Total** [1]
	Amount Spent	**Public LSLs Removed**	**Amount Spent**	**Public LSLs Removed**		
2009	$7,721,922	32	$100,000	10	$43,700	$7,865,622
2010	$3,873,982	0	$50,000	5	$21,700	$3,945,682
2011	$7,782,380	0	$40,000	4	N/A	$7,822,380
2012	$5,199,487	0	$170,000	17	N/A	$5,369,487
2013	$3,655,581	0	$130,000	13	N/A	$3,785,581
2014	$3,291,194	36	$110,000	11	N/A	$3,401,194
2015	$787,823	0	$140,000	14	N/A	$927,823
2016	$2,399,499	0	$100,000	10	N/A	$2,499,499
2017	$4,939,198	34	N/A	0	N/A	$4,939,198
Estimated Average Cost Per Public LSL Replacement [2]						
During capital replacement projects: $4,000/replacement During repair operations projects: $10,000/replacement						

Notes:

1. Numbers presented in this table may not be comprehensive, as records are currently being reviewed.
2. Estimated cost per replacement includes materials, labour, and restoration (curb gutter, driveway, boulevard, etc.).

SECTION 2

Identification of Internal Corrosion Problems and Sources of Contamination

This section provides a review of and presents sampling results for water quality parameters related to the release of lead and other corrosion by-products, and to corrosion control. The results are used to examine internal corrosion problems, identify sources of contamination in the system, and assess the nature of corrosion occurring in the SWDS. The latter includes an assessment of the magnitude of, extent of, and factors that can promote and/or control lead release. The results will also provide the baseline conditions to develop alternatives for corrosion control.

The primary purpose of this review is to determine the source of lead measured at the tap. If it can be confirmed that lead is not present in the source water, treated water, and distribution system, it can be concluded that the source of lead is from the service lines and/or premise plumbing. Data for corrosion by-products such as iron are also reviewed to determine whether these are present in the source water, treated water, and/or distribution system, and whether they need to be considered in the assessment of corrosion and corrosion control.

2.1 Evaluation of Water Quality Parameter Monitoring Data

A list of water quality data reviewed during the preparation of this LRP is presented in Table 2-1. These data consist of routine monitoring data, special monitoring data (e.g., Drinking Water Surveillance Program, DWSP), and data collected in 2017 to support this LRP. All sampling has been carried out by OCWA, who is contracted by LAWSS to provide operation services for the LAWSS WTP and distribution system sampling within the SWDS on behalf of the City of Sarnia.

Table 2-1. Sources of Data Reviewed as Part of the Lead Reduction Plan

Location	Parameter	Frequency	Duration	Purpose
Raw water	pH Alkalinity	Daily	5 years	Assess baseline water quality, including variability
	Lead Copper Iron	DWSP	5 years	Confirm or dismiss occurrence in the raw water
Treated water	pH Alkalinity Dissolved inorganic carbonate (DIC)	Daily (pH) DWSP	5 years	Assess conditions that may or may not favour lead release Evaluate feasibility of alternative measures for corrosion control
	Chlorine residual	Annual summary of routine monitoring data	7 years	Comment on the oxidation reduction potential of the water
	Conductivity Total dissolved solids Chloride Sulphate	DWSP	5 years	Comment on the potential corrosivity of the water
	Lead Copper Iron	DWSP	5 years	Determine which contaminants need to be controlled in addition to lead, as this will influence the choice for corrosion control measure

Location	Parameter	Frequency	Duration	Purpose
	Manganese Aluminum Calcium Sodium	Daily (aluminum) Annual Report (sodium) DWSP	5 years	Assess potential for secondary impacts
Distribution system	Lead Iron	Schedule 15.1 Summer 2017	5 sampling rounds	Determine which contaminants need to be controlled in addition to lead, as this will influence the choice for corrosion control measure
	pH	Schedule 15.1	5 sampling rounds	Assess pH variability across the system
	Chlorine residual	Annual summary of routine monitoring data	9 years	Comment on the oxidation reduction potential of the water
	Manganese Aluminum Calcium	Summer 2017		Assess potential for secondary impacts
Premise plumbing	Lead	May 2007 (Director's Order) Schedule 15.1 Summer 2017	5 sampling rounds	Assess extent and magnitude of lead at the customer's tap (residential and non-residential)
	pH			Assess pH variability across the system

Notes: DWSP – Drinking Water Surveillance Program is a voluntary program usually implemented quarterly.

2.2 LAWSS WTP Raw and Treated Water Quality

The raw and treated water quality of the LAWSS WTP is summarized in Table 2-2 and Table 2-3, respectively. The discussion that follows focuses on water quality parameters of potential interest in lead release and corrosion control.

Table 2-2. Overview of Raw Water Quality

Parameter	Data Source	Average	Min	Max	No. of Samples
pH	Daily WTP data	8.25	7.82	8.62	1,827
Alkalinity, mg/L as $CaCO_3$	DWSP	79	70	84	12
Carbon; Dissolved Inorganic, mg/L	DWSP	20.0	18.9	21.2	14
Hardness, mg/L as $CaCO_3$	DWSP	98	95	103	4
Conductivity, µS/cm	DWSP	216	205	239	14
Solids; Dissolved, mg/L	DWSP	116	113	118	2
Turbidity, NTU	Daily WTP data	2.50	0.1	217	1,827
Temperature, °C	Daily WTP data	13.1	4.0	25.3	1,827
Chloride, mg/L	DWSP	7.2	6.3	10.9	16
Sulphate, mg/L	DWSP	16.2	15.4	17.4	13
Lead, µg/L	DWSP	0.1	0	0.2	15
Copper, µg/L	DWSP	3.5	1.1	7.3	15

Parameter	Data Source	Average	Min	Max	No. of Samples
Iron, µg/L	DWSP	19	0	100	15
Manganese, µg/L	DWSP	1.7	0.6	7.8	16
Aluminum, µg/L	DWSP	13	2.5	69	15
Calcium, mg/L	DWSP	26.8	25.3	28.2	5
Magnesium, mg/L	DWSP	7.8	7.5	8.0	3
Sodium, mg/L	DWSP	4.5	4.3	4.7	4
Fluoride, mg/L	DWSP	0.08	0.07	0.08	3
Carbon; Dissolved Organic, mg/L	DWSP	1.5	1.1	1.8	14
Carbon; Total Organic, mg/L	DWSP	1.7	0.9	2.3	15
Colour; True, TCU	DWSP	2.6	1.1	10.2	15
Langeliers Index Calculation	DWSP	0.167	0.074	0.26	2
Saturation pH Estimated	DWSP	7.99	7.97	8.01	2
Phosphorus; Phosphate, mg/L	DWSP	0.0032	0.0005	0.009	14
Phosphorus; Total, mg/L	DWSP	0.0047	0.002	0.006	7
Silicon; Reactive Silicate, mg/L	DWSP	0.84	0.70	0.98	14

Notes: DWSP – Drinking Water Surveillance Program

Table 2-3. Overview of Treated Water Quality

Parameter	Ontario Guideline or Standard [1]	Data Source	Average	Min	Max	No. of Samples
pH	OG: 6.5 to 8.5	Daily WTP data DWSP	7.56 7.82	6.75 7.53	7.91 8.10	1,826 18
Alkalinity, mg/L as $CaCO_3$	OG: 30 to 500 mg/L as $CaCO_3$	DWSP	72	65	78	14
Carbon; Dissolved Inorganic, mg/L	N/A	DWSP	18.5	17.1	20.1	14
Hardness, mg/L as $CaCO_3$	OG: 80 to 100 mg/L as $CaCO_3$	DWSP	98	95	102	4
Conductivity, µS/cm	N/A	DWSP	229	217	254	16
Solids; Dissolved, mg/L	AO: 500 mg/L	DWSP	139	120	154	7
Turbidity, NTU	AO: 5 NTU (at point of consumption)	Daily WTP data	0.054	0.036	0.25	1,800
Temperature, °C	AO: 15 °C	Daily WTP data	10.8	1.5	22.7	1,823
Chloride, mg/L	AO: 250 mg/L	DWSP	9.4	8.2	11.1	16
Sulphate, mg/L	AO: 500 mg/L	DWSP	22.5	16.2	24.9	15
Lead, µg/L	MAC: 10 µg/L (measured at the tap)	DWSP	0.01	0	0.1	15

Parameter	Ontario Guideline or Standard [1]	Data Source	Average	Min	Max	No. of Samples
Copper, µg/L	AO: 1,000 µg/L	DWSP	0.7	0.5	2.4	15
Iron, µg/L	AO: 300 µg/L	DWSP	1.3	0	10	15
Manganese, µg/L	AO: 50 µg/L [2]	DWSP	0.7	0.1	7.8	16
Aluminum, µg/L	OG: 100 µg/L	Daily WTP data DWSP	92 89	7 3.4	2,380 177	1,718 15
Calcium, mg/L	N/A	DWSP	26.7	25.6	27.9	5
Magnesium, mg/L	N/A	DWSP	7.8	7.6	8.0	3
Sodium, mg/L	AO: 200 mg/L; Notify local Medical Officer of Health if above 20 mg/L	LAWSS annual reports DWSP	Not reported 6.3	5.7 6.1	6.1 6.6	8 4
Fluoride, mg/L	MAC: 1.5 mg/L	LAWSS annual reports	Not reported	0	2.00	61,320
Free chlorine residual, mg/L	Minimum: 0.05 mg/L MAC: 4.0 mg/L	LAWSS annual reports	Not reported	0.18	2.45	61,320
Carbon; Dissolved Organic, mg/L	AO: 5 mg/L	DWSP	1.2	0.8	1.4	14
Carbon; Total Organic, mg/L	N/A	DWSP	1.4	1.2	1.5	7
Colour; True, TCU	AO: 5 TCU	DWSP	0.5	0.2	1.1	13
Langeliers Index Calculation	N/A	DWSP	-0.127	-0.260	0.007	2
Saturation pH Estimated	N/A	DWSP	8.03	8.02	8.05	2
Phosphorus; Phosphate, mg/L	N/A	DWSP	0.0032	0.0005	0.0077	14
Phosphorus; Total, mg/L	N/A	DWSP	0.0046	0.002	0.005	7
Silicon; Reactive Silicate, mg/L	N/A	DWSP	0.90	0.72	1.04	14

Notes:

1. MAC – Maximum Acceptable Concentration; AO – Aesthetic Objective; OG – Operational Guideline; DWSP – Drinking Water Surveillance Program.
2. Health Canada has proposed to reduce the AO for manganese from 50 to 20 µg/L, and has proposed a new health-based MAC of 100 µg/L.

pH. The daily raw and treated water pH recorded by SCADA at the LAWSS WTP between 2012 and 2016 is shown in Figure 2-1. Seasonal variability in raw water pH was observed (higher pH during summer months) and ranged between 7.82 and 8.62. As expected from the use of acidified alum (which has been used at the WTP for at least 15 years), the treated water pH was lower than that of the raw water, ranging between 6.75 and 7.91, though it was typically (98% of measurements) within the range of 7.3 to 7.8. The average treated water pH over this historic period was 7.56. Generally, the solubility of metals (i.e., their tendency to dissolve in water) decreases with increasing pH. In addition, the variability in pH plays an important role in scale stability (and metals release), with constant pH values promoting more stable scale (corrosion products) and variable pH resulting in less stable scale and potential release. The treated water pH variability observed between 2012 and 2016 was ±0.25 pH units based on the typical pH range of 7.3 to 7.8, however the variability considering the minimum and maximum observed pH was high (-0.81/+0.35 pH units). Tighter control of treated water pH (i.e., ±0.1 pH units) promotes more stable scale and minimizes subsequent metals release, dirty water complaints, taste and odour problems, and microbial sloughing, and is usually preferred for control corrosion.

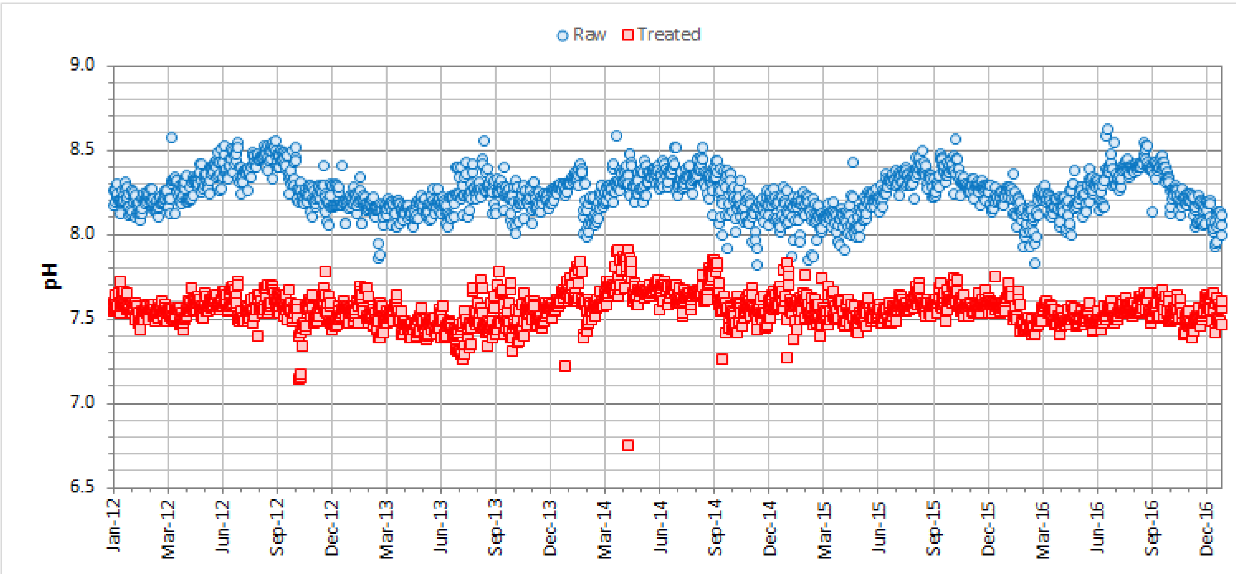

Figure 2-1. Raw and Treated Water pH, 2012 to 2016

Alkalinity and dissolved inorganic carbonate (DIC). Limited DWSP data were available for treated water alkalinity and DIC; these are summarized in Table 2-2 and Table 2-3. Between 2012 and 2016, treated water alkalinity was 72 mg/L as $CaCO_3$ on average, and ranged between 65 and 78 mg/L as $CaCO_3$. This moderate level of alkalinity (which is typical of the Great Lakes) suggests that the water provides some buffering capacity or resistance to pH change. This is confirmed by the DIC available in the treated water, which ranged from 17.1 to 20.1 mg/L (average of 18.5 mg/L) between 2012 and 2016. The treated water's pH, alkalinity, and DIC influence lead solubility and affect the feasibility of corrosion control using a treatment-based approach; in general, the influence of pH on lead solubility is stronger in low DIC waters. These parameters will be of interest in Section 4.1 as part of the identification of corrosion control alternatives.

Occurrence of corrosion-related metals. Limited DWSP data were available for raw and treated water lead, copper, and iron. As expected, concentrations of **lead** in the raw (average of 0.1 µg/L; max of 0.2 µg/L) and treated water (average of 0.01 µg/L; max of 0.1 µg/L) are negligible, as are concentrations of **copper** in raw (average of 3.5 µg/L; max of 7.3 µg/L) and treated water (average of 0.7 µg/L; max of 2.4 µg/L). **Iron** has been detected in the raw water at low concentrations (average of 19 µg/L) however the maximum concentration observed (100 µg/L) is one third of the AO (300 µg/L). Iron in treated water, however, is negligible (average of 1.3 µg/L; max of 10 µg/L). From these data, it can be assumed that treated water is not a significant source of the corrosion-related metals, lead, copper, and iron.

Other water quality parameters of interest. Limited DWSP data were available for raw and treated water aluminum, calcium, sodium, and manganese. Daily treated water aluminum data were available and are plotted in Figure 2-2. The concentration of aluminum, calcium, sodium, and manganese in the treated water are relevant due to their potential to cause secondary impacts when evaluating the feasibility of applicable corrosion control treatment alternatives, as described in the following paragraphs.

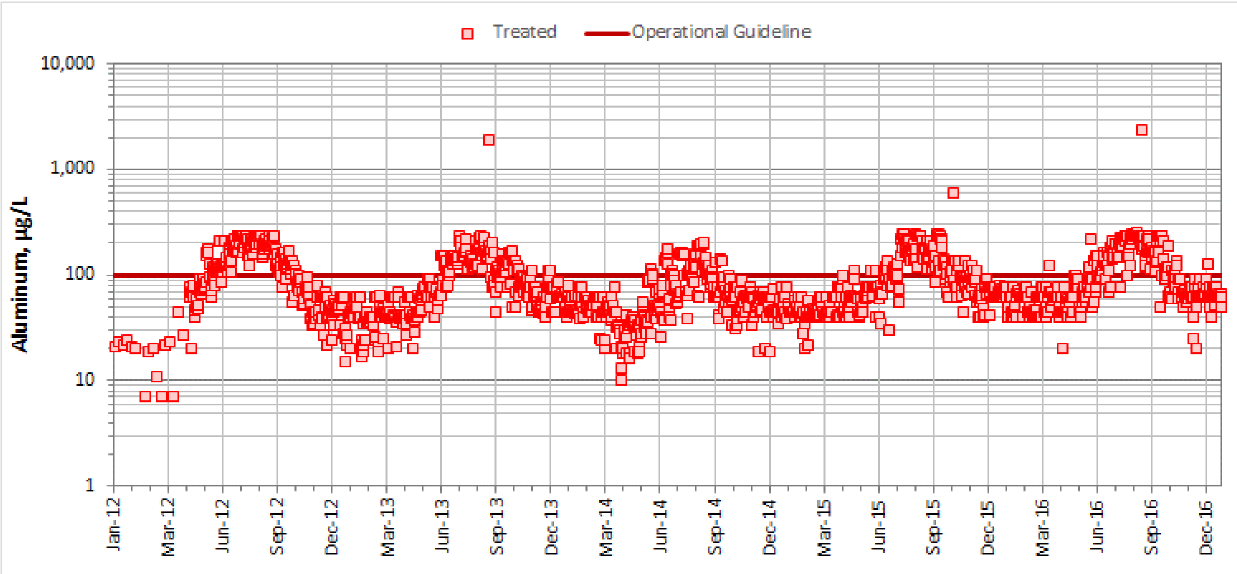

Figure 2-2. Treated Water Aluminum, 2012 to 2016

Aluminum can react with phosphate to form a precipitate in the distribution system, which can lead to aesthetic impacts (customer complaints) and can reduce corrosion control efficacy. This secondary impact has been observed to occur in systems where aluminum in the treated water exceeds the OG of 100 µg/L. Aluminum can be present in treated water as a result of treatment processes such as coagulation with aluminum-based coagulants or the use of lime. As with several other Great Lakes water users, treated water from the LAWSS WTP seasonally exceeds the OG for aluminum. The annual average concentration of aluminum (92 µg/L) is just below the OG, while the summer average, at 126 µg/L, exceeds the OG. In the past five years, three instances of very high aluminum concentrations have been observed in the treated water (values of 2,380 µg/L, 1,920 µg/L, and 610 µg/L); however, these appear to be outliers. Excluding these three values, the maximum concentration observed during the summer months is typically around 250 µg/L, which is more than twice the OG. Based on the seasonally high treated water aluminum levels, it is expected that the distribution system scale contains appreciable concentrations of aluminum, and that phosphate may precipitate in the distribution system if a phosphate-based corrosion control approach is implemented.

Like aluminum, **calcium** can react with phosphate to form a precipitate in the distribution system, which can lead to aesthetic impacts (customer complaints) and can reduce corrosion control efficacy. Calcium is also used to assess the potential of calcium carbonate precipitation. Natural hardness of the source water is usually the source of calcium. From limited DWSP data, the concentration of calcium in the raw and treated water historically ranged between 26 and 28 mg/L in treated water, with an average value of 27 mg/L.

Background levels of **sodium** are used to assess whether corrosion control treatment alternatives will cause the level of sodium to exceed the AO (200 mg/L) or the health-based level above which the Local Medical Officer of Health must be notified (20 mg/L). Naturally occurring sodium in the raw water as well as the use of sodium-containing treatment chemicals may contribute to the concentration of sodium in treated water. Limited DWSP data were available for raw and treated water sodium, and treated water sodium data were available from the LAWSS Annual Report. Raw water sodium ranged between 4.3 and 4.7 mg/L, with an average value of 4.5 mg/L. Treated water sodium was slightly higher due to the use of sodium hypochlorite in the treatment process, ranging between 5.7 and 6.6 mg/L, with an average value of 6.3 mg/L.

The presence of **manganese** in the raw and/or treated water may influence the selection of corrosion control treatment. Additionally, low levels of manganese can accumulate in distribution system scale to significant concentrations and can be released at a later time at levels of concern. Naturally occurring manganese in the raw water as well as trace concentrations in treatment chemicals may contribute to manganese in the treated water. From limited DWSP data, the treated water manganese, was determined to range between 0.1 and 7.8 µg/L, with an average value of 0.7 µg/L. These concentrations are well below the current AO of 50 µg/L, and Health Canada's proposed AO of 20 µg/L and proposed health-based maximum acceptable concentration (MAC) of 100 µg/L.

2.3 Sarnia Water Distribution System

The water quality of the Sarnia Water Distribution System is summarized in Table 2-4. Water quality parameters monitored through Schedule 15.1 sampling are summarized in Table 2-5. The discussion that follows focuses on water quality parameters of potential interest in lead release and corrosion control.

Table 2-4. Overview of Distribution System Water Quality

Parameter	Data Source	Average	Min	Max	No. of Samples
pH	Schedule 15.1 Summer 2017 sampling	7.64 7.48	7.36 7.00	8.05 7.70	160 12
Alkalinity, mg/L as $CaCO^{3}$	Schedule 15.1 Summer 2017 sampling	76 75	66 70	145 105	160 12
Chloride, mg/L	Summer 2017 sampling	10.2	9.7	12.0	10
Sulphate, mg/L	Summer 2017 sampling	21	20	22	10
Lead, µg/L	Director's Order Schedule 15.1 Summer 2017 sampling	0.43 0.17 0.19	0.21 <0.01 <0.01	0.65 1.34 0.47	3 160 12
Iron, µg/L	Summer 2017 sampling	Total: 488 Dissolved: 87	T: 17 D: <7	T: 1,120 D: 382	10
Manganese, µg/L	Summer 2017 sampling	Total: 24.8 Dissolved: 3.7	T: 0.4 D: 0.1	T: 59.2 D: 18.8	10
Aluminum, µg/L	Summer 2017 sampling	Total: 555 Dissolved: 163	T: 191 D: 86	T: 1,530 D: 367	10
Calcium, mg/L	Summer 2017 sampling	28.8	27.6	32.1	10
Oxidation-reduction potential, mV	Summer 2017 sampling	638	512	686	10
Free chlorine residual, mg/L	Sarnia annual reports Summer 2017 sampling	Not reported 1.26	0.18 0.69	2.16 1.63	19,740 9
Trihalomethanes; Total, µg/L	Sarnia annual reports	18	16	28	9

Table 2-5. Average and Range of Schedule 15.1 Sampling Results for the SWDS

Sampling Round	No. of Samples	Lead, µg/L	pH	Alkalinity, mg/L as $CaCO_3$
Round 1 – Winter 2008	16	A: 0.28 R: 0.06 to 0.68	A: 7.46 R: 7.42 to 7.51	A: 73 R: 70 to 76
Round 2 – Summer 2008	16	A: 0.14 R: 0.04 to 0.44	A: 7.60 R: 7.49 to 7.72	A: 75 R: 70 to 80
Round 3 – Winter 2009	16	A: 0.10 R: 0.02 to 0.25	A: 7.44 R: 7.39 to 7.52	A: 75 R: 72 to 78
Round 4 – Summer 2009	16	A: 0.10 R: 0.05 to 0.31	A: 7.70 R: 7.57 to 7.83	A: 78 R: 66 to 83
Round 5 – Winter 2010	16	A: 0.35 R: 0.06 to 1.34	A: 7.52 R: 7.36 to 7.67	A: 76 R: 67 to 83
Round 6 – Winter 2011	8	A: 0.14 R: 0.02 to 0.22	A: 7.71 R: 7.62 to 7.92	A: 90 R: 73 to 145
Round 7 – Winter 2012	8	A: 0.11 R: 0.02 to 0.24	A: 7.58 R: 7.51 to 7.69	A: 75 R: 66 to 78
Round 8 – Summer 2012	8	A: 0.08 R: 0.03 to 0.22	A: 7.77 R: 7.70 to 7.91	A: 71 R: 70 to 71
Round 9 – Winter 2013	8	A: 0.22 R: 0.02 to 0.70	A: 7.55 R: 7.42 to 7.71	A: 71 R: 68 to 73
Round 10 – Summer 2013	8	A: 0.25 R: 0.03 to 1.32	A: 7.56 R: 7.45 to 7.71	A: 74 R: 71 to 79
Round 11 – Winter 2014	8	A: 0.11 R: 0.01 to 0.54	A: 7.82 R: 7.77 to 7.89	A: 77 R: 73 to 79
Round 12 – Summer 2014	8	A: 0.07 R: 0.02 to 0.22	A: 7.98 R: 7.93 to 8.05	A: 79 R: 76 to 81
Round 13 – Winter 2015	8	A: 0.11 R: 0.01 to 0.31	A: 7.59 R: 7.40 to 7.70	A: 78 R: 77 to 79
Round 14 – Summer 2015	8	A: 0.14 R: 0.05 to 0.30	A: 7.90 R: 7.80 to 8.00	A: 77 R: 73 to 80
Round 15 – Winter 2016	8	A: 0.12 R: 0.01 to 0.57	A: 7.81 R: 7.80 to 7.90	A: 74 R: 72 to 79

Notes: Per Schedule 15.1, winter sampling occurs between December 15 and April 15, and summer sampling occurs between June 15 and October 15.

pH. Though a tight control (±0.1 pH units) of treated water pH is recommended, various processes can contribute to a greater degree of pH variability in the distribution system (for example, localized microbial activity can act to lower pH, while mortar linings and the corrosion of concrete pipe can increase pH), therefore a wider range of ±0.3 pH units for distribution system pH variability is considered acceptable. The Sarnia Distribution System pH, as measured during Schedule 15.1 sampling, is shown in Figure 2-3. Distribution system pH (average of 7.64, with a range of 7.36 to 8.05) has been observed to be higher than the treated water pH (average of 7.56, with a range of 6.75 to 7.91; from daily WTP data). The variability of distribution system pH (-0.28/+0.41 pH units) is based on data collected from different locations within the distribution system as part of Schedule 15.1 sampling, therefore it is not necessarily comparable to the variability in treated water pH.

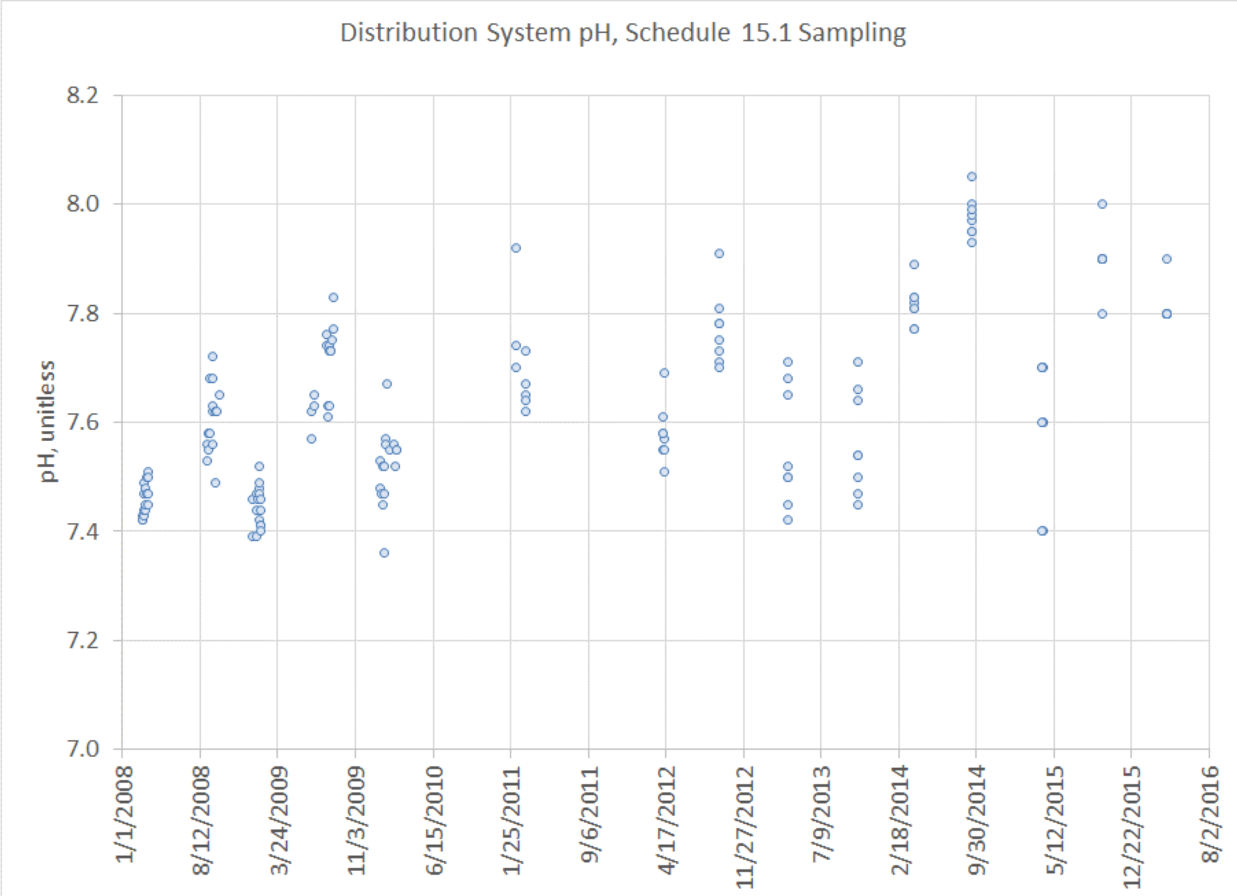

Figure 2-3. Distribution System pH from Schedule 15.1 Sampling, 2008 to 2016

Alkalinity. Alkalinity in the distribution system should be such that it provides adequate buffering capacity to allow for the maintenance of a stable pH (which can be achieved when alkalinity is above 0.1 meq/L or 5 mg/L as $CaCO_3$), without causing calcium carbonate precipitation (calcium carbonate precipitation potential or CCPP below 7 mg/L as $CaCO_3$ is preferred). As can be seen in Figure 2-4, alkalinity in the Sarnia Distribution System as measured during Schedule 15.1 sampling is well above 0.1 meq/L, meaning that it provides sufficient buffering capacity to promote pH stability. The variability in the alkalinity measured in the distribution system is low, with the exception of January 2011 when the alkalinity was recorded at 145 mg/L as $CaCO_3$ at one site, which is nearly double the average concentration (76 mg/L as $CaCO_3$) measured in the Sarnia Distribution System. Under typical water quality conditions observed in the Sarnia Distribution System, the alkalinity is such that it does not cause the CCPP to exceed 7 mg/L as $CaCO_3$, meaning that excessive precipitation of calcium carbonate is not expected under existing conditions in this system.

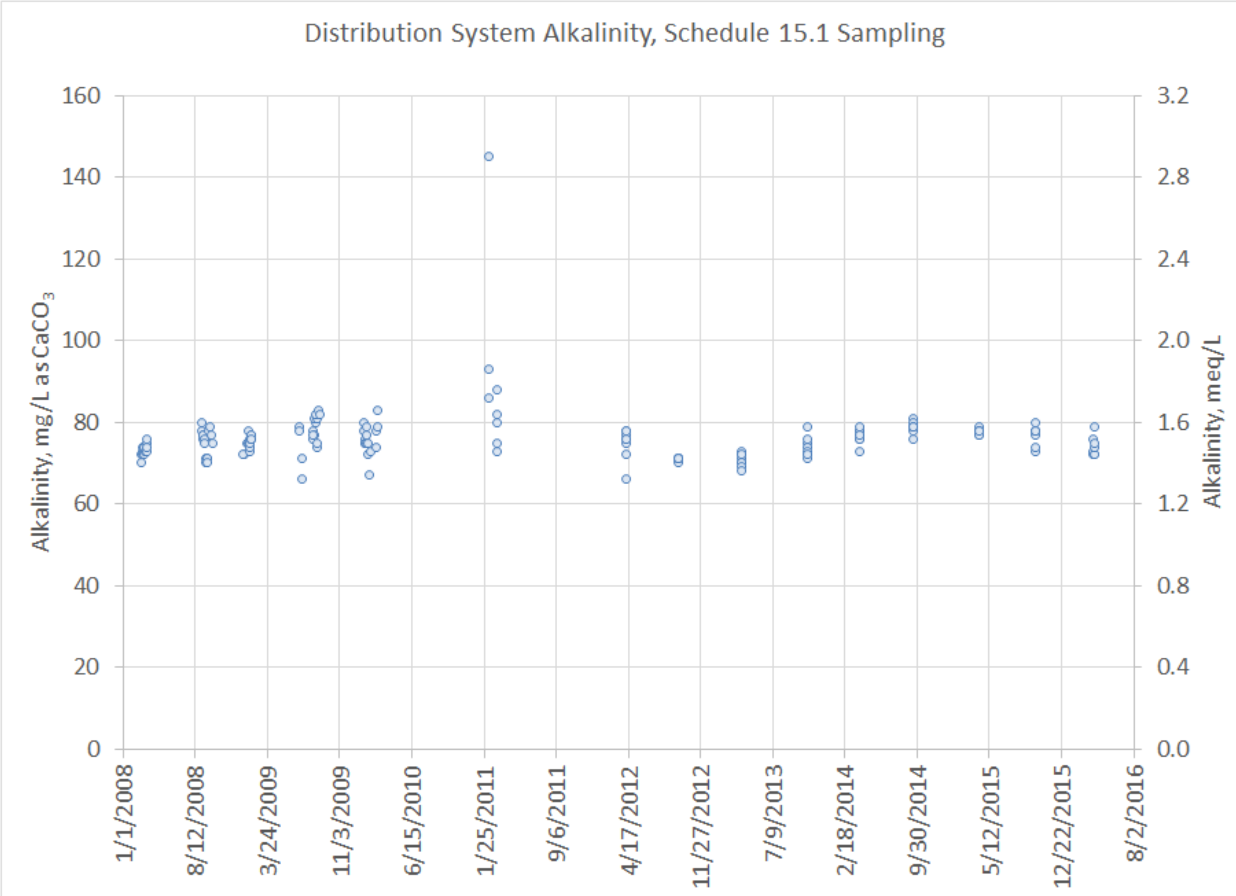

Figure 2-4. Distribution System Alkalinity from Schedule 15.1 Sampling, 2008 to 2016

Occurrence of corrosion-related metals. Various materials used in distribution system components may be a source of **lead** including brass and bronze used for fittings, valves, and meters; zinc coatings and iron scale layers on galvanized steel pipes; leaded gaskets; and hydrant components made of lead. The concentration of lead measured in the Sarnia Distribution System during Schedule 15.1 sampling is shown in Figure 2-5; average, minimum, and maximum concentrations during winter and summer rounds are shown in Figure 2-6. Additionally, three samples collected from hydrants were analyzed for lead during the sampling conducted in response to the 2007 Director's Order (these results are summarized along with the residential and non-residential results in Table 2-6), and twelve samples were collected from hydrants and analyzed for lead during the summer 2017 sampling. As expected, lead in the Sarnia Distribution System is low, with a maximum observed concentration of 1.3 µg/L. Based on these data, the distribution system is not considered to be a source of lead measured at the tap.

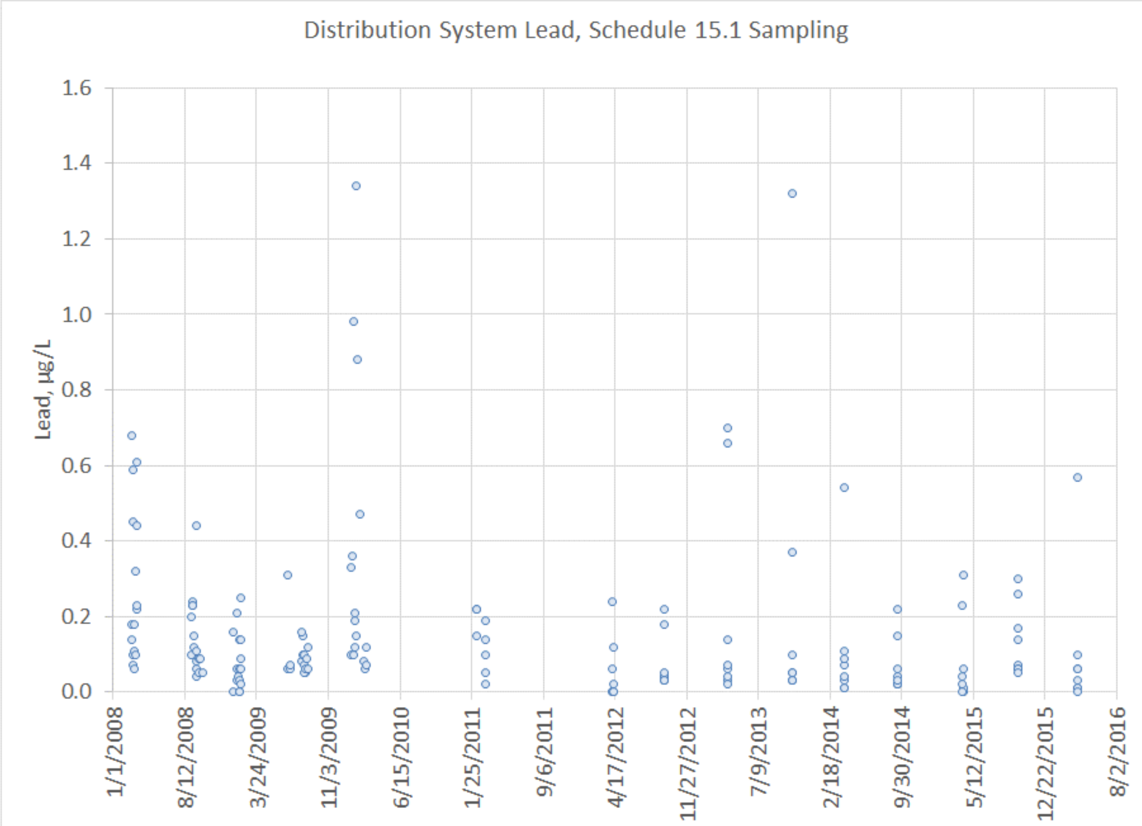

Figure 2-5. Distribution System Lead from Schedule 15.1 Sampling, 2008 to 2016

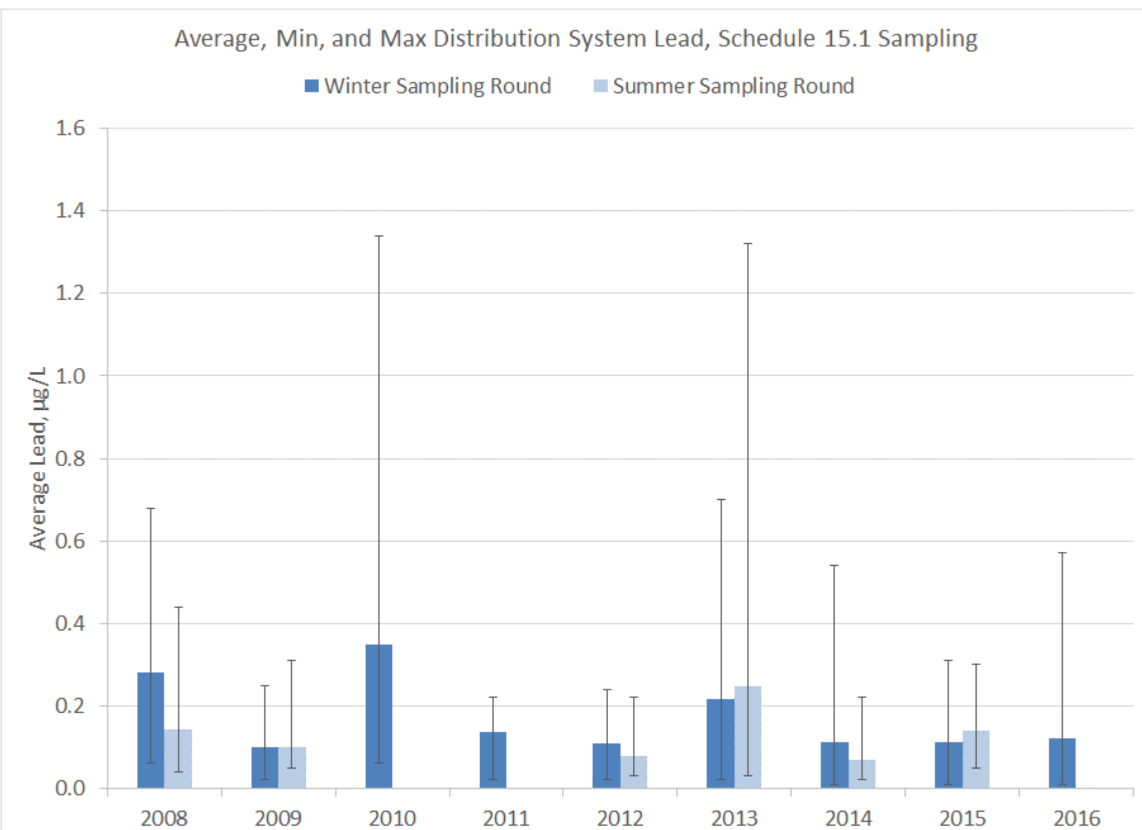

Figure 2-6. Comparison of Distribution System Lead During Winter and Summer Sampling Rounds, 2008 to 2016

Samples collected from ten hydrants during the summer of 2017 were analyzed for total and dissolved **iron** (Figure 2-7). These samples were collected from hydrants flowing at a velocity (1,000 to 2,000 L/min or 250 to 500 USgal/min) sufficient to disrupt the upper loose layer of pipe scale, and therefore results are representative of the distribution system's scale composition and not bulk water quality. In samples collected from hydrants fed by cast iron mains, iron was present at high concentrations (up to 1,120 µg/L), indicating that iron corrosion is occurring which is typical of older unlined cast iron watermains. The majority of the iron measured in these samples was present in the particulate form, ranging from 63% to 99%. Dissolved iron in one sample was significant (382 µg/L), suggesting porous scale in the area that is subject to easy iron release. The concentration of iron measured in samples collected from a hydrant fed from a ductile iron watermain was below the AO, and that measured in samples collected from hydrants fed from PVC watermains was negligible, as expected.

Though high levels of iron were present in the scale from cast iron watermains, the City has not typically received discoloured water complaints. Due to the natural corrosion of these cast iron watermains, however, it is likely that iron is present in the scale formed over decades on lead service lines and premise plumbing, which has implications for the sorption of lead and its subsequent release. This could be confirmed through analysis of iron in residential lead scale samples. Like aluminum and calcium, iron can also react with phosphate to form a precipitate in the distribution system, which can lead to aesthetic impacts (customer complaints) and can reduce corrosion control efficacy. The high concentrations of iron measured in the hydrant samples suggests that the City would benefit from a watermain cleaning program (such as unidirectional flushing), particularly if a treatment-based approach to corrosion control is undertaken.

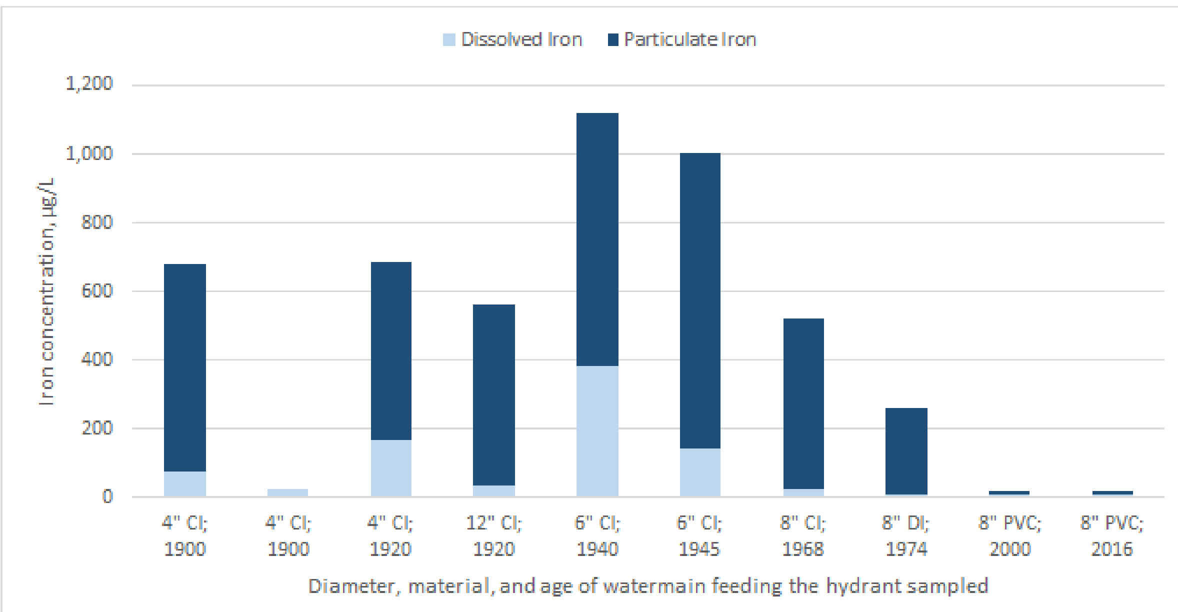

Figure 2-7. Dissolved and Particulate Iron Measured in Watermain Scale from Hydrant Samples, 2017

Other water quality parameters of interest. Samples collected from hydrants during the summer of 2017 (as described above for iron) were also analyzed for total and dissolved aluminum, total and dissolved manganese, total calcium, chloride, sulphate, and oxidation-reduction potential.

As shown in Figure 2-8, **aluminum** was present in pipe scale at high concentrations, and was predominantly present in the particulate form. This confirms that aluminum has precipitated and accumulated in the distribution system over decades of discharging treated water with seasonally high concentrations of aluminum (Figure 2-2). Additionally, sources of elevated aluminum can be found on the fresh surfaces of cement mortar lining that has not been thoroughly flushed after the pipe has been placed back in service. The sample collected from a hydrant fed by a ductile iron main had a significantly higher concentration of aluminum (1,530 µg/L) which suggests that this watermain had recently been relined. If a phosphate-based corrosion control approach is implemented, a unidirectional flushing program will be required to remove this accumulation of aluminum, which will otherwise react with phosphate. This potential impact is discussed further in Section 4.5.

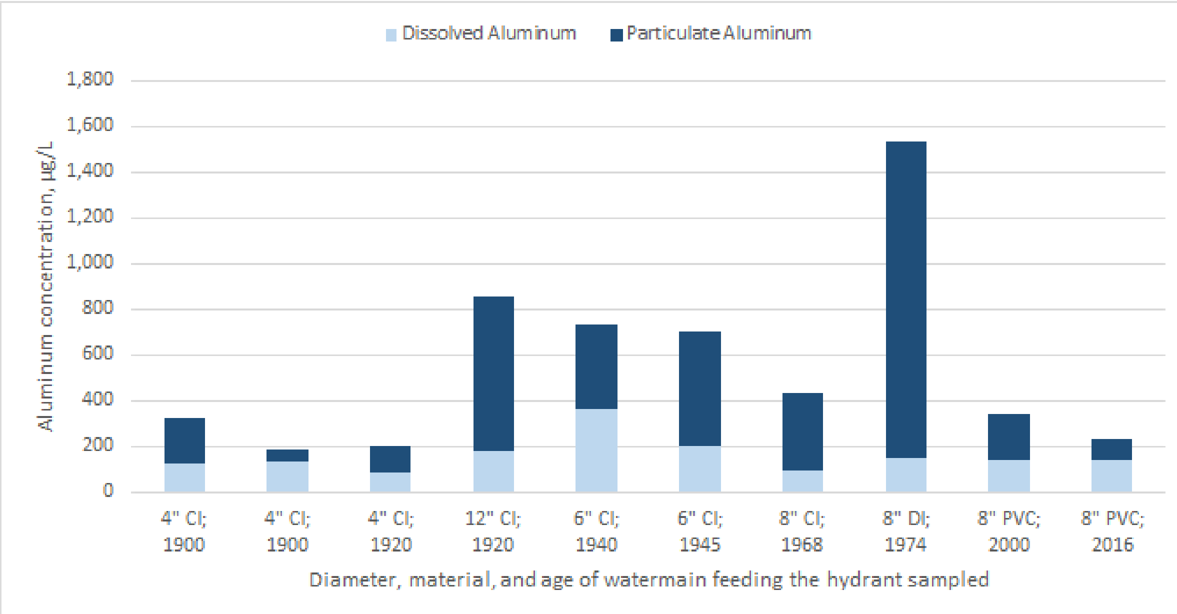

Figure 2-8. Dissolved and Particulate Aluminum Measured in Watermain Scale from Hydrant Samples, 2017

Manganese was also present in the pipe scale at appreciable concentrations (Figure 2-9) considering the trace level of manganese typically observed in the treated water (Table 2-3). The high proportion of particulate manganese suggests that manganese is most likely associated with other metals such as iron. If treatment-based corrosion control is implemented, pipe scales may destabilize during the acclimation period, which could potentially result in the release of manganese (potentially above the AO of 50 µg/L) and other corrosion by-products such as iron which are present in the pipe scale.

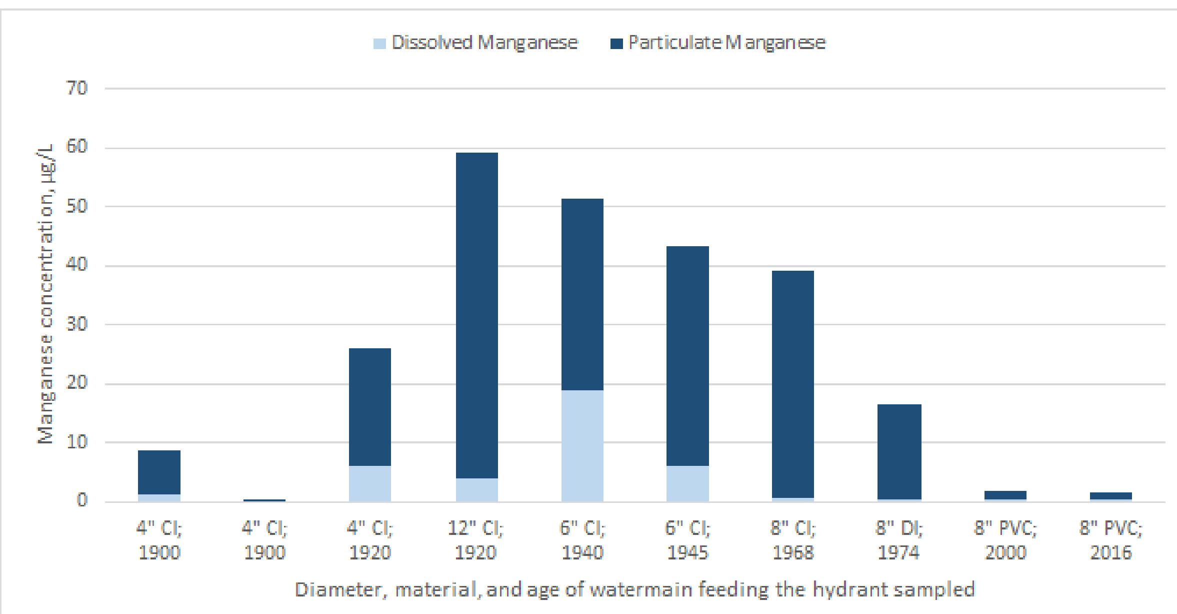

Figure 2-9. Dissolved and Particulate Manganese Measured in Watermain Scale from Hydrant Samples, 2017

Calcium was present in the pipe scale (ranging from 27 to 32 mg/L) at concentrations just above the treated water concentration (ranging from 25 to 28 mg/L), suggesting that a minor amount of calcium carbonate precipitation occurs under existing conditions in the Sarnia Distribution System. The potential for calcium carbonate precipitation to increase under a pH-based treatment approach for corrosion control is discussed further in Section 4.1.2.1. Additionally, calcium can react with phosphate to form a precipitate in the distribution system, which can lead to aesthetic impacts (customer complaints) and can reduce corrosion control efficacy.

The **oxidation-reduction potential (ORP)** and free chlorine residual measured in samples collected from hydrants is shown in Figure 2-10. The ORP measured in samples with a free chlorine residual above 1.0 mg/L (636 to 686 mV) was lower than would be expected (typically 690 to 730 mV). However the lower ORP could be due to the ORP probe or due to mature, anaerobic biofilm in the underlying scale.

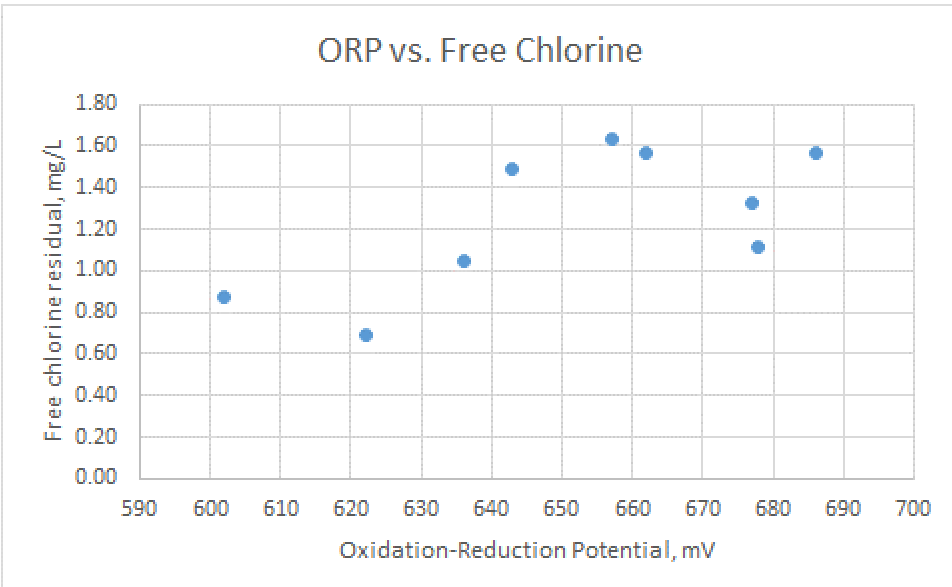

Figure 2-10. ORP and Free Chlorine from Hydrant Samples, 2017

A low **chloride to sulphate mass ration (CSRM)** is beneficial for minimizing galvanic corrosion, particularly that occurring from soldered joints and brass. The CSMR measured in the Sarnia Water Distribution system was between 0.45 and 0.55, which can be considered as the baseline level for this system. An increase in CSMR resulting from treatment changes and/or changes in source water may increase the potential for lead release.

2.4 Premise Plumbing

2.4.1 2007 Director's Order

In May of 2007, 36 municipalities across Ontario including Sarnia were issued a Provincial Order by the MOE's Chief Drinking Water Inspector to sample for lead at the tap. Under this Order, samples were collected at 20 residential homes after a five-minute flush of the tap. Each home required a corresponding sample from a hydrant near the home. Results from this sampling are summarized in Table 2-6. Lead was present at concentrations above 10 µg/L in 19% (4 samples) of the 21 samples collected at residential and non-residential sites. The maximum lead level measured during this testing was 32.4 µg/L.

Table 2-6. Results from 2007 Director's Order Sampling

Parameter		Plumbing Locations (Residential and Non-Residential)	Hydrants (Distribution)
No. of samples		21	3
Lead, µg/L	Average	5.7	0.43
	Min	0.06	0.21
	Max	32.4	0.65
	90th Percentile	11.5	0.61
	Number >10 µg/L	4	0
	Percentage >10 µg/L	19%	0%

Notes: Sampling protocol not recorded, but believed to be a 5-minute flush.

2.4.2 Schedule 15.1 Sampling

Sarnia participated in Schedule 15.1 residential and non-residential sampling between 2008 and 2010, after which regulatory relief from sampling in premise plumbing was received[1]. Samples were collected using a five-minute flush followed by a 30-minute stagnation protocol, per the Schedule 15.1 requirements. Results from this testing are summarized in Table 2-7 and Figure 2-11 to Figure 2-16. Key observations from these data are discussed within the following paragraphs.

Table 2-7. Summary of Residential and Non-Residential Samples, Schedule 15.1 Lead Sampling Program

Parameter		**Round 1** Winter 2008	**Round 2** Summer 2008	**Round 3** Winter 2009	**Round 4** Summer 2009	**Round 5** Winter 2010
Sampling round duration		Feb. 25 to Apr. 14, 2008	Jul. 8 to Oct. 7, 2008	Jan. 8 to Feb. 3 2009	Jun. 29 to Sep. 24 2009	Jan. 13 to Mar. 8 2010
No. of samples	Total	90	89	88	90	88
	Residential	82	81	80	82	80
	Non-residential	8	8	8	8	8
Lead, µg/L	Average	5.2	3.0	1.9	2.6	0.9
	Min	0.04	0.06	0.08	0.08	0.08
	Max	43.8	20.2	46.2	39.4	11.7
	90th Percentile	14.2	11.2	2.9	7.5	1.6
	Number >10 µg/L	13	11	4	7	1
	Percentage >10 µg/L	14%	12%	5%	8%	1%
pH	Average	7.5	7.6	7.5	7.7	7.5
	Min	7.4	7.3	7.4	7.5	7.4
	Max	7.7	7.9	7.7	7.9	7.7

Note: Per Schedule 15.1, winter sampling occurs between December 15 and April 15, and summer sampling occurs between June 15 and October 15. The date range shown represents the actual time period over which samples were collected during each round.

[1] Distribution sampling under Schedule 15.1 continued beyond 2010 as discussed in Section 2.3.

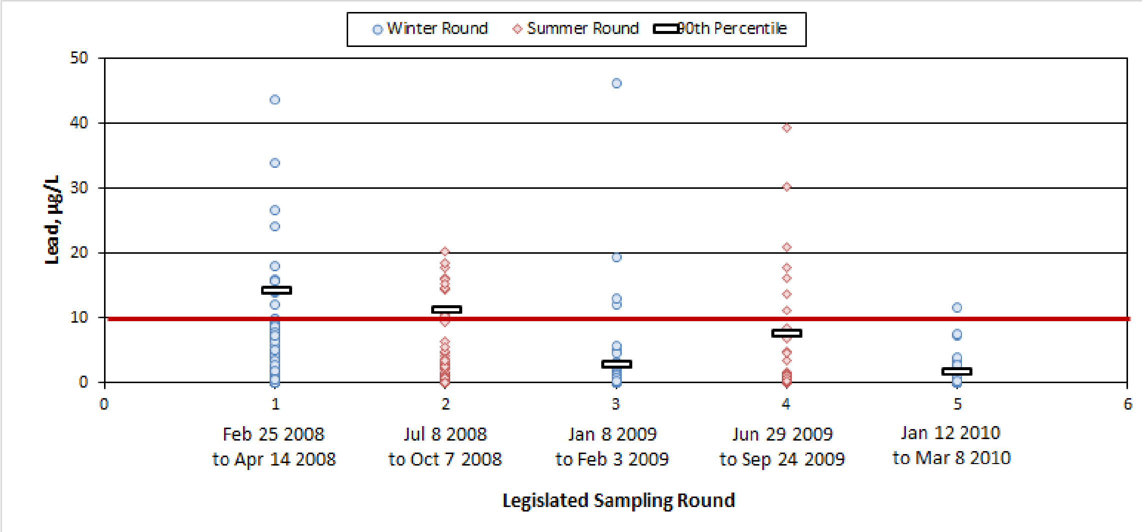

Figure 2-11. Residential and Non-Residential Schedule 15.1 Legislated Lead Results, Spread by Sampling Round

Exceedance of MAC. More than the allowable 10% of samples collected during rounds 1 and 2 exceeded the MAC of 10 µg/L, however more than 90% of samples were below the MAC during rounds 3, 4, and 5 (Figure 2-11). Since lead release increases at higher temperature, it is notable that the MAC was not exceeded by more than 10% of samples in Round 4, which was a summer sampling round.

Geographic extent of lead release. The geographic extent of lead exceedances (Figure 2-13) was limited to the City's estimated lead zone**Error! Reference source not found.**. Watermain materials in exceedance locations included PVC and cast iron.

Magnitude of lead release. Lead was greater than 5 µg/L at 14% (62) of the 445 residential and non-residential sites sampled during all five rounds of Schedule 15.1 sampling, whereas lead was above 10 µg/L at only 8% (36) of the sites. The highest lead result observed during Schedule 15.1 sampling was 46.2 µg/L, which was identified as a post-LSL-replacement lead spike (see subsequent paragraph about impact of LSL replacement on lead release). The majority (86%) of sites sampled had lead levels at or below 5 µg/L. These values are indicative of the degree to which lead can be released into the water.

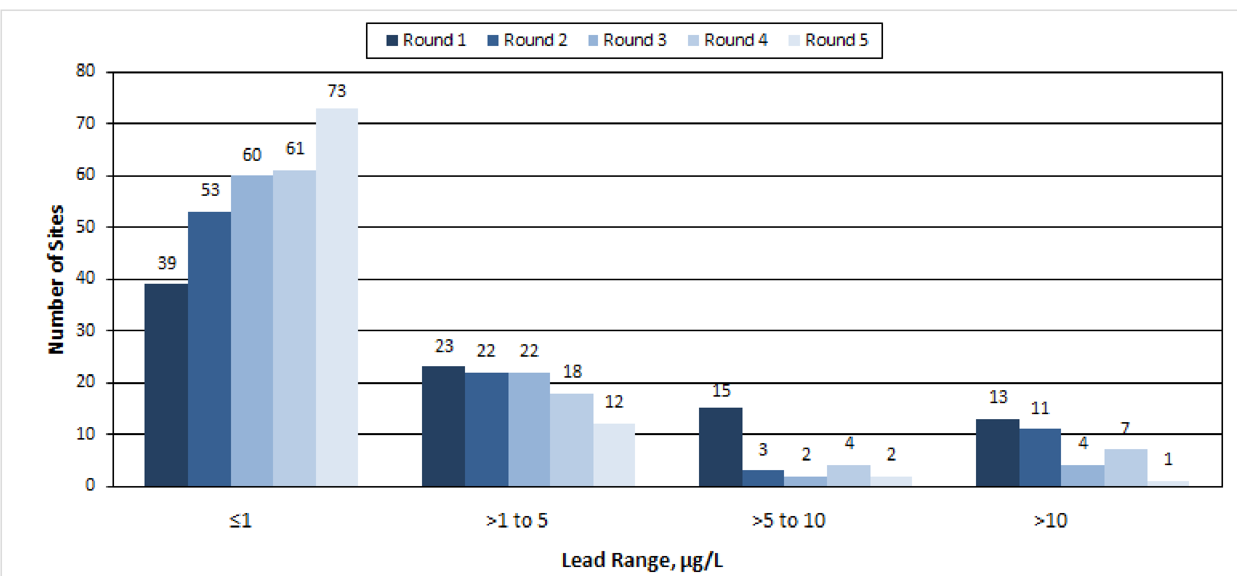

Figure 2-12. Distribution of Lead Concentrations, Residential and Non-Residential Sites

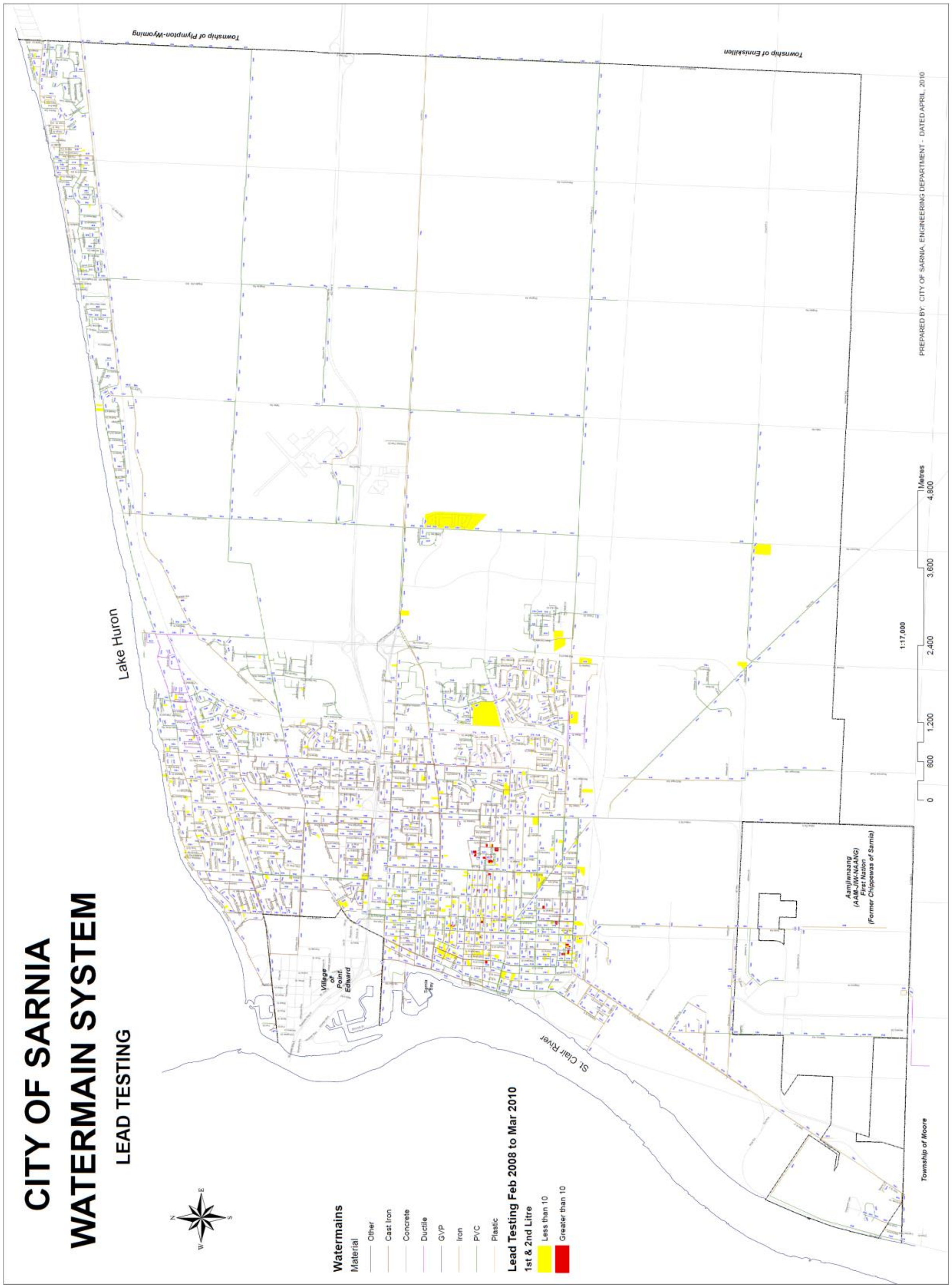

Figure 2-13. Geographic Extent of Lead Exceedances Observed in the Sarnia Distribution System During Schedule 15.1 Sampling, 2008 to 2010

Source of lead release. Schedule 15.1 sampling requires that two consecutive 1 L samples be collected following the stagnation period, and both be analyzed for lead. The highest of the two results is then used to determine compliance with the MAC. The first draw sample is usually indicative of lead release from premise plumbing (e.g., faucets/fixtures, plumbing pipes, solder, water meter), while the second draw sample is usually indicative of lead release from premise plumbing, and—depending on the diameter and length of plumbing within the house—may also be representative of lead release from the service line.

Lead was measured at a higher concentration more often (71% of residential sites) in the first draw sample than in the second draw sample (Figure 2-14). The magnitude of lead in first and second draw samples was also compared and is shown in Figure 2-15. First and second draw samples in the top 15% of lead results differed somewhat: second draw samples were slightly higher than first draw samples in winter sampling, however during summer sampling, the first and second draw samples were similar. The three highest lead results measured during Schedule 15.1 sampling were from second draw samples.

Taken together, these results suggest that both premise plumbing and the service lines are contributing to lead measured at the tap, however additional studies such as lead profile testing and plumbing surveys at individual homes would be required to confirm this. Corrosion occurring on private property should be taken into consideration if partial (City-owned) LSL replacement is implemented.

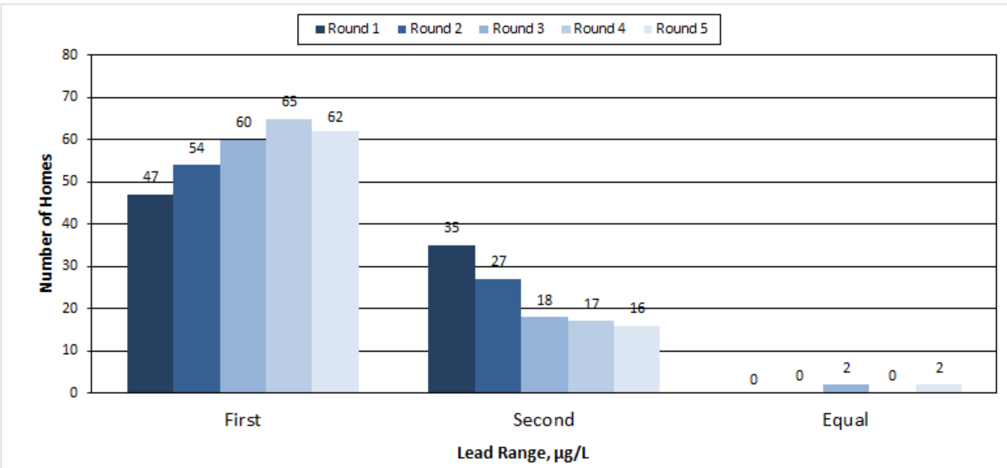

Figure 2-14. Sample Results Used to Determine Regulatory Compliance, Residential Sites

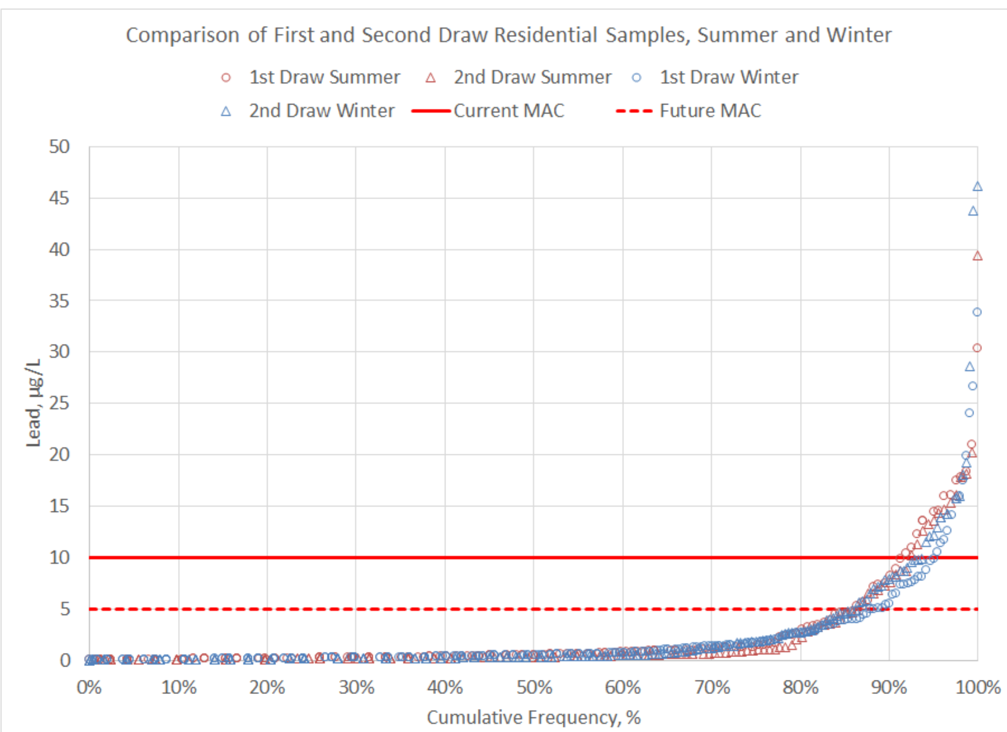

Figure 2-15. Cumulative Frequency of Lead Concentration as a Function of Sample Sequence and Season

Impact of temperature on lead release. System-wide evaluation of Schedule 15.1 results suggested that lead release during summer and winter was similar (e.g., Figure 2-11 and Figure 2-15), however since this is inconsistent with theory, it was explored further on an individual site basis to clarify and confirm trends. Over the course of the five rounds of Schedule 15.1 sampling, there were 41 residential and non-residential sites at which both summer and winter sampling occurred (Figure 2-16). As expected, summer lead results were higher than winter lead results at most sites where lead was present (i.e., >1 µg/L), and summer concentrations of lead generally increased with increasing winter concentrations of lead. Two outliers were observed in which summer lead was significantly higher than winter lead. At a house on Brock St. N., the LSL had been replaced between the collection of the summer and winter samples. The reason for the difference seen at the house on Walnut Ave. S. could not be explained with available data.

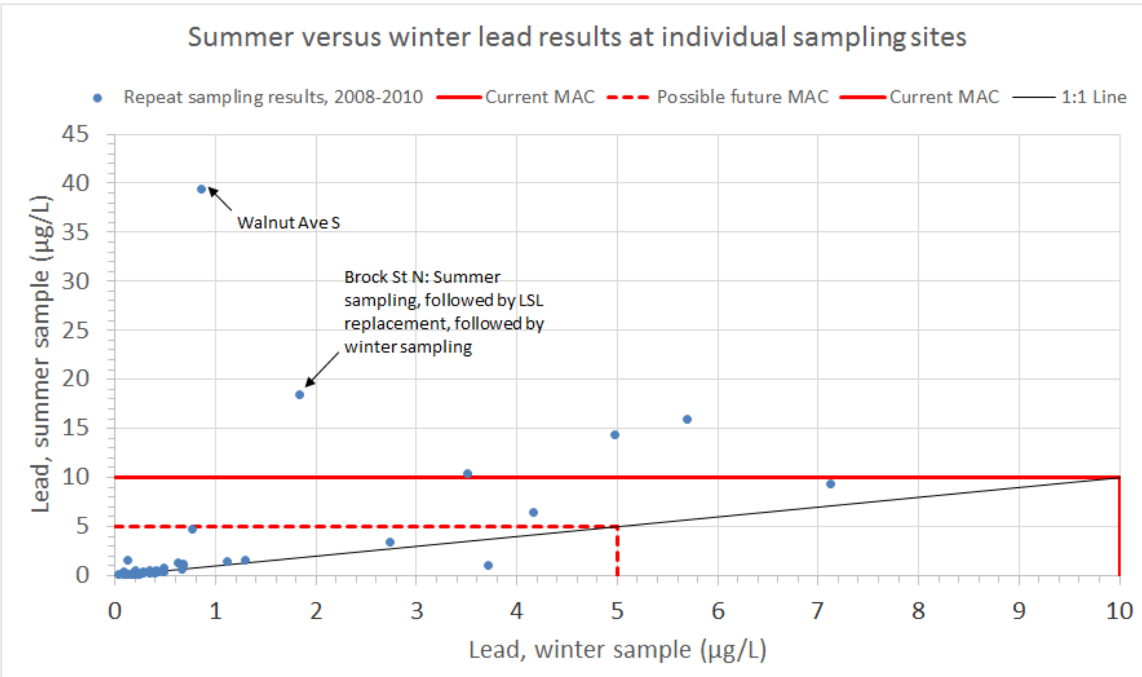

Figure 2-16. Summer v. Winter Schedule 15.1 Lead Results at Individual Residential and Non-Residential Sites

Impact of LSL replacement on lead release. The City does not currently have a post-replacement lead monitoring program. To assess the impact of LSL replacement on lead release, the City's Schedule 15.1 database was cross-referenced with their LSL replacement database to identify houses where sampling had been conducted post-replacement, which are shown in Table 2-8. The post-replacement sampling in each case occurred within 6 to 8 months following LSL replacement. The type of replacement (partial or full) carried out at these houses and the service line material removed was not documented and is therefore unknown.

With the exception of House 1 on Brock St. N., pre-replacement lead concentrations at these houses are not known. These data therefore cannot be used to assess the reduction in lead contributed by LSL replacement. However, the magnitude of the post-replacement lead result is of interest in understanding whether LSL replacement results in compliance, and to identify the occurrence of secondary impacts such as lead spikes. To this end, the following observations can be made from these data:

- Lead spikes above the MAC (19.3 and 46.2 µg/L) were observed in two of the seven homes where Schedule 15.1 sampling had been carried out three to eight months following LSL replacement (the type of replacement—partial or full—was not known), under cold water conditions. Lead spikes following LSL replacement are typically associated with particulate lead release. The occurrence of post-replacement lead spikes in the Sarnia system demonstrates that a lead management strategy based on LSL replacement will require measures to mitigate the impact from post-replacement lead spikes, to protect vulnerable populations.

- Post-replacement tap water lead levels were well below the MAC in the other five homes following LSL replacement. Lead levels in these homes ranged from 0.12 to 1.83 µg/L following LSL replacement. Since these samples were collected during the winter, the cold temperature may have contributed to the low lead levels observed. The pre-replacement lead values at these homes was not measured, therefore the reduction associated with LSL replacement cannot be assessed.
- A pre-replacement lead sample had been collected at House 1 on Brock St. North. Removal of the LSL (not known whether full or partial) at this location resulted in a 90% reduction in lead compared to the pre-replacement level (18.4 µg/L prior to replacement and 1.83 µg/L post-replacement). Since the pre-replacement and post-replacement samples were collected during different seasons (summer and winter, respectively), the apparent reduction in lead level may have been due to the combination of LSL replacement and the cold water temperature effect. A summer sample was collected from this home in 2017 (approximately 9 years following replacement, refer to Section 2.4.3); the lead level measured at the tap in 2017 was low (0.33 µg/L), demonstrating long-term reduction. This single data point may not be representative of the overall performance that would be achieved at all locations.

Taken together, these data suggest that LSL replacement can be an effective means of reducing lead in the Sarnia Distribution System, however care must be taken to protect vulnerable populations from lead spikes that may occur following LSL replacement, such as can be achieved with faucet and pitcher filters. Because the type of replacement (partial or full) was not known, additional testing would be valuable in confirming this conclusion.

Table 2-8. Lead Following LSL-Replacement

Location [1]	**Pre-Replacement Lead Sample**		**LSL Replacement Date**	**Post-Replacement Lead Sample**	
	Date [2]	**Result (µg/L)**		**Date** [2]	**Result (µg/L)**
Maxwell St.	N/A	N/A	7/3/2008	1/9/2009 (W)	0.24
Walnut Ave. N.	N/A	N/A	7/9/2008	1/12/2009 (W)	19.3
Brock St. N. (House 2)	N/A	N/A	5/5/2008	1/14/2009 (W)	0.62
Cameron St.	N/A	N/A	7/7/2008	1/15/2009 (W)	0.5
Cromwell St.	N/A	N/A	8/19/2008	1/19/2009 (W)	46.2
Maria St.	N/A	N/A	9/19/2006	2/11/2010 (W)	0.12
Brock St. N. (House 1)	9/4/2008 (S)	18.4	10/14/2008	1/12/2009 (W)	1.83

Notes:

1. For privacy reasons, specific addresses are not shown.
2. ‘S’ refers to a summer sampling round, and ‘W’ refers to a winter sampling round.

2.4.3 Summer 2017 Sampling

Additional residential sampling using the Schedule 15.1 sampling protocol was conducted in June 2017 at three houses, to provide additional information in support of this Lead Reduction Plan. These houses included House 1 on Brock St. N., and two houses on Ann St.. Repeat sampling was carried out at the two Ann Street locations in August, which included analysis for both total and dissolved lead. Results from this testing are presented in Figure 2-17 and Figure 2-18 and are discussed below.

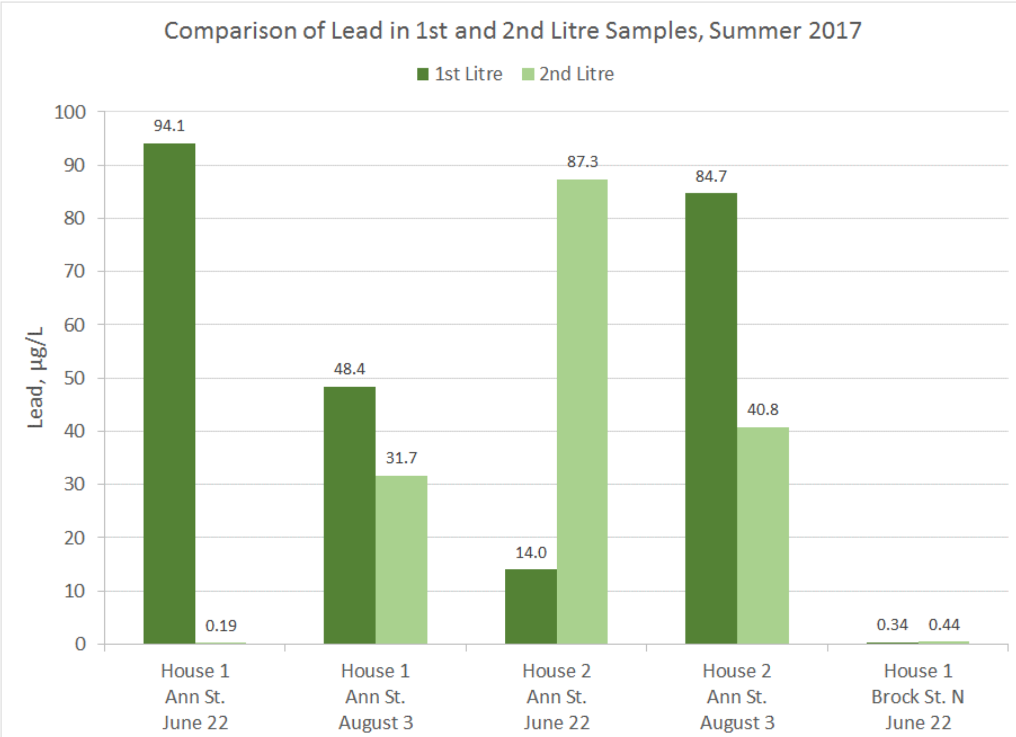

Figure 2-17. Lead Measured in 1st and 2nd Litre Residential Samples, Summer 2017

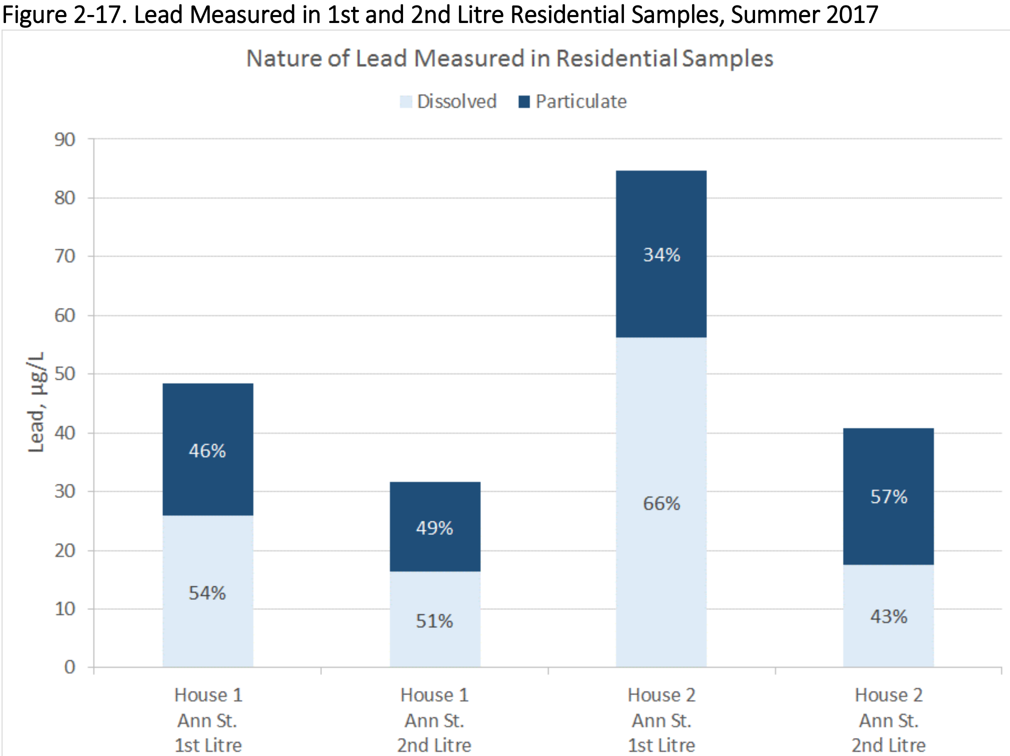

Figure 2-18. Nature of Lead Measured in Residential Samples, August 3, 2017

Collected more than 8 years following LSL replacement, the lead measured from House 1 on Brock St. N. was very low (≤0.44 µg/L), confirming the earlier observation that LSL replacement can be an effective means of reducing lead. However, the results from House 1 and House 2 on Ann St. (94.1, 48.4, 87.3, and 84.7 µg/L) were significantly higher than (more than double) the maximum which had been observed during Schedule 15.1 sampling between 2008 and 2010. One sample from House 1 on Ann St. was more than nine times the MAC of 10 µg/L. At both houses, the public portion of the service line had been replaced 40 years previously (in 1977), however the material of the private service line is unknown. Lead levels of this magnitude suggest that further data need to be collected on the merits of partial LSL replacement, and confirm that partial LSL replacement may not be suitable or effective in all circumstances.

The nature of lead (particulate and dissolved) measured at House 1 and House 2 on Ann St. is shown in Figure 2-18. In addition to the first draw samples having higher lead than the second draw samples, the high fraction of particulate lead in the first draw samples suggest that iron scale release occurring inside these houses is likely contributing to these high lead levels. The source of this iron scale could be the cast iron main (with iron scale having settled in the premise plumbing over time) or galvanized pipe within the home. Iron scales downstream of a lead source provide an adsorptive sink for lead accumulation. Iron scales can be fragile and when released due to high flow or pressure changes will also release the lead that was adsorbed to the iron.

Additional sampling for total and dissolved lead and iron within these homes and adjacent hydrants is recommended. It is also recommended that a plumbing survey be conducted in these homes to verify whether galvanized pipe is present. Based on these results, similar testing to confirm or dismiss the contribution of galvanized pipe to lead release in other homes within the Sarnia Distribution System is also warranted and strongly recommended.

When galvanized pipe is the source of lead release, treatment with phosphate may improve lead levels measured at the tap, however it cannot protect against lead release caused by pressure surges and flushes which can easily disturb galvanized pipe scale. Removal of a lead service line can disturb galvanized pipe within the home sufficiently to disturb the galvanized iron scale, cause a release of particulate lead. In these cases, the preferred approach is to provide faucet or pitcher filters until all of the galvanized pipe (including the service line and premise plumbing) is replaced.

SECTION 3

Assessment of the Significance of Contaminants and Sources

3.1 Identification of Source and Extent of Corrosion Problems

The occurrence and origin of corrosion by-products in the Sarnia Drinking Water System are summarized in Table 3-1. Lead is not present in the source and treated water, and based on the data review, lead measured at the tap is believed to originate from both service lines and premise plumbing. A review of the City's records and results of sampling conducted to date suggests that lead exceedances occur in the older portions of the City, where homes built prior to the mid 1950s predominate.

Corrosion by-products for which corrosion control is necessary include lead. Though the distribution system contains a significant concentration of unlined cast iron mains which naturally corrode over time, corrosion control treatment for iron is not warranted. The latter can instead be managed through a watermain cleaning program such as unidirectional flushing. Data to assess copper release at the tap were not available. Based on data reviewed within this report, the potential effects of aluminum, calcium, sodium, and manganese should be considered when evaluating potential secondary impacts of alternative measures for corrosion control.

Alternative measures for lead control are examined in Section 4, including non-treatment and treatment based approaches.

Table 3-1. Summary of Origin of Target Corrosion By-Products for Corrosion Control

Parameter	Source Water	Treated Water	Distribution System	Premise Plumbing
Primary corrosion by-products				
Lead	Negligible	Negligible	Negligible	Present
Copper	Negligible	Negligible	Not measured	Not measured
Iron	Present (Measured up to 33% of the AO)	Negligible	Present in watermain scale	Not measured
Other parameters for consideration (secondary impacts)				
Aluminum	Present (Measured up to 69% of the OG)	Present (Regularly exceeds the AO during the summer)	Present in watermain scale	Not measured*
Calcium	Present	Present	Present in watermain scale	Not measured*
Sodium	Present	Present	Not measured; no change expected from treated water	Not measured*
Manganese	Present (Measured up to 16% of the AO)	Present (Measured up to 16% of the AO)	Present in watermain scale	Not measured*

*No change expected from distribution system

3.2 Source Summary Table

The magnitude and extent of the release of the corrosion by-products of lead and iron in the Sarnia Distribution System are summarized in Table 3-2. Data were not available for copper.

Table 3-2. Source Summary Table

Contaminant	Source	Location	Extent/Results				
			No. of Samples	Avg	Min	Max	Significant (Y/N)
Lead, µg/L	Director's Order, 2007	Tap	21	5.7	0.06	32.4	**Y**
	Schedule 15.1 (5 rounds)		445	2.7	0.04	46.2	
	Summer 2017 sampling (3 homes)		5	63.0	0.44	94.1	
	Director's Order, 2007	Distribution System (bulk water)	3	0.43	0.21	0.65	N
	Schedule 15.1 (15 rounds)		160	0.16	<0.01	1.34	
	Summer 2017 sampling (hydrants)		12	0.19	<0.01	0.47	
Iron, µg/L	Summer 2017 sampling (hydrants)	Distribution System (pipe scale)	10	488	17	1,120	Bulk water: N Scale: Y

3.3 Establish Baseline Conditions

The baseline conditions or design basis used to develop and evaluate alternatives are summarized in Table 3-3.

Table 3-3. Summary of Baseline Conditions for Corrosion Control

Facility	Flow Rates (ML/d)	pH	Alkalinity (mg/L as $CaCO_3$)	Other Considerations Average (Range)
Lambton Area Water Supply System WTP	Rated: 181.8 2012-2016 Average: 53.8	Average: 7.56 Typical range: 7.3 to 7.8 Absolute range: 6.75 to 8.10	Average: 72 Range: 65 to 78	DIC, mg/L: 18.5 (17.1 to 20.1) *Tr.* Lead, µg/L: 2.7 (<0.02 to 94) *Tap* Iron, µg/L: 1.3 (0 to 10) *Tr.*; 488 (17 to 1,120) *DSS* Manganese, µg/L: 0.7 (0.1 to 7.8) *Tr.*; 25 (0.4 to 59) *DSS* Aluminum, µg/L: 92 (7 to 2,380) *Tr.*; 555 (191 to 1,530) *DSS* Calcium, mg/L: 27 (26 to 28) *Tr.*; 29 (28 to 32) *DSS* Sodium, mg/L: 6.3 (5.7 to 6.6) *Tr.*

Note: Tr. – Treated water; Tap – Tap water; DSS – Distribution system, pipe scale

The following baseline conditions are relevant for the development of non-treatment alternatives:

- Number of addresses with known or suspected **public LSLs: 4,483**
- Number of addresses with known or suspected **private LSLs: 8,643**

3.4 Water Quality Objectives for Lead Reduction Strategy

The City's current water quality objective for lead is to reduce tap water lead concentrations to below the current MAC of 10 µg/L (0.010 mg/L). In anticipation of upcoming regulatory changes (see Section 4.3.1), the proposed water quality objectives for the City of Sarnia's Lead Reduction Strategy are as follows:

- Reduce tap water lead concentrations (based on a sample collected using a 5 minute flush followed by 30 minute stagnation protocol) such that they are at or below:
    - **5 µg/L** (0.005 mg/L) in the **summer** (June 15 to October 15)

SECTION 4

Lead Reduction Alternatives and Their Impacts

This Section identifies suitable treatment- and non-treatment-based lead management alternatives for the City of Sarnia, based on water quality conditions and supported by an overview of regulatory trends and case studies of similar systems. Potential impacts associated with suitable alternatives are discussed. The rationale behind the proposed treatment- and non-treatment-based alternatives for the City is presented and alternatives are summarized.

4.1 Identification of Suitable Treatment Alternatives

In this Sub-section, potential treatment alternatives are discussed based on the water quality assessment described in Section 2 and summarized in Section 3.

4.1.1 Flow Chart of Treatment Options

The *Guidance Document for Preparing Corrosion Control Plans for Drinking Water Systems* includes a series of flow charts which can be used to identify appropriate corrosion control treatment approaches based on the treated water pH and DIC.

Between 2012 and 2016, Sarnia's treated water pH was 7.56 on average, and was typically in the range of 7.3 to 7.8 (the absolute pH range was 6.75 to 8.10). During this same period, the treated water DIC was on average 18.5 mg/L, and ranged from 17.1 to 20.1 mg/L. On this basis, the flow chart shown in Figure 4-1 identifies **two potential *treatment* options for the Sarnia system:**

3. Raise the pH in 0.3 unit increments using caustic or soda ash or potash, or
4. Add orthophosphate

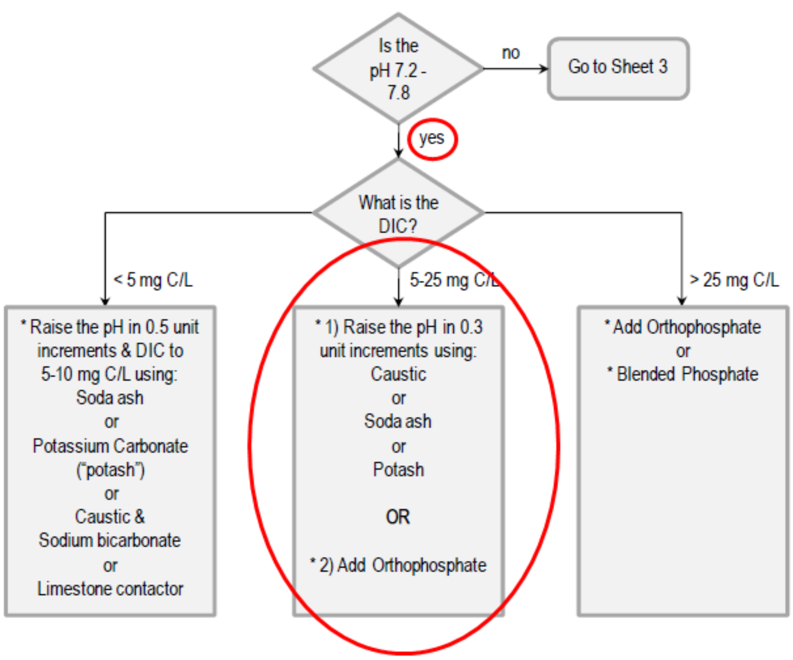

Figure 4-1. Flow Chart to Select Corrosion Control Treatment Alternatives

Source: *Guidance Document for Preparing Corrosion Control Plans for Drinking Water Systems* (MOE, 2009)

4.1.2 Suitable pH Target for Upward Adjustment

Care must be taken when increasing the pH of treated water to avoid creating other problems, as discussed in the following sub-sections.

4.1.2.1 Calcium Carbonate Precipitation Potential

Figure 4-2 is used to estimate the pH above which calcium carbonate precipitation would likely occur. The concentration of calcium in Sarnia's treated water historically ranged between 26 and 28 mg/L, with an average value of 27 mg/L. As noted earlier, the DIC was on average 18.5 mg/L. Based on Figure 4-2, the saturation pH for calcium carbonate precipitation is estimated to be around 8.2.

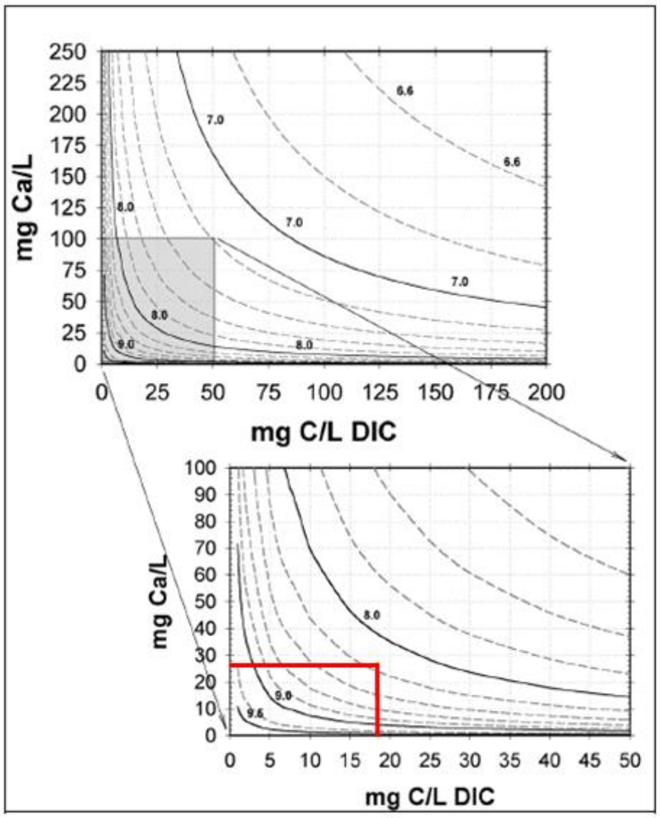

Figure 4-2. Saturation pH for Calcium Carbonate Precipitation

Source: *Guidance Document for Preparing Corrosion Control Plans for Drinking Water Systems* (MOE, 2009)

Corrosion control treatment alternatives based on upward pH adjustment above the estimated saturation pH should be assessed in terms of their potential to cause excessive calcium carbonate precipitation. To this end, the calcium carbonate precipitation potential for Sarnia's treated water was assessed using a desktop equilibrium chemistry model (Water!Pro Version 5.1).

Sarnia's existing treated water quality is such that the calcium carbonate precipitation potential (CCPP) is negative (-8.2 mg/L as $CaCO_3$) under average conditions, meaning that the water is undersaturated with respect to calcium and has a tendency to dissolve calcium carbonate. Increasing the pH above 8.2 in this water would cause the water to become supersaturated with respect to calcium (i.e., the CCPP would increase above zero), meaning that it will have a tendency to precipitate calcium carbonate. It is estimated that calcium carbonate precipitation would become excessive in the Sarnia Distribution System at treated water pH greater than 9.0 under average temperature conditions. Under summer temperature conditions, excessive precipitation may occur at a lower pH (e.g., 8.6).

4.1.2.2 Iron Corrosion

The corrosion of iron watermains results in the formation of oxidized iron-based corrosion scale, which depending on its characteristics, can either serve to promote (if porous) or minimize (if dense) corrosion of the underlying iron pipe. The iron scale can also be a reservoir of corrosion by-products that can be released through dissolution, diffusion, or particulate detachment in response to changes in water quality and hydraulics.

Corrosion of iron pipe results in the release of dissolved ferrous (Fe^{2+}) iron, which can be present within the scale as solid or dissolved ferrous iron species. These can be oxidized to ferric (Fe^{3+}) species, which are generally less soluble. pH is a key parameter related to iron corrosion because among other things, it impacts the solubility of these corrosion by-products. Under conditions of lower solubility, ferrous and ferric iron species would be more likely to precipitate within the iron scale thereby reducing its porosity, which would serve to lower the rate of iron corrosion and by-product release.

As shown in Figure 4-3, under current water quality conditions, solid ferric iron hydroxide would be expected as the predominant iron species. Figure 4-4 shows the solubility of iron species as a function of pH: initially, iron solubility decreases with increasing pH until it reaches a point of minimum solubility (around 8.8 in Figure 4-4); beyond this point, iron solubility increases with increasing pH. Sarnia's current pH of 7.5 is on the decreasing side of the iron solubility curve, meaning that improvements in iron corrosion could be realized by increasing the pH to within the range typically applied for corrosion control of lead.

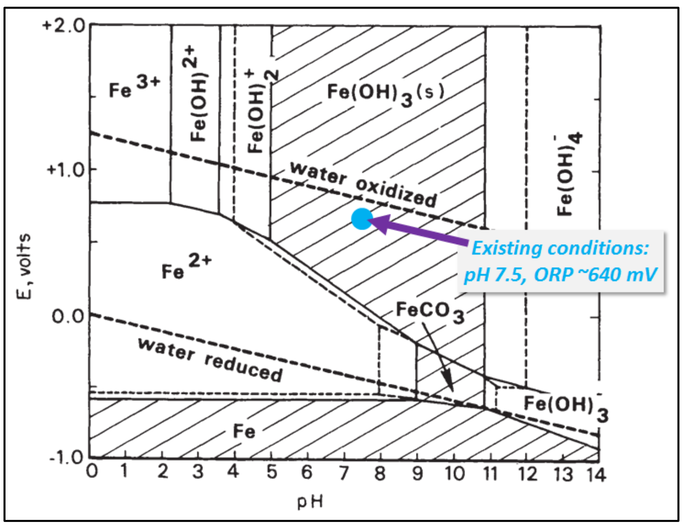

Figure 4-3. Pourbaix Diagram for Iron at 25°C and 4.8 mg/L DIC

Source: AWWA M58, 1st Edition (2011)

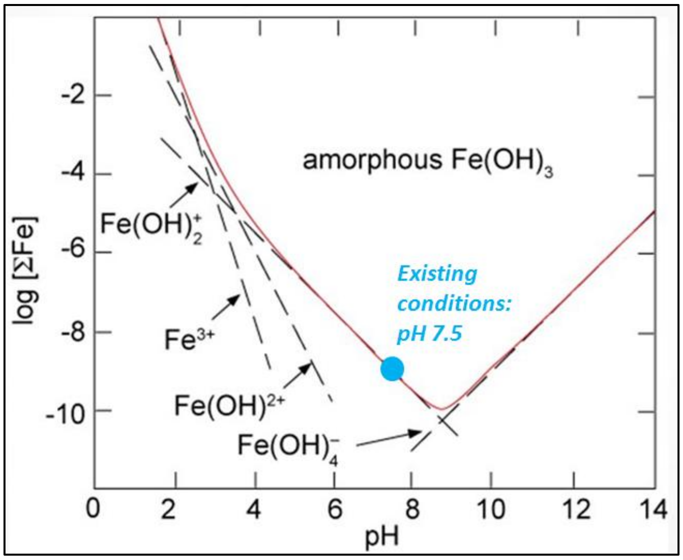

Figure 4-4. Iron Solubility as a Function of pH

4.1.2.3 Buffer Intensity

In carbonate systems, the buffer intensity (or capacity) is a measure of the water's ability to resist upward or downward pH changes. A greater degree of pH stability can be expected at higher buffer intensity, which is desirable in terms of maintaining effective corrosion control. At lower buffer intensity, pH in the distribution system may experience large swings in response to localized interactions and chemical/biological processes occurring in watermains.

The buffer intensity is a function of pH, DIC, and alkalinity. Buffer intensity increases with increasing DIC, however, the degree to which DIC impacts buffer intensity is pH-dependent. As shown in Figure 4-5, buffer intensity is lowest in the pH range of 8.0 to 8.5, and above pH 8.3, a greater degree of stability (through increased buffer intensity) can be achieved by increasing the pH, compared to increasing the DIC.

As noted earlier, Sarnia's treated water pH and DIC were on average 7.56 and 18.5 mg/L, respectively. From Figure 4-5, increasing the treated water pH above 7.56 causes the buffer intensity to decrease, meaning that a greater degree of pH instability could be expected in the distribution system relative to current conditions. A concurrent increase in DIC may help to offset this effect; this may however, lower the calcium saturation pH.

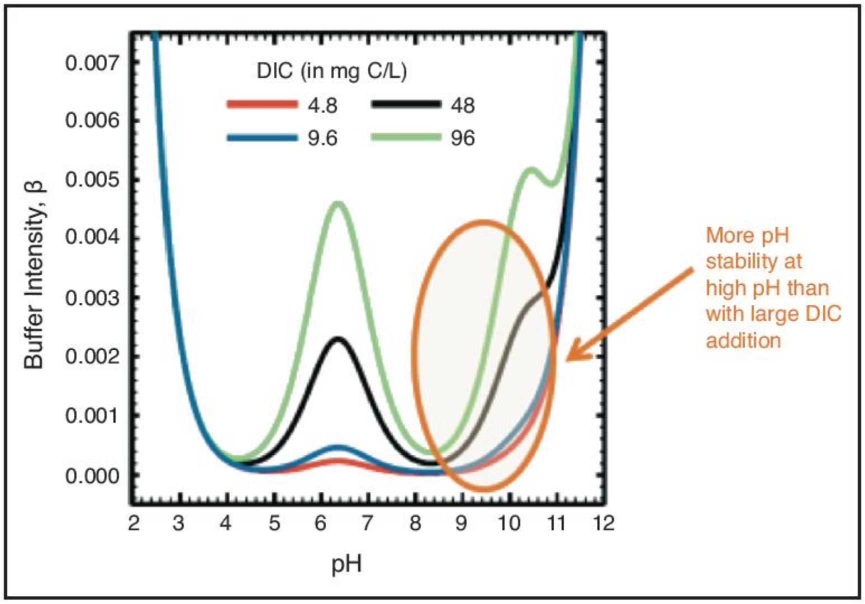

Figure 4-5. Effect of pH and DIC on Buffer Intensity

Source: AWWA M58, 2nd Edition

4.1.2.4 Estimated Impact on Lead Solubility

Corrosion control based on upward pH adjustment in this water may be bound by the following limitations:

- Upper limit around 8.6 based on managing excessive calcium carbonate precipitation under summer temperature conditions.
- A greater degree of pH instability can be expected in the range of 8.0 to 8.5 (due to lower buffer intensity); this may be manageable through other water quality adjustments (e.g., increasing alkalinity and DIC).

As noted in Figure 4-1, the guidance recommended incremental pH adjustment (e.g., in 0.3 pH unit increments), which would allow for a gradual change and monitoring of potential secondary impacts. For the purpose of this water quality assessment, a target pH of **8.6** was assumed, however this would need to be confirmed through further study.

Figure 4-6 presents the theoretical lead solubility under different conditions of pH and DIC, and similarly Figure 4-7 presents the same information in addition to pH and buffer intensity as a function of pH adjustment chemical dosage for a) caustic soda (i.e., sodium hydroxide) and b) soda ash (i.e., sodium carbonate) assuming treated water quality conditions consistent with those typically observed in Sarnia. Sodium carbonate increases alkalinity more so than sodium hydroxide.

This type of relationship can be used to assess the anticipated change in lead solubility resulting from manipulation of these water quality parameters. As shown in Figure 4-6, lead solubility would be expected to decrease by approximately 25% from ~0.25 to 0.18 mg/L, by increasing the pH from 7.5 to 8.6. A similar decrease in lead solubility can be observed in Figure 4-7 as the caustic soda dosage is increased to 4.8 mg/L (to achieve a pH of approximately 8.6), or alternatively, as the sodium carbonate dosage is increased to 12.7 mg/L (to achieve a pH of approximately 8.6). Figure 4-7 also demonstrates that below pH 8.3, only marginal reductions in lead solubility would be expected, whereas a larger reduction in lead solubility would be expected if the pH is increased beyond 8.6 (the impact on buffer intensity would also be lessened above this pH). However as previously noted, caution should be taken in increasing the pH above 8.6 in this water to avoid excessive calcium carbonate precipitation.

It should be noted that Figure 4-6 and Figure 4-7 cannot be taken as a representation of the expected reduction in lead levels measured at the tap from this treatment since it refers only to lead release from uniform corrosion. Lead release related to other important mechanisms such as lead scale dissolution and particulate release are not captured by these figures.

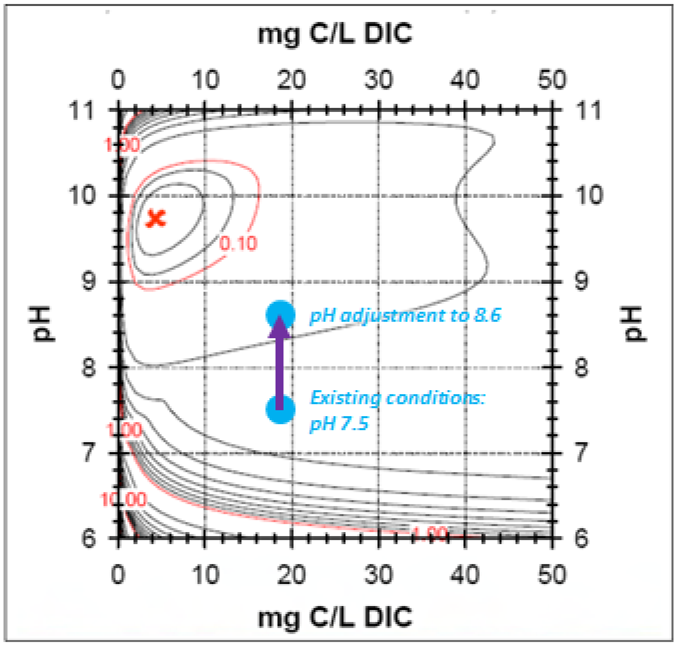

Figure 4-6. Theoretical Lead Solubility as a Function of pH and DIC

Source: *Guidance Document for Preparing Corrosion Control Plans for Drinking Water Systems* (MOE, 2009)

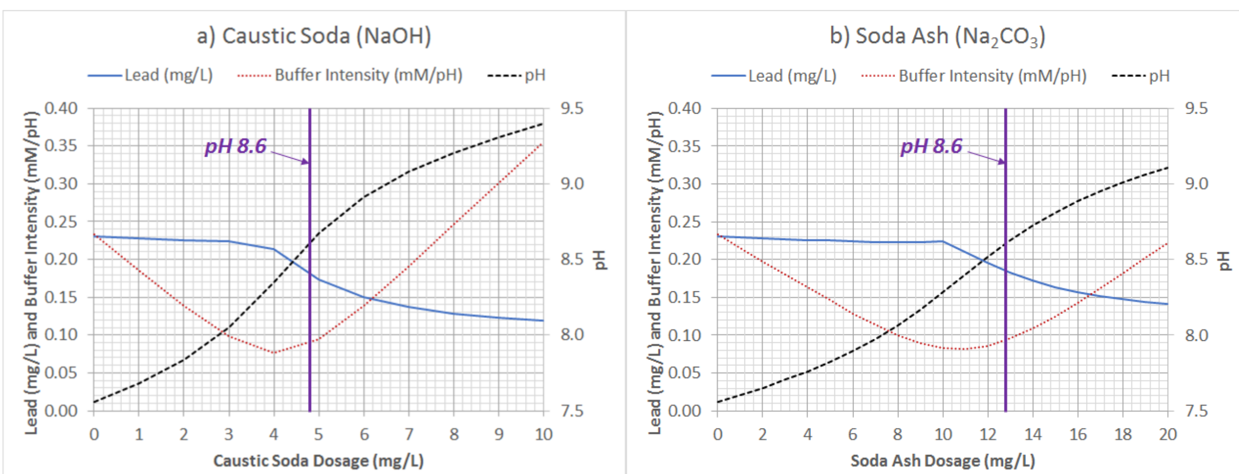

Figure 4-7. Theoretical Lead Solubility, pH, and Buffer Intensity as a Function of a) Caustic Soda Dosage and b) Soda Ash Dosage, Assuming Sarnia's Water Quality

Source: Generated using Water!Pro Version 5.1

4.1.3 Suitable Orthophosphate Dose

As shown in Figure 4-8, the efficacy of orthophosphate for reducing lead levels is strongly impacted by pH and DIC. Expected lead release (due to uniform corrosion) as a function of orthophosphate dose was modelled using a desktop equilibrium chemistry model, assuming treated water quality conditions consistent with those typically observed in Sarnia. As seen in Figure 4-9, lead solubility (due to uniform corrosion) would be expected to decrease by approximately 85% at an orthophosphate dosage of

2 mg/L as PO_4. This reduction is significantly higher than that which would be expected from increasing the pH to 8.6 (see Section 4.1.2.4). However, it is noted that this model does not address lead release from mechanisms other than uniform corrosion (e.g., lead scale dissolution and particulate release) and cannot be used to predict orthophosphate dosages that would be needed to achieve compliance, which must be assessed through a pipe loop study.

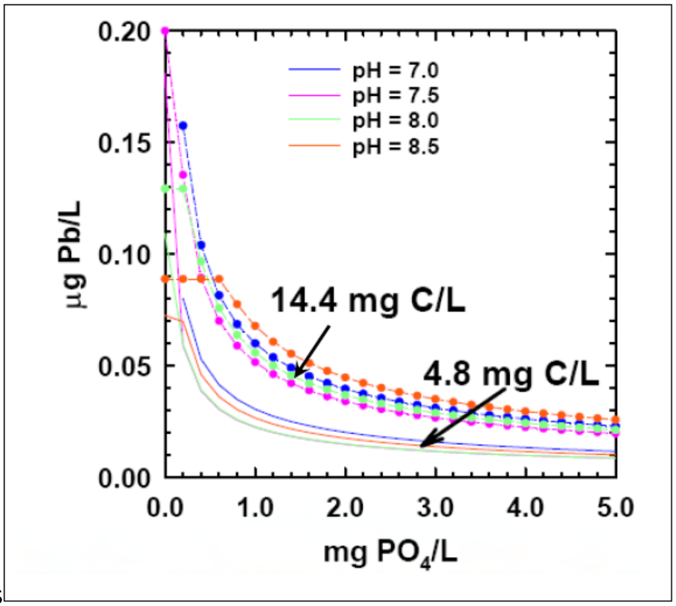

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Figure 4-8. Theoretical Lead Solubility as a Function of Orthophosphate Dosage, pH, and DIC

Source: *Guidance Document for Preparing Corrosion Control Plans for Drinking Water Systems* (MOE, 2009)

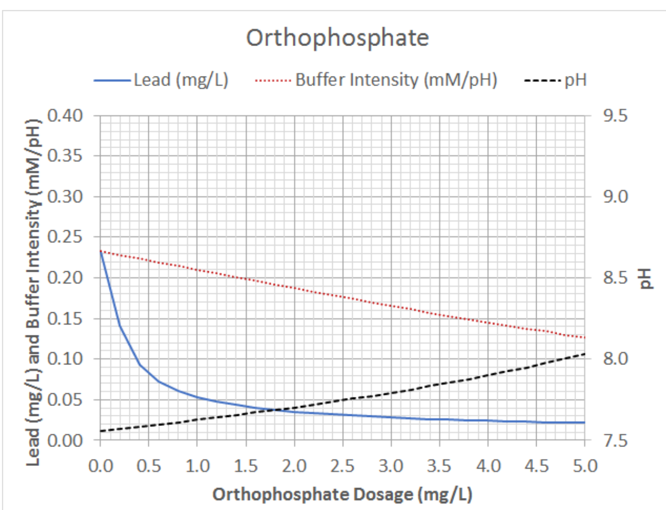

Figure 4-9. Theoretical Lead Solubility, pH, and Buffer Intensity as a Function of Orthophosphate Dosage, Assuming Sarnia's Water Quality

Source: Generated using Water!Pro Version 5.1

4.1.4 Identification and Evaluation of Chemical Choices

A summary of alternative chemicals for different applications is provided in Table 4-1 along with a brief discussion of some of the costs and benefits associated with their use. To facilitate the discussion on phosphate-based inhibition, chemicals for both upward and downward pH adjustment are included in Table 4-1, should pH control be considered for the optimization of phosphate-based inhibition.

Table 4-1. List of Chemical Agents

Purpose	Alternatives	Comment
Lead corrosion control – Phosphate-based Inhibitors	Phosphoric acid Sodium phosphate Potassium phosphate	These are examples of 100 percent orthophosphate Typical dose 2 to 3.5 mg/L as PO_4
	Polyphosphate, various products	May be combined with zinc and may be a proprietary product This is not a corrosion inhibitor, but may breakdown to produce low doses of orthophosphate. Polyphosphates are primarily used as a sequestering agent. Typical dose 1 to 3 mg/L as polyphosphate
	Blend of ortho- and polyphosphates, various products	May be combined with zinc and is a proprietary product Typical dose 2 to 5 mg/L as blended phosphate (wet weight) Can contain up to 75% orthophosphate
Lead corrosion control – Silicate-based Inhibitors	Sodium silicate	Can increase pH. Can sequester iron and manganese. Expected dose range 10 to 25 mg/L
Upward pH Adjustment	Calcium oxide (aka lime)	Lime may impart turbidity and aluminum to water but is very cost effective; final pH may be difficult to control and may require a second chemical to suppress the pH. Higher maintenance costs.
	Sodium hydroxide (aka caustic soda)	Sodium hydroxide can be fed accurately to achieve a desired pH but has specific safety, handling, and storage needs and a volatile pricing history. Can be hard to control in low alkalinity waters.
	Potassium hydroxide (aka caustic potash)	Potassium hydroxide is easier to handle. Unlike sodium hydroxide, it does not impart sodium to water but does come at a cost premium. Can be hard to control in low alkalinity waters.
	Sodium carbonate (aka soda ash)	Soda ash, like lime, is a powder and feed system maintenance costs are typically high in comparison to liquid chemical feed systems. pH is easier to control in low alkalinity waters with this chemical.
Downward pH Adjustment	Sulphuric acid	Sulphuric acid will consume alkalinity, which is not desired in soft waters.
	Carbon dioxide	Carbon dioxide will convert hydroxide alkalinity to maintain carbonate alkalinity.

For the purpose of developing alternatives, the following is assumed:

- **Phosphoric acid** as the source of orthophosphate
    - This is the cheapest source of orthophosphate and the benefits of proprietary sources or blends (with or without zinc) would need to be demonstrated to balance the typically higher chemical costs when compared with phosphoric acid.
    - Orthopolyphosphate blends were dismissed from consideration because they are generally less effective than orthophosphate for lead corrosion control. This is because the scale formed by orthopolyphosphate blends tends to be more porous and fragile.
    - If elevated turbidity and iron levels in the distribution system are common, products which provide iron sequestration (e.g., the polyphosphate component of

orthopolyphosphate blends; sodium silicate) may be of benefit for minimizing the occurrence of red water. However, since long-term use of orthophosphate will serve the purpose of hardening the iron scales and reducing iron release, the benefit of iron sequestrants would need to be demonstrated. Since the City does not routinely experience elevated turbidity and iron levels, it is not expected that iron sequestration will be required.

- **Sodium hydroxide** for upward pH adjustment.
  - For every 1 mg/L of sodium hydroxide added, 0.6 mg/L of sodium is added. Background levels of sodium are approximately 6 mg/L suggesting that up to 23 mg/L of sodium hydroxide can be added to the water while maintaining treated water sodium levels below 20 mg/L (the concentration at which the local Medical Officer of Health is notified). This is well above the dosage required to achieve the desired treated water pH.
  - In order to maintain a target pH of about 8.6 and reduce the potential of pH swings in the distribution system, the buffer intensity of the water may need to be adjusted. **Sodium carbonate (i.e., soda ash)** may be preferred over sodium hydroxide in this regard since it provides a greater increase in DIC via carbonate addition. However, as seen in Figure 4-7, sodium carbonate did not significantly improve buffer intensity compared to sodium hydroxide at the dosage required to achieve the target pH of 8.6 in this water. Both chemicals resulted in a significant buffer intensity decrease relative to current conditions because of the pH being targeted. The combination of sodium carbonate and carbon dioxide may allow for a higher DIC to be achieved at the target pH (thereby improving the buffer intensity). This approach would require further investigation and its benefits would need to be demonstrated to justify the added costs associated with two chemical systems.
  - Lime was dismissed from consideration due to feed equipment complexity and maintenance needs and since it would add calcium to the water.
- **Carbon dioxide** for downward pH adjustment, if necessary to reduce the variability of the pH in treated water.
  - Based on the review of historical data for pH in treated water, it is unlikely that downward pH adjustment is necessary based on the current coagulation practice. It's applicability in this case would be to manage variability in treated water pH, i.e., to maintain treated water pH within an acceptable target range for corrosion control. As noted earlier, downward pH adjustment may also be needed to achieve a desired alkalinity adjustment, if that approach is pursued.
  - Sulphuric acid was dismissed from consideration due to its consumption of alkalinity.

4.2 Non-Treatment Approach (LSL Replacement)

The feasibility and effectiveness of lead reduction will depend on water quality conditions, the magnitude and extent of lead release in a system, and the system features and configuration. Four issues that need to be reviewed when considering the role of lead reduction as part of a corrosion control strategy are described below:

- The municipality typically owns only a portion of the service line, with the homeowner also responsible for a portion. The number of privately-owned LSLs is often unknown, but is likely more than the number of municipally-owned LSLs. With a few exceptions (e.g., Saskatoon, SK and Madison, WI), replacement of LSLs on private property is typically not mandated by the municipality (it remains the responsibility of the individual homeowner). There is currently no regulatory framework in Ontario that would allow Sarnia to mandate private LSL replacement to ultimately achieve removal of all LSLs in the system (private and public portions).

- The accuracy of records documenting the number of municipally-owned LSLs is key to determining the level of effort associated with a lead reduction strategy. It is difficult to quantify the number of public LSLs remaining in the system. Quantifying remaining private LSLs can be even more difficult, as there is no mechanism available to require homeowners to report back should they replace the private LSL independently of the public LSL replacement, though some municipalities have used building permits as a means to track private LSL replacements.
- Regarding partial LSL replacement, lead levels may:
    1) **Be higher** following partial LSL replacement (typically short-term) due to particulate lead release (aka "lead spikes") associated with the disturbance of lead scale remaining in the service line and premise plumbing,
    2) **Remain unchanged** (long-term) due to continued lead release from the remaining partial LSL, or
    3) **Be lower** following the partial LSL replacement. This lead level may or may not be below the compliance level.

  Without replacement of the private LSL, the intended benefit from replacement of the public portion of the LSL may not be fully realized. Many municipalities do not practice partial LSL replacement in their systems in order to better manage the risk of lead exposure following a partial LSL replacement.
- LSLs may not be the only source of lead contributing to concentrations measured at the tap. LSLs and water meters made of lead-containing-brass are typically the largest contributors to lead at the tap. However, other lead-contributing sources include brass fittings, lead solder, and galvanized piping. Replacing only the LSL, though it may decrease lead levels, may not be enough to achieve regulatory compliance for lead at the tap in some systems.

Some Ontario municipalities have opted to rely on LSL replacement in the absence of treatment, to manage lead measured at the tap. This approach typically requires a comprehensive program that is based on locating LSLs, accelerated LSL replacement, homeowner support to promote full LSL replacement, interim protection measures, post-replacement monitoring, and crucial to all of these, effective public communication and outreach. LSL replacement approaches are discussed in detail in Sections 4.3, 4.4, and 4.5.

As a measure of the feasibility of this approach for Sarnia, limited post-replacement lead data were available for review (refer to Section 2.4.2 and Table 2-8, and Section 2.4.3) in order to assess the degree to which LSL replacement will reduce lead levels measured at the tap in Sarnia. Although these data were limited (a total of seven homes), some key observations can be made:

- Lead spikes above the MAC (19.3 and 46.2 µg/L) were observed in two of the seven homes where Schedule 15.1 sampling had been carried out three to eight months following LSL replacement (the type of replacement—partial or full—was not known), under cold water conditions. Lead spikes following LSL replacement are typically associated with particulate lead release. The occurrence of post-replacement lead spikes in the Sarnia system demonstrates that a lead management strategy based on LSL replacement will require measures to mitigate the impact from post-replacement lead spikes, to protect vulnerable populations.
- Post-replacement tap water lead levels were well below the MAC in the other five homes following LSL replacement. Lead levels in these homes ranged from 0.12 to 1.83 µg/L following

LSL replacement. Since these samples were collected during the winter, the cold temperature may have contributed to the low lead levels observed. The pre-replacement lead values at these homes was not measured, therefore the reduction associated with LSL replacement cannot be assessed.

- A pre-replacement lead sample had been collected at one of these homes (House 1 on Brock St. North). Removal of the LSL (not known whether full or partial) at this location resulted in a 90% reduction in lead compared to the pre-replacement level (18.4 µg/L prior to replacement and 1.83 µg/L post-replacement). Since the pre-replacement and post-replacement samples were collected during different seasons (summer and winter, respectively), the apparent reduction in lead level may have been due to the combination of LSL replacement and the cold water temperature effect. A summer sample was collected from this home in 2017 (approximately 9 years following replacement); the lead level measured at the tap in 2017 was low (0.33 µg/L), demonstrating long-term reduction. This single data point may not be representative of the overall performance that would be achieved at all locations.
- Additional sampling was carried out in summer 2017 at two homes where a partial (City-side) LSL replacement had occurred 40 years previously, in 1977. The material of the private service line was not known. Lead measured at these houses was high; in one case, lead was measured at more than nine times the MAC. Lead levels of this magnitude suggest that further data need to be collected to demonstrate the merits of partial LSL replacement, and confirms that partial LSL replacement may not be suitable or effective in all circumstances.

4.3 Regulatory Trends and Industry Guidance

This Section describes upcoming changes and industry guidance that will impact the development of corrosion control alternatives.

4.3.1 Potential Reduction in MAC for Lead

Ontario's current limit for lead in drinking water is 10 µg/L, which is based on Health Canada's Guideline. The latter had last been updated in 1992, and was based on a tolerable weekly intake of lead established by the World Health Organization (WHO) that showed no increase in blood lead levels, and therefore was not expected to pose a health risk.

In January 2017, Health Canada issued a consultation document[2] on lead in drinking water which identified reductions in IQ as the critical effect of lead, and proposed a new maximum acceptable concentration (MAC) of 5 µg/L for total lead in drinking water based on analytical achievability.

Should Health Canada choose to adopt this new MAC for lead within their Guidelines for Canadian Drinking Water Quality, Ontario's Drinking Water Quality Standard for lead will most likely be updated to reflect the guideline. The MOECC has indicated that this could occur within as little as six months from Health Canada's guideline update, and that Ontario's guidance for complying with O. Reg. 170/03, Schedule 15.1 would most likely also be updated, following a revision to the MAC.

The lead reduction plan being developed herein for Sarnia therefore considers both the **existing MAC of 10 µg/L** and the proposed **future MAC of 5 µg/L**.

4.3.2 Potential Reduction in Reference BLL for Children

In 2012, the US Centres for Disease Control and Prevention (CDC) reduced the reference value for the blood lead level (BLL) in children under age six from 10 to 5 µg/dL. At that time, the CDC also renamed

[2] https://www.canada.ca/en/health-canada/programs/consultation-lead-drinking-water/document.html

the benchmark from a "level of concern" to a "reference value", to better reflect the fact that this threshold does not delineate a "safe level" of lead—a safe level of lead in children has not been identified. The reference value is used to identify children who have been exposed to lead and who require case management.

The CDC reassesses the reference value every four years. The CDC is reviewing a recommendation by one of its advisory boards to lower the reference value from 5 to 3.5 µg/dL[3].

4.3.3 Approach to LSL Replacement

Since most municipalities do not have the authority to replace service lines and premise plumbing located on private property, it has been a common practice for municipalities to conduct partial LSL replacements, where only the publicly-owned portion of the service line is replaced.

Based on the industry's evolving understanding of the impacts associated with partial LSL replacement, recent guidance discourages partial LSL replacement. Instead, municipalities are encouraged to work with homeowners to carry out full LSL replacements.

Furthermore, whereas many municipalities have historically replaced LSLs through an "as encountered" approach, recent guidance recommends that municipalities develop proactive LSL replacement programs, in combination with optimized corrosion control treatment.

Key points related to **proactive, full LSL replacement** are described in the following sub-sections.

4.3.3.1 CDC Study on Child BLL Following Partial LSL Replacement

In January 2010, the US Centre for Disease Control and Prevention released a letter advising municipalities of the preliminary findings of a study that examined the relationship between blood lead levels in children and water quality (including lead) following partial LSL replacement. The research findings were published in December 2010 and it was concluded that partial LSL replacement may not reduce public health risk from lead, putting into question the effectiveness of LSL replacement programs where some lead remains within the privately-owned property (whether the private portion of the LSL or the premise plumbing) after the public portion of the LSL is replaced.

4.3.3.2 SAB Evaluation of Partial LSL Replacement

The USEPA's Science Advisory Board (SAB) was tasked with evaluating the effectiveness of partial LSL replacement (PLSLR). In 2011, the SAB issued its findings[4], which are summarized as follows:

> *"The SAB finds that the quantity and quality of the available data are inadequate to fully determine the effectiveness of PLSLR in reducing drinking water lead concentrations. The small number of studies available have major limitations (small number of samples, limited follow-up sampling, lack of information about the sampling data, limited comparability between studies, etc.) for fully evaluating PLSLR efficacy. Nevertheless, despite these limitations, the SAB concludes that PLSLRs have not been shown to reliably reduce drinking water lead levels in the short term, ranging from days to months, and potentially even longer. Additionally, PLSLR is frequently associated with short-term elevated drinking water lead levels for some period of time after replacement, suggesting the potential for harm, rather than benefit during that time period. Available data suggest that the elevated tap water lead levels tend to then gradually stabilize over time following PLSLR, sometimes at levels below and sometimes at levels similar to those observed prior to PLSLR."*

[3] https://www.statnews.com/2017/01/20/cdc-lead-children/

[4] https://www.epa.gov/sites/production/files/2015-09/documents/sab_evaluation_partial_lead_service_lines_epa-sab-11-015.pdf

4.3.3.3 NDWAC Recommendations

In December 2015, the National Drinking Water Advisory Committee (NDWAC) issued recommendations[5] to the USEPA for long-term revisions to the Lead and Copper Rule (LCR). These recommendations are based on a report[6] (dated August 24, 2015) prepared by the NDWAC's Lead and Copper Rule Working Group. The NDWAC qualified that it considers its recommendations to be "an integrated package, rather than a menu of choices" for strengthening public health protection.

The Lead and Copper Rule Working Group's recommendations for LCR revisions, as outlined in their 2015 report, are as follows:

- *"Require proactive lead service line (LSL) replacement programs, which set replacement goals, effectively engage customers in implementing those goals, and provide improved access to information about LSLs, in place of current requirements in which LSLs must be replaced only after a lead action level (AL) exceedance;*
- *Establish more robust public education requirements for lead and LSLs, by updating the Consumer Confidence Report (CCR), adding targeted outreach to consumers with lead service lines and other vulnerable populations (pregnant women and families with infants and young children), and increasing the information available to the public;*
- *Strengthen corrosion control treatment (CCT), retaining the current rule requirements to re-assess CCT if changes to source water or treatment are planned, adding a requirement to review updates to EPA guidance to determine if new scientific information warrants changes;*
- *Modify monitoring requirements to provide for consumer requested tap samples for lead and to utilize results of tap samples for lead to inform consumer action to reduce the risks in their homes, to inform the appropriate public health agency when results are above a designated household action level, and to assess the effectiveness of CCT and/or other reasons for elevated lead results;*
- *Tailor water quality parameters (WQPs) to the specific CCT plan for each system, and increase the frequency of WQP monitoring for process control;*
- *Establish a health-based, household action level that triggers a report to the consumer and to the applicable health agency for follow up;*
- *Separate the requirements for copper from those for lead and focus new requirements where water is corrosive to copper; and*
- *Establish appropriate compliance and enforcement mechanisms."*

The NDWAC's recommendations included the following enhancements to the Lead and Copper Rule Working Group's recommendations:

- *"Creating a national clearinghouse of information for the public and templates for PWSs, tailoring the Consumer Confidence Report, immediately engaging the health community to understand contribution of water to overall exposure to lead, adding targeted outreach and remedies to consumers with lead service lines;*
- *Improving consumer confidence in drinking water;*

[5] https://www.epa.gov/dwstandardsregulations/ndwac-recommendations-administrator-long-term-revisions-lead-and-copper-rule

[6] https://www.epa.gov/sites/production/files/2016-01/documents/ndwaclcrwgfinalreportaug2015.pdf

- *Requiring corrosion control re-evaluation if changes to source water or treatment are planned;*
- *Clarifying the expectations for small- and medium-systems not requiring CCT under the current rule;*
- *Closing the science gaps and providing guidance in sampling methodologies and techniques to ensure the samples provide the desired information;*
- *Considering alternate ways to demonstrate steady-pace improvement in LSLR in addition to percentage targets;*
- *Investigating the need for a maximum number of customer-requested samples, and establishing criteria for satisfying the minimum number of samples;*
- *Establishing a health-based, household action level that triggers a report to the consumer and to the applicable health agency for follow up;*
- *Separating the requirements for copper from those for lead and focusing new requirements where water is corrosive to copper; and*
- *Establishing appropriate compliance and enforcement mechanisms."*

4.3.3.4 AWWA Policy Statement on LSL Management

In January 2017, the American Water Works Association issued a policy statement[7] on Lead Service Line Management, which—in support of the NDWAC recommendations—encourages **full replacement of LSLs while maintaining optimal corrosion control**. The policy statement reads as follows:

> *"The American Water Works Association (AWWA) is committed to protecting public health through the reduction of exposure to lead in drinking water. AWWA encourages communities to develop a lead reduction strategy that includes identifying and removing all lead service lines over time. As part of this effort, water utilities and stakeholders should work collaboratively to expand outreach efforts to alert property owners and consumers in properties with lead service lines about the risks posed by lead and the appropriate steps to reduce those risks. AWWA encourages water providers to maintain optimal corrosion control. These measures are critical steps to ensure all people have access to safe and reliable water, recognizing that as long as there is lead in contact with drinking water, some risks remain.*
>
> *AWWA supports the U.S. National Drinking Water Advisory Council's (NDWAC) recommendations to reduce lead in drinking water through the complete removal of lead service lines while ensuring optimal corrosion control measures. Support of the NDWAC recommendations underscores the importance of protecting the public from lead exposure through the development of collaborative community-based approaches to remove all lead service lines in their entirety. Effective lead service line replacement requires solutions that successfully address the often shared ownership of these lines, the associated financial burden, and other barriers and risks posed for individuals and communities as a whole."*

4.3.3.5 AWWA Standard for Replacement and Flushing of LSL

In November 2017, the American Water Works Association issued a new standard titled "ANSI/AWWA C810-17: Replacement and Flushing of Lead Services Lines". The standard describes appropriate procedures for LSL replacement, including appropriate tools and techniques; flushing a service line (and premise plumbing) after replacement; optimizing flushing; communicating with affected customers; and verification of lead level management prior to return to service. Guidance is also provided on several of

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[7] https://www.awwa.org/about-us/policy-statements/policy-statement/articleid/4515/lead-service-line-management.aspx

the challenges associated with LSL replacement such as locating LSLs; prioritizing LSL replacements; purchaser options and alternatives; and property owner refusal to participate.

This standard states outright that "*partial LSL replacements should be discouraged*", though it acknowledges that it may not be possible or practical to conduct full LSL replacements in some situations:

> *"Although every effort shall be made to avoid partial replacements, it may be necessary to accommodate partial replacement situations as an interim measure. Partial replacement is not desirable because of the potential for increased release of lead into the water."*

The standard therefore includes recommended procedures for carrying out partial LSL replacements and for repair situations, to minimize lead release during these situations.

4.4 Similar Systems Evaluated

Case studies from analogous systems (similar water quality and treatment situations) were reviewed to explore the potential effectiveness of various treatment and non-treatment alternatives as well as program components and implementation issues. The case studies are discussed in the following sub-sections, and an overview is provided in Table 4-2.

4.4.1 London, Ontario

Background. The City of London receives treated drinking water from the Lake Huron Primary Water Supply System (LHPWSS) and the Elgin Area Primary Water Supply System (EAPWSS). Both supply systems treat Great Lakes water (Lake Huron and Lake Erie, respectively) which is transmitted through a large diameter transmission system to their customers (each supply system services eight municipalities), with terminal reservoirs for each supply system being located in the City of London.

Treatment added. Prior to implementation of corrosion control, the treated water had moderate alkalinity with pH in the low to mid 7s. Approximately 50% of the City of London's tap samples exceeded the ODWQS of 0.010 mg/L. To reduce the corrosivity of treated water, the LHPWSS and EAPWSS implemented upward pH adjustment (high 7s to low 8s) with sodium hydroxide in 2008 at the Lake Huron WTP and in 2012 at the Elgin Area WTP. Calcium precipitation occurred at the point of sodium hydroxide injection at the Lake Huron WTP.

Accelerated LSL replacement program. Upward pH adjustment reduced the percentage of samples exceeding the MAC to 20%, however the latter remained above the 10% permitted by the regulation. To achieve regulatory compliance, the City of London is undertaking an aggressive LSL replacement program. Between 2006 and 2016, the City of London replaced over 4,600 public LSLs at an annual replacement rate of approximately 450. Most replacements occur through watermain replacement projects, however outside of these projects, the City will replace the public LSL in response to a homeowner replacing the private side.

Loan program. To encourage full LSL replacement, the City offers homeowners financial assistance for the cost of replacing the private LSL through an interest-bearing loan. The loan amount is added to the homeowner's property tax bill and the amount is repaid over a 10-year period. The homeowner must submit three contractor quotes and the maximum loan amount is determined on a case-by-case basis by the City's Engineer. More information about the City's loan program can be found at the following URL: https://www.london.ca/residents/Water/Water-System/Pages/Lead-Service-Replacement-Loan-Program.aspx

Public outreach. The City offers free lead testing for older homes and to date, more than 12,000 homes have been tested. When elevated lead is present, the City provides an information package from the

Health Unit, which explains methods to reduce lead exposure and provides information about point-of-use (POU) filters, bottled water, and lead service replacement.

Relevance to Sarnia. This case study is of relevance to Sarnia because it demonstrates that in similar water quality, compliance may not be achieved from pH adjustment alone. In this case, accelerated LSL replacement was required to achieve compliance and a loan was offered to promote homeowner participation in achieving full LSL replacement. Another parallel can be drawn from this case study in the two-tier water supply structure: both levels (the water board and the City) participated in the lead reduction strategy.

4.4.2 Windsor, Ontario

Background. The City of Windsor Drinking Water System treats water from the Detroit River at two water treatment facilities, the Old WTP and the A.H. Weeks WTP which have a combined rated capacity of 349 ML/d. The City was required to prepare a Corrosion Control Plan based on exceedance of the Ontario Drinking Water Quality Standard for lead in more than ten percent of residential tap water samples. The CCP concluded that addition of a phosphate-based inhibitor to the treated water was the most appropriate option for controlling lead in the Windsor Drinking Water System, and a pilot-scale investigation was recommended to identify the appropriate phosphate-based product.

Pipe loop study. The pipe loop testing apparatus consisted of eleven 20 mm (¾-inch) LSLs that were harvested from the City of Windsor Distribution System. Since elevated iron had been observed in distribution system samples, the pipe loop study evaluated the potential need for iron corrosion control in addition to lead control. Five influent conditions were tested: a treated water control (with an ambient pH of 7.1), orthophosphate with and without pH adjustment to 7.6, and orthopolyphosphate with and without pH adjustment to 7.6. The pipe loop was operated for 8 months. Based on the pipe loop testing program results, orthophosphate at an initial dose of 2 mg/L as PO_4, without pH adjustment, was recommended for implementation at full-scale for lead control.

Treatment implemented. Implementation of the new treatment was facilitated through reuse of abandoned fluoride tanks. Treatment with phosphoric acid at the A.H. Weeks WTP commenced in 2016, and Windsor has implemented their two-tier monitoring program to track corrosion control effectiveness and the occurrence of secondary impacts. Treatment was not implemented at the smaller Old WTP.

LSL replacement. In addition to corrosion control treatment, Windsor replaces the public portion of LSLs as encountered during watermain replacement projects; approximately 500 public LSLs are replaced annually through these projects. Windsor informs the homeowner when lead is found on the private side. It is estimated that approximately 8,000 public LSLs remained in the system as of 2016.

Relevance to Sarnia. This case study is of relevance to Sarnia because it is an example of orthophosphate implementation in a similar water quality. Even with this treatment, accelerated LSL replacement is being carried out.

Table 4-2. Summary of Case Studies Reviewed

Municipality		Source Water	Treated Water pH and Alkalinity [1]	Secondary Disinfectant	Lead Management Strategy	Approximate Number of Known or Suspected Public LSLs [2]	Comments
	Sarnia, ON	Lake Huron	pH: Mid 7s Alk: Moderate	Free chlorine	TBD	2017: 4,500	Two-tier water supply arrangement (water supplied by LAWSS)
Most comparable	London, ON	Lake Huron and Lake Erie	pH: Pre-CC, low to mid 7s Post-CC, high 7s to mid 8s Alk: Moderate	Free chlorine	Upward pH adjustment (sodium hydroxide) in combination with LSL replacement	2006: 9,000 2017: 4,300	Two-tier water supply arrangement (water supplied by LHPWSS and EAPWSS) pH adjustment implemented at Lake Huron WTP in 2008 and at Elgin Area WTP in 2012. Compliance not achieved with pH adjustment on its own.
Most comparable	Windsor, ON	Detroit River (from Lake Huron)	pH: Low 7s Alk: Moderate	Free chlorine	Orthophosphate LSL replacement	2008: 24,000 2016: 8,000 (records review + LSL replacement)	Phosphate implemented in 2016 ~500 LSLs replaced annually through capital replacement projects
Most comparable	Welland, ON	Welland Canal (from Lake Erie)	pH: High 7s to low 8s Alk: Moderate	Free chlorine	LSL replacement	2010: 600	Two-tier water supply arrangement (water supplied by Niagara Region)
Similar	Toronto, ON	Lake Ontario	pH: Mid 7s Alk: Moderate	Chloramine	Orthophosphate LSL replacement	2008: 65,000 2017: 30,000	Phosphate implemented in 2014
Similar	Washington, DC	Potomac River	pH: Mid 7s Alk: Moderate	Chloramine	Orthophosphate with pH adjustment LSL replacement		Two-tier water supply arrangement Milky water issue required reduction in orthophosphate dose 1.5 years after implementation Proactive full LSL replacement program
Similar	Hamilton, ON	Lake Ontario	pH: Mid to high 7s Alk: Moderate	Chloramine	Orthophosphate (to be implemented late 2018) LSL replacement	2009: 25,000 2017: 20,000	Orthophosphate dosing will commence Q4 of 2018
Of interest, though water quality differs	Guelph, ON	Groundwater (19 wells)	pH: Mid 7s Alk: High	Free chlorine	LSL replacement	2009: 3,750 (records review) 2010: 1,800 (verification sampling) 2016: <200	Very hard water
Of interest, though water quality differs	Halifax, NS	Pockwock Lake and Lake Major	pH: Mid 7s Alk: Low	Free chlorine	Zinc orthophosphate LSL replacement	2016: 2,500	Very soft water Phosphate implemented in 2002 Partial LSL replacement halted in 2013 Proactive full LSL replacement program
Of interest, though water quality differs	Saskatoon, SK	South Saskatchewan River	pH: Mid 8s Alk: High	Chloramine	pH adjustment (8.4 to 8.6) Full LSL replacement	2010: 6,000 2017: 4,900	Mandatory full LSL replacement implemented in 2010 Systematic approach to full LSL replacement implemented in 2017 Compliance not achieved with pH adjustment on its own.

Notes:

1. Alkalinity defined as: Low – ≤50 mg/L; Moderate – 50 to >100 mg/L; High – >100 mg/L
2. Reduction in the estimated number of public LSLs in these municipalities may have occurred through more than one means, including records review, verification sampling, and LSL replacement.

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4.4.3 Welland, Ontario

Background. Niagara Region, a two-tier municipality, owns and operates six drinking water treatment plants that treat and transmit safe drinking water to a total serviced population of approximately 400,000 in eleven area municipalities. The Region's Welland WTP provides drinking water to a serviced population of approximately 50,000 in the City of Welland, the Town of Pelham, and a small portion of the City of Thorold. The source water for the Welland WTP is Lake Erie via the Welland Canal.

Lead source reduction strategy. The City of Welland was required to prepare a Corrosion Control Plan for compliance with Schedule 15.1 of O. Reg. 170/03 following more than ten percent of samples exceeding the Ontario Drinking Water Quality Standard for lead (10 µg/L). The plan was prepared jointly with Niagara Region. Lead source reduction was identified as the preferred lead management strategy for this system, due to several factors including the low number of LSLs which were located within a relatively small geographical extent; the City's existing accelerated LSL replacement program; treated water pH that was not suitable for phosphate use; regional considerations related to the future of the Welland WTP; and the potential for water quality changes to impact regional blending.

LSL database. At the time of the Corrosion Control Plan, the City estimated that there were approximately 1,300 known or suspected LSLs remaining in the City, of which less than half (approximately 600) were on the City side. This estimate was based on a service line database which tracked City-side material at the main and at the curb stop, and private-side material at the curb stop and at the house.

Grant program. To encourage homeowner participation, the City offers a partial LSL replacement grant. The homeowner must submit two contractor quotes to the City, and the maximum grant amount is determined as follows:

- Maximum grant amount for eligible costs is $1,500. If total eligible costs are less than $1,500, only eligible costs will be funded.
- If the lowest quote is greater than $3,000, the maximum grant amount can be increased to $2,000.
- A maximum grant amount of $750 applies if the homeowner has not submitted two quotes, or for retroactive grants.

The plumbing permit fee of $130 is not eligible for reimbursement. More information about the City's LSL replacement grant can be found at the following URL: https://www.welland.ca/Building/LASSR.asp.

Relevance to Sarnia. This case study is of relevance to Sarnia because it is an example of an Ontario municipality with similar water quality that implemented a non-treatment approach. Like Sarnia, this is also a two-tier water supply scenario. In this case, the non-treatment approach could be justified on the basis of the small number of LSLs in this system, which was supported by a well-defined database. A grant was offered to promote full LSL replacement.

4.4.4 Toronto, Ontario

Background. The City of Toronto treats water from Lake Ontario at four water treatment plants which combined, service a population of over 2.6 million. The City of Toronto also supplies bulk potable water to parts of the Regional Municipality of York. As of 2008, the City of Toronto had an estimated 65,000 LSLs in its distribution system. The City's 2010 Corrosion Control Plan identified phosphate-based treatment as the best approach for corrosion control (pH adjustment and aggressive LSL replacement were also considered). Pipe loop testing was used to establish design criteria such as the phosphate type and dose.

Phosphate dosing. The City of Toronto began dosing phosphoric acid at all of its WTPs in 2014. The initial phosphate dose is based on achieving a residual of 3.0 mg/L as PO_4 in treated water. The dose was reduced in 2016 to achieve a residual of 2.5 mg/L as PO_4, to mitigate the possibility of releasing water to the environment with >1 mg/L phosphorus when tanks and reservoirs are emptied. The current strategy is to target a phosphate residual of 2.0 mg/L as PO_4 for cold water conditions, and 2.5 mg/L as PO_4 for warm water conditions. Toronto Water intends to lower the phosphate dose to achieve a maintenance residual (possibly as low as 1 mg/L as PO_4) when sufficient lead reductions have been achieved.

Pre-filter phosphate dosing. In anticipation of phosphate precipitating with aluminum (which is seasonally high), a pre-filter phosphate dosing location was included at all four plants. The initial expectation was that the post-filtration dosing point would be used most of the year, and that the pre-filtration dosing point would be used as well during warm water conditions to manage aluminum-phosphate precipitation. However, precipitation occurred in cold water conditions, resulting in output turbidity above 0.1 NTU. To maintain low turbidity output water, the pre-filter dosing point is now used year-round. The usual pre-filter dose is 0.8 mg/L as $PO_{4;}$ however, under warm water conditions, upwards of 2 mg/L as PO_4 is dosed pre-filter to prevent post-filtration precipitation of aluminum. Pre-filter phosphate dosing had no observed impact on filtration (coagulant dose, filter run time, filter effluent turbidity, etc.). Phosphate losses through filtration are small (<15%).

Lead sampling. Toronto Water was granted relief from regulatory sampling until 2017. In the interim, Toronto Water has conducted year-round verification sampling, consisting of a 5-minute-flushed sample collected by the homeowner. Prior to corrosion control implementation, a lead threshold of 1 µg/L was used to identify the presence of a LSL; this threshold has been reduced to 0.5 µg/L following the implementation of corrosion control. Additionally, Toronto Water operates an automated lead pipe loop system (12 lead pipe sections to test different dose conditions) and two “sentinel” lead loops in the distribution system for monitoring the performance of corrosion control.

LSL replacement. Private LSL replacement uptake had historically been low and there was no available mechanism to force residents to replace their private LSLs. Public-side LSL replacement programs have continued in a planned and systematic manner to avoid unnecessary costs. “One-off” LSL replacements are available at the request of residents, but the public side is only replaced if the resident has already replaced the private side, or committed to do so. More information about the City’s LSL replacement programs can be found at the following URL: https://www.toronto.ca/services-payments/water-environment/tap-water-in-toronto/lead-drinking-water/capital-water-service-replacement-program/.

Secondary impacts. Aluminum residuals in the treated water have declined by 50% due to the pre-filtration application of phosphate. In 2013, the average aluminum concentration in the treated water was 0.068 mg/L, but in 2015, the average dropped to 0.034 mg/L. If Toronto Water increases the proportion of pre-filter phosphate dosing, further decreases in aluminum concentration are expected. The phosphate dosing has resulted in a commensurate increase in total phosphorus concentration at the wastewater treatment plants. To achieve total phosphorus concentrations below 1 mg/L in wastewater effluent, higher ferrous chloride doses are required. At one wastewater treatment plant, the ferrous chloride dose increased by 80%.

Relevance to Sarnia. This case study is of relevance to Sarnia because it is an example of an Ontario municipality with similar water quality that has implemented orthophosphate. Key points of note include the dosing strategy and the use of pre-filter dosing to manage aluminum-based secondary impacts; the City’s approach for verification sampling; sentinel lead loops in the distribution system for monitoring; systematic LSL replacement through roads projects; and observed impacts on wastewater treatment.

4.4.5 Washington, DC (United States)

Background. DC Water (formerly DC WASA) receives treated Potomac River water from the US Army Corps of Engineers. Initially, DC Water managed lead corrosion through upward pH adjustment (to 8.0). A switch from free chlorine to chloramine to reduce formation of disinfection by-products caused a decrease in oxidation-reduction potential (ORP) which resulted in a significant increase in tap water lead concentrations. After exceeding the US EPA's action level for lead (15 µg/L), alternative corrosion control approaches were investigated; orthophosphate was identified as the preferred alternative, since excessive calcium carbonate precipitation was anticipated if the pH were to be increased to 8.5. Phosphoric acid was initially applied in an isolated portion of the system (the "4th High" pressure zone) in June 2004. The purpose of this partial system test was to identify any potential secondary impacts. System-wide treatment (initial dose of 3.4 mg/L) commenced in August 2004.

Secondary impacts. During the partial system test, elevated heterotrophic plate counts, colour, and iron were observed. After full-scale implementation, there was a spike in coliform bacteria for approximately one month (believed to be related to changes in the scales), then the levels decreased and stayed low. An extensive unidirectional flushing program consisting of flushing the entire system within one year (ordered by the USEPA) was initiated to address the coliform exceedances. Approximately 1.5 years after implementation, there was a milky white discoloration of the water in dead end areas (Figure 4-10). This was associated with the accumulation of phosphate in stagnant areas, which was reacting with iron, calcium, and aluminum to form a precipitate. The orthophosphate dose was reduced to 2.4 mg/L which addressed the milky white precipitate issue.

Figure 4-10. Phosphate precipitate (bottle on the left) which can cause milky water complaints.

Source: AWWA M58

Communication strategy. While DC WASA did have a communication plan, the media played a large part in raising awareness about the lead issue in 2004. Because of the extensive involvement of the media (and negative tone of many of the stories), transparency was an important factor in DC WASA's communications with the public. Prior to the partial test, the public was notified of the new treatment through press releases, a factsheet mail out to customers in the 4th High pressure zone, and public meetings. DC Water continues to maintain an extensive public communication and outreach program with emphasis on LSL replacement.

LSL replacement program. DC Water's accelerated LSL replacement program is based on full LSL replacement. This program differs from many other municipalities in that DC Water conducts the full LSL replacement themselves, instead of encouraging the homeowner to hire their own contractor to carry out the private replacement. After estimating costs for the full replacement based on the service line length, DC Water issues a contract with the homeowner and subsequent to contract signing, carries out the work.

Relevance to Sarnia. Though this case study is based in a different jurisdiction, it is of relevance to Sarnia because of the aluminum-based aesthetic impact that was experienced following the implementation of orthophosphate. DC Water's approach to full LSL replacement and emphasis on transparent communications are also relevant to Sarnia.

4.4.6 Hamilton, Ontario

Background. Treating water from Lake Ontario, the 909 ML/d Woodward Avenue WTP supplies drinking water to the Woodward Sub-System of the Hamilton Drinking Water System, which services a population of more than 500,000 through over 135,000 service connections. The distribution system is primarily comprised of cast and ductile iron mains. In 2009, the City estimated that there were approximately 25,000 lead services in their system.

Comprehensive fact-based planning approach. The City's 2010 Corrosion Control Plan identified phosphate-based treatment as the best approach for corrosion control. Subsequent studies were carried out to further define program needs, including:

- Pipe loop testing and a subsequent peer-review of the latter established design criteria for the new treatment system, and the City planned for implementing corrosion control treatment using phosphoric acid at an initial dose of 3 mg/L.
- Lead profile testing was carried out in homes to investigate secondary impacts.
- A detailed, two-tier post-implementation monitoring plan to assess the effectiveness of corrosion control and identify secondary impacts and water quality aesthetics. Like Toronto, Hamilton will also make use of sentinel distribution system pipe loops for post-implementation monitoring.
- A communications plan for the implementation of corrosion control complete with public outreach content, and a review of communications best practices.
- Bench-scale testing to optimize the dosing conditions for coagulation and corrosion control chemical necessary to manage potential secondary impacts (formation of an aluminum-phosphate precipitate in the distribution system). Pre-filter phosphate dosing was identified as one means of controlling this impact, and plans were made to incorporate this design element into the full-scale treatment system design.
- A Distribution System Best Practices Review focused on identifying best practices (primarily centered on flushing) for preparing a distribution system for the implementation of phosphate-based corrosion control. A multi-pronged pre- and post-implementation strategy was developed that would allow the City to adapt their approach in response to secondary impacts, should they occur.
- A unidirectional flushing (UDF) pilot study and step-velocity trials were carried out to identify adequate flushing protocols and train staff. High levels of aluminum observed in the system prompted the City to lower the planned initial orthophosphate dose.

With these studies, the City carefully considered important information before implementing corrosion control, and made adjustments to their strategy where required. They also took steps to plan and prepare for responding to potential secondary impacts, should they occur. The City anticipates commencing corrosion control treatment in late 2018.

LSL replacement. In the interim, the City has continued to replace approximately 500 public LSLs annually when they are encountered during watermain replacements and in response to homeowner requests. When the City replaces a public LSL, they strongly encourage the homeowner to replace their half, to avoid creating a partial LSL. The LSL estimate has been reduced from approximately 25,000 in 2009 to approximately 20,000 in 2017.

Loan program. The City offers a loan to help homeowners pay for the replacement of their private LSL. The interest-bearing loan is structured based on a maximum amount of $2,500 which is transferred to the customer's tax roll for repayment over a period of up to ten years. The homeowner must also pay a

$50 administrative fee. Following replacement of the private LSL, the City provides homeowners with POU filters certified to remove lead until the City-side LSL is replaced. More information about the City's LSL replacement loan can be found at the following URL: https://d3fpllf1m7bbt3.cloudfront.net/sites/default/files/media/browser/2016-04-05/lead-water-service-replacement-loan-package-application-april-2016.pdf.

Communications program. The City commenced communications with the public and ICI users well ahead of corrosion control implementation. Their communications strategy includes many mediums—from targeted homeowner communications within the lead zone, to social media, YouTube videos (Figure 4-11), the City's website, and even training for front-line workers such as operators who may interact with the public.

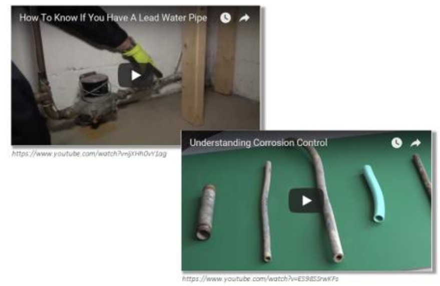


Figure 4-11. The City of Hamilton developed YouTube videos about lead

Relevance to Sarnia. This case study is of relevance to Sarnia because it is an example of an Ontario municipality with similar water quality that selected a lead management strategy based on orthophosphate. Key points of note include the detailed studies that supported the fact-based development of Hamilton's comprehensive strategy; implementation of pre-filter phosphate dosing and a flushing program to manage aluminum-based secondary impacts; the combination of treatment and accelerated LSL replacement; and the loan program to promote full LSL replacement.

4.4.7 Guelph, Ontario

Background. The Guelph Water System services a population of approximately 120,000 from 13 treatment facilities which obtain groundwater from a series of 19 wells located throughout the City and a shallow groundwater collector system. Treatment consists of disinfection with sodium hypochlorite (and in some facilities, UV), and sodium silicate is added for iron sequestration in two of the facilities. Due to the large number of sources, a large degree of blending occurs within the system and as a result water quality is variable.

Lead source reduction strategy. The City of Guelph was required to prepare a Lead Reduction Plan for compliance with Schedule 15.1 of O. Reg. 170/03 following more than ten percent of samples exceeding the Ontario Drinking Water Quality Standard for lead (10 µg/L). Lead source reduction was identified as the preferred lead management strategy for this system, due to several factors including the low number of LSLs; the City's existing accelerated LSL replacement program; the high level of homeowner participation for LSL replacement; and the large number of treatment facilities which would require treatment upgrades if a chemical treatment approach was selected.

LSL identification. Prior to preparing their Lead Reduction Plan, the City had undertaken an aggressive LSL identification program which consisted of a detailed records review and verification sampling to identify the presence of LSLs (via detection of lead in a 5-minute flushed sample). These efforts had allowed the City to reduce the number of known or suspected LSLs to 3,750 in 2009 following the records review, and down to 1,800 in 2010 following verification sampling.

LSL replacement. The City's approach to accelerated LSL replacement was based on targeted, individual replacement. Though the City also replaced LSLs as encountered through other projects, this represented a relatively small proportion of all replacements carried out. At the time of the Lead Reduction Plan, the City replaced approximately 100 public LSLs annually, and full replacements had become more prevalent due to the City's outreach efforts to encourage homeowner participation and through uptake of their LSL replacement grant program.

Grant program. The City offers homeowners a grant for the replacement of the private LSL. The grant is structured as follows:

- If the private replacement occurs independently of the City-side replacement (or if the City side is not lead), the maximum grant amount is $2,000.
- If the private replacement occurs in conjunction with the City-side replacement, the maximum grant amount is $1,000. The amount is lower in this case because of cost savings realized due to the public and private replacements occurring at the same time.

The homeowner must submit two contractor quotes for the work. The building permit fee is an eligible cost for reimbursement through the grant. More information about the City's LSL replacement grant can be found at the following URL: https://guelph.ca/living/environment/water/drinking-water/drinking-water-and-lead/replacement-program/.

Filter rebate program. The City also manages a filter rebate program, in which homeowners can receive a rebate of up to $100 per calendar year for NSF-053 filtration devices and/or replacement filter cartridges. To quality for the filter rebate program, homeowners must allow the City to collect a water sample from their home to test for lead, and the presence of an LSL must be confirmed. More information about the City's filter rebate program can be found at the following URL: https://guelph.ca/living/environment/water/drinking-water/drinking-water-and-lead/replacement-program/water-filter-rebate-program/.

Post-replacement monitoring. The City had commenced a post-replacement monitoring program prior to the development of their Lead Reduction Plan. Through this program, the City had amassed a data set of lead levels pre-replacement and at 6, 12, and 18 months following replacement. With these data, the City demonstrated that significant reductions in lead levels could be achieved through full LSL replacement. Results for partial LSL replacements were less consistent, and though reductions were achieved in many cases, the data confirmed the occurrence of post-replacement lead spikes and showed that compliance at individual sites was less likely compared to full LSL replacement.

Outreach program. Public outreach and communication was the foundation of the City's lead management strategy. Prior to the Lead Reduction Plan, the City had conducted a telephone survey to seek the public's opinion on the preferred approach (treatment or lead source reduction). The City took a very proactive approach to communication which included a public open house following the MOE's 2007 sampling order; outreach through multiple mediums (e.g., newspaper, bus shelters, website, posters, brochures); targeted communications (e.g., door knockers, phone calls, letters); public open houses; booths at community events; and communication with community partners such as daycare centres and doctor's offices.

Relevance to Sarnia. Though Guelph's water quality differs from that of Sarnia, this case study is of relevance because it is an example of an Ontario municipality that implemented a comprehensive non-treatment approach. In this case, the non-treatment approach could be justified on the basis of the small number of LSLs in this system, which was supported by verification sampling. This case study highlights all of the key program components which are required to support non-treatment approaches.

4.4.8 Halifax, Nova Scotia

Background. Treating water from Pockwock Lake and Lake Major, Halifax's treated water is very soft with a pH in the mid 7s. Corrosion control treatment was implemented in 2002 with a blended orthopolyphosphate product. The utility has moved away from orthopolyphosphate products and currently applies an orthophosphate product.

Monitoring program. In 2011, Halifax initiated a comprehensive pre- and post-replacement profile sampling program consisting of collecting four 1-L samples following a minimum of 6-hour stagnation before replacement and at 72-hours, 1-month, 3-months, and 6-months following replacement. A fifth 1-L sample is collected at each sampling event to monitor water quality in the main. Results from this monitoring program showed that partial LSL replacement often resulted in prolonged increases in lead levels.

LSL replacement program. Halifax historically replaced public LSL when they were encountered during watermain renewal projects, street reconstructions, and sidewalk renewals. However in 2013, this program was suspended due to the health risks associated with partial LSL replacement, which had been identified through the monitoring program. Under this new policy, the majority of public LSL replacements now occur in response to a private LSL replacement. To facilitate this process, Halifax has set up a standing offer with several contractors who can perform both the public and private LSL replacements at the same time. The work is carried out under two separate contracts: one between the contractor and the City, for the public LSL replacement; and one between the contractor and the homeowner, for the private LSL replacement. The cost of the public LSL replacement is borne by Halifax, while the cost of the private LSL replacement is borne by the homeowner. Halifax does still carry out partial (public) LSL replacements where necessary, however in these cases, information is provided to the homeowner highlighting the benefits of replacing the private LSL and on lead exposure resulting from partial LSL replacements.

Relevance to Sarnia. Though Halifax's water quality differs from that of Sarnia and is in a different jurisdiction, this case study is of relevance because it is an example of a municipality that has ceased the practice of partial LSL replacements as part of road/watermain renewal projects. Halifax's pre-and post-replacement profile sampling program is also of interest to Sarnia.

4.4.9 Saskatoon, Saskatchewan

Background. The City of Saskatoon uses conventional treatment with chlorine to treat the South Saskatchewan River, a source water that is characterized by moderate hardness, moderate alkalinity and pH in the low 8s. The pH of treated water is adjusted to between 8.4 and 8.6 to minimize the water's corrosivity. Lead was measured above 10 µg/L in 22 percent of 55 samples collected in 2009, after flushing for 3 ½ minutes (Fox, 2010).

Mandatory full LSL replacement. Prior to April 12, 2010, it was up to the homeowner to decide whether to replace the private LSL when the public LSL was being replaced. As of April 12, 2010, full LSL replacement became mandatory in the City of Saskatoon in response to a letter released by the CDC about the relationship between partial LSL replacements and children's blood lead levels. The City of Saskatoon used provisions in the provincial statute known as the Cities Act to address privately-owned LSLs (Province of Saskatchewan, 2009):

> *22(1) The Owner of a parcel of land is responsible for the construction, maintenance, repair and replacement of a service connection of a public utility located above, on, or underneath the parcel of land, unless otherwise determined by the City.*
>
> *22(2) if the City is not satisfied with the construction, maintenance, repair or replacement of a service connection by the Owner of a parcel of land, the City may require the Owner to construct, maintain, repair or replace the service connection of a public utility in accordance with the City's instructions within a specified time.*

Move toward systematic LSL replacement. Up until July of 2016, the City maintained a voluntary LSL replacement list and conducted individual full LSL replacements based on this list. In 2017, the City embarked on their "Water Main, Sanitary Lining and Lead Water Pipe Replacement Initiative", which is a large-scale water and wastewater infrastructure rehabilitation program. This $31.6M initiative was funded through a combination of federal (up to $15.8M from the Government of Canada through the Clean Water and Wastewater Fund), provincial (up to $7.9M from the Government of Saskatchewan), and municipal funding ($7.9M from the City of Saskatchewan). Through this program, the City has moved away from singular LSL replacement toward a neighbourhood LSL replacement approach. Approximately 900 LSLs were slated to be replaced in 2017. The City intends to replace approximately 400 LSLs annually in subsequent years concurrent with watermain and road projects. The City estimates that all 4,900 LSLs will be replaced by 2027.

Cost sharing and payment options. The City of Saskatoon does not allow partial LSL replacements. Full LSL replacements are conducted by contractors, and the cost of the full LSL replacement is shared between the City (60%) and the homeowner (40%). The City offers the homeowner five interest-free payment options:

1. Paid in full at time of LSL replacement: The City pays the contractor for their portion and the homeowner pays the contractor for their portion when the work is complete.
2. One-year deferral: The City pays the contractor for the full replacement cost (public + private portion). The homeowner's portion of the cost is added to the property tax bill and paid back to the City within one year. Payment can be either in monthly installments or paid in full.
3. Three-year deferral: The City pays the contractor for the full replacement cost (public + private portion). The homeowner's portion of the cost is added to the property tax bill and paid back to the City over a period of three years. The City also adds a $190 administrative fee to the homeowner's property tax bill.
4. Five-year deferral: The City pays the contractor for the full replacement cost (public + private portion). The homeowner's portion of the cost is added to the property tax bill and paid back to the City over a period of five years. The City also adds a $240 administrative fee to the homeowner's property tax bill.
5. Ten-year deferral: The City pays the contractor for the full replacement cost (public + private portion). The homeowner's portion of the cost is added to the property tax bill and paid back to the City over a period of ten years. To quality for this option, homeowners must meet the Low Income Cut Off (LICO) criteria as published by Statistics Canada. The City also adds a $365 administrative fee to the homeowner's property tax bill.

Relevance to Sarnia. Though Saskatoon's water quality differs from that of Sarnia and is in a different jurisdiction, this case study is of relevance because it is an example of a municipality that has mandated full LSL replacement. Like London, this system did not achieve compliance from pH adjustment alone, and accelerated LSL replacement is therefore carried out systematically through road projects. A loan is offered to homeowners to support full LSL replacement.

4.5 Identification of Potential Secondary Impacts and Implementation Issues

Based on the review described to this point, feasible alternatives include LSL replacement (a non-treatment approach) and two treatment-based alternatives: phosphate-based inhibition and upward pH adjustment. This Section describes potential secondary impacts and implementation issues associated with these three alternatives in the context of the Sarnia Distribution System, and identifies potential mitigation measures to address these impacts and issues. The need for mitigation measures will define required program components for the alternatives, as presented in Section 4.6.

Table 4-3. Potential Secondary Impacts, Implementation Issues, and Related Mitigation Measures for Sarnia

Secondary Impact	LSL Replacement	Phosphate	pH Adjustment
Particulate lead spikes *Lead scale present on LSLs or within premise plumbing may be disrupted and dislodged during LSL replacement, watermain replacement, and other repair projects due to vibrations and rattling of the pipes. The release of small fragments of lead scale (known as particulates) can cause intermittently high levels of lead in tap water, referred to as "lead spikes". If ingested, these lead particulates can be a significant one-time exposure for vulnerable populations. When lead particulates accumulate in premise plumbing (e.g., in faucet aerators that are not regularly cleaned out by homeowners), they can significantly increase lead levels measured at the tap over an extended period of time.* *The occurrence of particulate lead spikes is commonly associated with partial LSL replacement and galvanized iron plumbing materials, however they can also occur in full LSL replacements, and they can continue to occur when corrosion control treatment is in place. Point-of-use (POU) filters approved to meet the National Sanitation Foundation standard NSF/ANSI 53 for lead can be used as an interim measure to capture particulate lead releases that are common following LSL replacement (these filters can also remove dissolved lead), however adequate instructions on the proper use of POU filters must be provided to the homeowners if POU filters are used as an interim protection measure.*	**Yes** Mitigation: • Provide POU filters • Post-replacement monitoring	**Yes** Mitigation: • Provide POU filters • Post-replacement monitoring	**Yes** Mitigation: • Provide POU filters • Post-replacement monitoring
Ability to reduce lead levels measured at the tap *Some lead management approaches may be more effective than others for reducing the level of lead measured at the tap.* • *Treatment approaches: Based on Sarnia's water quality, it is expected that lower lead levels can be achieved with orthophosphate than with pH adjustment, however as noted above, lead spikes related to LSL replacement may continue to occur even with treatment in place. For this reason, it is usually recommended to continue LSL replacement using the same mitigation strategies—even with treatment in place—to ultimately remove the primary source of lead.* • *Non-treatment approaches: Lower lead levels would be expected when carrying out full LSL replacements compared to partial LSL replacements, as was noted in the Guelph case study.* *The choice of lead management approach will therefore impact the City's ability to achieve compliance with the MAC of 10 µg/L. This will be of greater importance if/when Ontario's MAC is decreased from 10 to 5 µg/L in response to Health Canada's proposed new MAC.*	**Yes** Mitigation: • Encourage full LSL replacement through tailored public outreach program • Homeowner support program (loan/grant) • Post-replacement monitoring	**Yes** Mitigation: • Encourage full LSL replacement through tailored public outreach program • Homeowner support program (loan/grant) • Post-replacement monitoring	**Yes** Mitigation: • Combine treatment with accelerated LSL replacement to achieve compliance • Encourage full LSL replacement through tailored public outreach program • Homeowner support program (loan/grant) • Post-replacement monitoring
Low homeowner participation *As highlighted in Section 4.3, industry recommendations are that LSL replacements should be based on removing the full length of lead from the watermain to the water meter. Industry guidance goes as far as discouraging partial LSL replacements, and several municipalities are taking this approach as highlighted through the case studies. Since homeowners usually own and are responsible for the portion of the service line between the curbstop and the water meter, their participation is required when targeting full LSL replacement.* *Since private LSL replacements cost several thousands of dollars, homeowners may have a low desire to participate, or may be unable to do so due to their financial situation. This lower rate of homeowner participation may be more prevalent among certain demographic groups, and this can result in socio-economic ethical issues. Some examples of causes for low homeowner participation include:* • *Having a low or fixed household income that cannot accommodate the costs of LSL and/or premise plumbing replacement. Homeowner incentive and assistance programs that take household income into consideration can help mitigate this. However, in some municipalities the spending of rate-based funds on private property may be discouraged or not permitted.* • *Tenants who rent from landlords do not have the authority to replace the LSL and/or premise plumbing within their dwelling. Targeted communications for renters and landlords, POU filter programs for renters, and incentive programs for landlords can help mitigate this.* • *Not receiving adequate communication about the issue due to a language barrier or accessibility issue. Public outreach programs should include appropriate communication methods which reflect the community. This may include making information available in multiple formats and languages.* *In the absence of legislation that gives the municipality authority to enforce the replacement of private lead sources, a tailored public outreach program is key for encouraging homeowner participation in full LSL replacement. Homeowner support programs such as loans or grants to assist homeowners with the cost of LSL replacement can also help improve the rate of homeowner participation.*	**Yes** Mitigation: • Tailored public outreach program • Homeowner support program (loan/grant) • Provide POU filters	**Yes** Mitigation: • Tailored public outreach program • Homeowner support program (loan/grant)	**Yes** Mitigation: • Tailored public outreach program • Homeowner support program (loan/grant)

Lead release from sources other than LSLs *In addition to the LSL, there may be other sources of lead that can contribute to lead measured at the tap. Examples include water meters, valves, lead solder, brass and bronze fixtures, and lead adsorbed to the scale of galvanized iron pipe. As of 2014, drinking water products sold or installed for use in public water systems, as well as plumbing in facilities, must meet a weighted average of not more than 0.25% lead. However, "lead-free" products manufactured prior to 2014 may contain up to 8% lead. Even when using lead-free or non-lead fixtures, lead may be measured in the bulk water due to poor manufacturing practices or localized areas within the fixture that have a relatively high percentage of lead. Some municipalities have considered the use of by-laws to control or minimize lead release from brass fixtures. Although this may help with the introduction of new sources of lead into premise plumbing, it does not help to control lead release from previously installed fixtures. Some municipalities have amended their building codes to address lead use in fixtures.* *Lead release from sources other than LSLs is controlled or minimized with corrosion control treatment. This may be mitigated in non-treatment approaches through public education and outreach (encouraging homeowners to replace lead-bearing fixtures with lead-free fixtures), monitoring, and more detailed investigation (e.g., lead profiling) where required.*	**Yes** *Mitigation*: • Tailored public outreach program	N/A	N/A
Interim exposure to lead *Interim exposure to lead may occur until the lead management strategy has been implemented system-wide. Interim protection must be provided for vulnerable populations such as infants, children under 6, and expecting or breastfeeding mothers. The period of interim exposure is usually longer for alternatives based on LSL replacement versus those based on treatment, however this depends on the number of LSLs present in the system and the annual rate of replacement. Appropriate public outreach and POU filters can be used as an means of providing interim protection of vulnerable populations.*	**Yes** *Mitigation*: • Tailored public outreach program • Verification sampling • Provide POU filters	**Yes** *Mitigation*: • Tailored public outreach program • Provide POU filters	**Yes** *Mitigation*: • Tailored public outreach program • Provide POU filters
Implementation in a Two-Tier System *The impact of treatment changes made at a WTP supplying multiple municipalities must be considered in two-tier water supply scenarios such as LAWSS's. Prior to implementing a treatment change, the following questions should be considered:* • *Is corrosion control treatment needed in other municipalities serviced by LAWSS, or just in Sarnia?* • *Will the implementation of corrosion control treatment cause secondary impacts in the other LAWSS systems?* • *How will operations and maintenance (e.g., flushing) be impacted in these systems?* • *Who should pay for the new treatment?*	N/A	**Yes** *Mitigation*: • Investigate these concerns prior to implementing treatment	**Yes** *Mitigation*: • Investigate these concerns prior to implementing treatment
Reaction of phosphate with other constituents (Al, Fe, Ca) *Phosphate can react with aluminum, iron, and calcium to form a hydraulically mobile precipitate. When this precipitate accumulates in the distribution system, the water can take on a "milky white" appearance (see Washington DC case study). In addition to this aesthetic impact, consumption of phosphate by constituents other than lead reduces corrosion control effectiveness.*	N/A	**Yes** *Mitigation*: • Coagulation optimization to reduce treated water aluminum • Pre-filter orthophosphate dosing • Unidirectional flushing to manage accumulation of precipitate	N/A
Increased bacteria *When watermain scales adjust to new water quality conditions (such as that experienced from a change in treatment), chlorine-demanding corrosion by-products such as iron can be released into the bulk water, which impacts disinfectant residual stability. Bacteria and biofilm can also be released from corrosion scales. As a result, bacterial counts can increase (see Washington DC case study).*	N/A	**Yes** *Mitigation*: • Distribution system monitoring • Unidirectional flushing	**Yes** *Mitigation*: • Distribution system monitoring • Unidirectional flushing
Wastewater impacts *Phosphate added to drinking water to control lead increases the baseline level of phosphorus in sewage. Chemical nutrient removal treatment processes at the wastewater treatment plant must be adjusted to account for the increased loading (see Toronto case study).*	N/A	**Yes** *Mitigation*: • Increase chemical use at WWTP to meet phosphorus discharge limit	N/A
Storm sewer impacts *When draining reservoirs or otherwise discharging drinking water to the storm sewer, an exceedance of the storm sewer limit for phosphorus may occur due to the presence of phosphate. Untreated, the phosphorus-laden drinking water can make its way to receiving waters, leading to an environmental impact. To prevent this impact, the phosphate dose applied to drinking water can be maintained below the storm sewer discharge limit (see Toronto case study).*	N/A	**Yes** *Mitigation*: • Maintain phosphate residual below the storm sewer discharge limit	N/A

Calcium carbonate precipitation *When the pH is increased above the calcium carbonate saturation pH, precipitation can occur within equipment (see London case study) and/or in the distribution system which may impact system hydraulics. The water quality review identified the saturation pH for calcium carbonate precipitation to be 8.2 in Sarnia's water, and that excessive calcium carbonate precipitation may be expected to occur in the summer (at warmer temperature) if the pH is increased above 8.6. To mitigate this impact, the pH can be kept at or below 8.6.*	N/A	N/A	**Yes (summer)** *Mitigation:* • Maintain pH at or below 8.6
Iron corrosion *The solubility of iron-based corrosion by-products is sensitive to pH. Changes in the latter must be assessed to avoid exacerbating iron release into the bulk water. The water quality review indicated that increasing the pH to levels targeted for lead control would provide a benefit in terms of managing iron release relative to current conditions. Current levels of iron release can be managed through unidirectional flushing.*	**Yes (existing)** *Mitigation:* • Manage through UDF	**Yes (existing)** *Mitigation:* • Manage through UDF	N/A (Improvement relative to current conditions)
Release of pipe scale constituents *Pipe scales are formed under a specific set of water quality conditions, and when the latter change, pipe scales undergo changes for a period of months to years until they adapt to the new set of water quality conditions. During this "acclimation phase", scale destabilization may result in the dissolution/release of metals such as manganese and arsenic which may only be present at trace levels in treated water, but are present at significant concentrations in pipe scales through years or decades of accumulation. In some cases the release of these constituents may cause an aesthetic impact (such as discoloured water) or a health impact (if released at concentrations above health-based MACs). The water quality review (Section 2) confirmed that manganese is present in Sarnia's distribution system scale. This potential secondary impact can be managed through unidirectional flushing ahead of and during corrosion control treatment implementation.*	N/A	**Yes** *Mitigation:* • Manage through UDF	**Yes** *Mitigation:* • Manage through UDF
Increased disinfection by-products *The formation of trihalomethanes (THMs) is catalyzed by hydroxide ions (OH^-) therefore increasing the pH of treated water would be expected to increase the level of THMs in the distribution system relative to current conditions. This potential secondary impact can be mitigated through monitoring. It is noted that current levels of THMs in the Sarnia Water Distribution System (18 µg/L on average) are well-below Ontario's MAC (100 µg/L).* *In contrast, the formation of haloacetic acids (HAAs) is enhanced under acidic conditions therefore increasing the pH of treated water would be expected to decrease the level of HAAs in the distribution system relative to current conditions.*	N/A	N/A	**Yes** *Mitigation:* • Distribution system monitoring

Sarnia Lead Reduction Plan - Summary of Alternatives

Program component	Description	*LSL REPLACEMENT OPTIONS* Option A: Accelerated LSL replacement over 15 years	Option B: Accelerated LSL replacement over 25 years	*TREATMENT OPTIONS* Option C: Treatment with phosphate (indefinite) plus LSL replacement over 50 years	Option D: Treatment with pH adjustment (indefinite) plus LSL replacement over 50 years	Option E: Treatment with pH adjustment (indefinite) plus accelerated LSL replacement over 40 years	*INTERIM INVESTIGATION OPTIONS* Option F: Interim data collection period (3 years) focused on verification sampling and treatment investigations, with full homeowner support, followed by re-evaluation of alternatives	Option G: Interim data collection period (3 years) focused on verification sampling and treatment investigations, with minor homeowner support, followed by re-evaluation of alternatives
	Time period (years)	15	25	50	50	40	3	3
	Estimated rate of PUBLIC LSL replacement or elimination through verification, assuming 50% of houses in lead zone have	150	90	40	40	60	750	750
	Estimated rate of PRIVATE LSL replacement or elimination through verification, assuming 50% of houses in lead zone	290	180	90	90	110	1,460	1,460
LSL Verification Program	Sampling protocol will consist of: **Tier 1:** Five minute flush followed by collecting a 1-litre sample for analysis of total lead by ICP-MS. Flushed sample may be conducted by homeowner or City staff (preferred). Sampling to occur in the summer only, e.g., June 15 to October 15, or based on a raw water temperature trigger of 15 °C. **Tier 2:** If lead is detected in the flushed sample at any concentration, go back to the home to conduct a lead profile consisting of a five minute flush followed by a 30 minute stagnation. During the stagnation, City staff conducts a plumbing survey. Collect first six litres in individual bottles for analysis of lead in the premise plumbing and the service line. Sampling conducted in the summer only, e.g., June 15 to October 15, or based on a raw water temperature trigger of 15 °C. The first two litres of this sampling may be used for Schedule 15.1 reporting.	Verification of 6.7% of residences in lead zone annually, between June 15 and October 15. This rate of replacement is consistent with US EPA requirements.	Verification of 4% of residences in lead zone annually, between June 15 and October 15.	Verification of 2% of residences in lead zone annually, between June 15 and October 15.	Verification of 2% of residences in lead zone annually, between June 15 and October 15.	Verification of 2.5% of residences in lead zone annually, between June 15 and October 15.	Target verification of as many houses in lead zone as possible annually, between June 15 and October 15. Verification sampling will be limited by homeowner participation, therefore it will not likely be possible to verify all houses in the lead zone in the 3 year period. Assumed verification sampling rate of 1,200 houses per year (40% of houses in potential lead zone over 3 years).	Target verification of as many houses in lead zone as possible annually, between June 15 and October 15. Verification sampling will be limited by homeowner participation, therefore it will not likely be possible to verify all houses in the lead zone in the 3 year period. Assumed verification sampling rate of 1,200 houses per year (40% of houses in potential lead zone over 3 years).
	Houses sampled annually:	590	350	180	180	220	1,200	1,200
LSL Replacement Program	Replacements can occur between April and November (175 business days), weather permitting. Replacement "as encountered" is assumed to match current levels. Remainder of replacements will be targeted, with preference given to full LSL replacements (i.e., where homeowner also replaces their portion of the LSL, or lead is only present on the City-							
	Replacements "as-encountered" during sewer separation projects:	40	40	40	40	40	40	40
	Targeted replacements:	110	50	0	0	20	50	0
Treatment and Distribution System Maintenance	Corrosion control treatment (Details TBD) and required distribution system maintenance resulting from treatment changes.			Assumed initial dose of 3 mg/L as PO_4; reduction to maintenance dose of 1.5 mg/L as PO_4 after 2 years.	Assumed target pH of 8.4 with pH adjustment using NaOH.	Assumed target pH of 8.4 with pH adjustment using NaOH.		
	Member municipality impact study (water quality and flushing)			Y	Y	Y	Y	Y
	Pipe loop study (pilot scale)			Y	Y	Y	Y	Y
	Coagulation optimization study			Y			Y	Y
	Design and services during construction for upgrades			Y	Y	Y		
	Capital cost for upgrades			Y	Y	Y		
	Annual chemical cost @ initial dose (first 2 years)			Y				
	Annual chemical cost @ maintenance dose			Y	Y	Y		
	Annual O&M cost (additional for OCWA)			Y	Y	Y		
	Increase in annual system flushing in response to water quality complaints due to addition of treatment			Y	Y	Y		
	Additional annual wastewater treatment cost			Y				
	Wastewater treatment upgrade cost			Y				
Homeowner Support Program	Homeowner support will include subsidy for private LSL replacement (loan), and NSF-approved filters (pitcher or faucet). **Private LSL replacement loan.** Maximum $2,000 per loan; maximum 10-year repayment period; budget for 50 loans per year. Condition of the loan is to allow City access to resample post-replacement. **Filters.** When lead is detected during verification program, homes with vulnerable populations (pregnant women; infants; children under 6) may apply for filter rebate (max $40). Maximum of 100 rebates available per year. Filters are provided to homeowners for free for 6 months following public LSL replacement.							
	Max number of loans	50	50				50	
	Max number of filter rebates	100	100	100	100	100	100	100
	Provide free filters after LSL replaced	150	90	40	40	60	90	40
	Public outreach will be targeted (e.g., within lead zone; vulnerable populations) however an initial public outreach campaign will be required for all options.	Y	Y	Y	Y	Y	Y	Y
Monitoring for Effectiveness	Monitoring will include lead in premise plumbing in addition to distribution system water quality.							
	Premise plumbing. Sampling protocol for lead consistent with Schedule 15.1, that is, 5 minute flush followed by 30 minute stagnation. Collect first two litres in individual bottles for analysis of total lead. Total iron will also be analysed.	Collect sample after approximately 6 and 12 months.	Collect sample after approximately 6 and 12 months.	Reduced Schedule 15.1 sampling i.e., 90 samples per year collected during summer only.	Reduced Schedule 15.1 sampling i.e., 90 samples per year collected during summer only.	Reduced Schedule 15.1 sampling i.e., 90 samples per year collected during summer only.	Collect sample after approximately 6 and 12 months.	Collect sample after approximately 6 and 12 months.
	Number of houses sampled annually:	200	140	90	90	90	140	40
	Distribution system. Two tier distribution system monitoring program used as process control for corrosion control treatment. Assumed Tier-1 sampling is conducted monthly at 16 sampling sites. When a Tier-1 parameter is out of acceptable range, return to the site to conduct Tier-2 parameter sampling. The monitoring plan sampling will include a combination of field parameters (analyzed by the operator) and lab analyses.			Y	Y	Y		
	Preparation of addendum to LRP based on results from verification sampling.						Y	Y
	Total Cost Summary							
	Total one-time capital cost (upgrades)	$0	$0	$2,150,000	$2,100,000	$2,100,000	$0	$0
	Total studies and one-time program costs	$75,000	$75,000	$475,000	$375,000	$375,000	$525,000	$525,000
	Total annual costs (including capital and operating)	**$1,733,000**	**$1,001,000**	**$524,000**	**$359,000**	**$581,000**	**$1,172,000**	**$496,000**
	Net present value of annual costs	$21,457,000	$18,443,000	$14,862,000	$10,182,000	$14,585,000	$3,347,000	$1,417,000
	Total life-cycle cost	$21,532,000	$18,518,000	$17,487,000	$12,657,000	$17,060,000	$3,872,000	$1,942,000
	Pros	- Addresses the cause of the problem by removing the source of lead - High level of homeowner support - Other LAWSS members not affected	- Addresses the cause of the problem by removing the source of lead - High level of homeowner support - Other LAWSS members not affected	- Lower annual cost - Very likely to achieve public health protection over short-term, independent of homeowner participation - Allows Sarnia to remove lead from the system over a longer period of time	- Lower annual cost - Possibility to achieve public health protection over short-term, independent of homeowner participation - Allows Sarnia to remove lead from the system over a longer period of time	- Lower annual cost - Likely to achieve public health protection over short-term, with reliance on homeowner participation for full LSL removal - Allows Sarnia to remove lead from the system over a longer period of time	- Provides information for sound decision-making - High level of homeowner support	- Provides information for sound decision-making - Lower annual cost
	Cons	- Higher annual cost - Continued exposure to lead due to long program duration - Performance is dependent on homeowner participation for full LSL removal - Secondary sources of lead not addressed - Potential for secondary impacts, which can be managed (e.g., lead spikes)	- Higher annual cost - Continued exposure to lead due to long program duration - Performance is dependent on homeowner participation for full LSL removal - Secondary sources of lead not addressed - Potential for secondary impacts, which can be managed (e.g., lead spikes)	- Higher up-front cost - Other LAWSS members potentially affected - Potential for secondary impacts, which can be managed (e.g., increased bacteria, milky water, wastewater impact, sewer use by-law impact) - Treatment continues in perpetuity	- Higher up-front cost - Other LAWSS members potentially affected - Potential for secondary impacts, which can be managed (e.g., increased bacteria, increased THMs) - May not be able to meet future MAC (5 µg/L) - Treatment continues in perpetuity	- Higher up-front cost - Other LAWSS members potentially affected - Potential for secondary impacts, which can be managed (e.g., increased bacteria, increased THMs) - May not be able to meet future MAC (5 µg/L) - Treatment continues in perpetuity	- Higher annual cost - Significant ramp-up required to rapidly implement several programs - Deferred decision/action results in longer exposure to lead	- Lower level of homeowner support - Deferred decision/action results in longer exposure to lead

Assumptions Lead zone includes 4483 houses that may have a public LSL and 8787 houses that may have a private LSLs. Calculation assumes that lead services will be found at 50% of the houses.

LSL replacement costs estimated based on typical costs in Sarnia: $4000 per replacement when combined with a sewer separation / watermain replacement project, or $10000 per replacement for standalone replacements.

Treatment costs for the LAWSS WTP estimated assuming an average daily flow of 54 MLD and a rated capacity of 181 MLD. Did not account for future changes in flow.

Figure 4-12. Summary of Proposed Lead Management Alternatives

4.6 Development of Proposed Alternatives

Based on the assessment of secondary impacts and implementation issues described in Section 4.5, seven lead management alternatives were developed for Sarnia. These alternatives were based on the three approaches previously identified: LSL replacement; phosphate-based treatment; and treatment based on pH adjustment. A fourth approach based on LSL replacement with a focus on interim investigation was included as an "interim alternative". The alternatives consisted of the following:

- **LSL-based alternatives:**
  - Option A: Accelerated LSL replacement over 15 years
  - *Option B: Accelerated LSL replacement over 25 years (screened out)*
- **Treatment-based alternatives:**
  - Option C: Treatment with phosphate (indefinite) with LSL replacement over 50 years
  - *Option D: Treatment with pH adjustment (indefinite) with LSL replacement over 50 years (screened out)*
  - Option E: Treatment with pH adjustment (indefinite) with accelerated LSL replacement over 40 years
- **Alternatives based on LSL replacement with interim investigations:**
  - Option F: Interim data collection period (3 years) focused on verification sampling and treatment investigations, with full homeowner support, followed by re-evaluation of alternatives
  - *Option G: Interim data collection period (3 years) focused on verification sampling and treatment investigations, with minor homeowner support, followed by re-evaluation of alternatives (screened out)*

As summarized in Figure 4-12 (on the previous page), the program components for these alternatives were defined based on the need for mitigation measures as identified in Table 4-3. After consultation with the project team and the MOECC, some of the alternatives were screened out and eliminated. This included:

- Option B which was eliminated because the LSL replacement period was too long. An acceptable timeframe for LSL replacement is not defined in Ontario's current regulatory framework or guidance, however consultation with the MOECC confirmed that 25 years would not be acceptable. The timeframe for Option A—15 years—is based on the replacement rate defined by the USEPA.
- Option D which was eliminated based on the water quality assessment and review of analogous systems, which suggested that it would be difficult to achieve regulatory compliance based on pH adjustment alone. For this reason, Option E was included, which provided for a slight acceleration of LSL replacement relative to the other two treatment options.
- Option G which was eliminated because the City of Sarnia is committed to protecting public health and it was felt that this alternative would not provide an adequate level of interim protection.

4.6.1 Overview of Program Components

The following subsections describe the proposed structure and costs for program components, from which alternatives (as outlined in Figure 4-12) were developed. Additional details and assumptions related to cost development are provided in Appendix A.

4.6.1.1 LSL Verification Program

Purpose. The purpose of the LSL verification program is to locate LSLs by inspecting and sampling homes located in the lead zone. Results from this sampling program will be used to prioritize replacement of the publicly-owned portion of encountered LSLs, as well as to encourage property owners to replace the private portion of the LSL where encountered. Additionally, this program will serve to identify homes that require interim protection due to vulnerable populations. Verification sampling was included in all of the alternatives.

Prioritization. Initially, prioritization for verification sampling can be placed on neighbourhoods comprised of wartime homes, that is, single family homes built during and following World War II for workers in defense-oriented industries and returning veterans. These small, 1 to 1.5 story (often prefabricated) homes were built in the 1940s and are characterized by a small volume of premise plumbing and small-diameter, long service lines. These very long service lines with a high surface-area-to-volume-ratio contribute to high lead concentrations measured at the tap, and consequently, to increased lead exposure for the occupants. Examples in Sarnia include the "tree streets" (i.e., near Germain/Coronation Parks), Ann/Emma St. area, etc.

Sampling rate. The required sampling rate for each alternative was based on sampling all of the homes in the lead zone over the program duration. For the interim investigation alternatives, it is not possible to sample all of the homes in the lead zone in a 3-year period. An aggressive rate of 1,200 homes sampled annually was therefore assumed for these alternatives, which would provide verification of 40% of the homes in the potential lead zone over the three-year period.

Sampling protocol. There is currently no guidance within Ontario's regulatory framework for conducting verification sampling, therefore literature was reviewed to identify appropriate sampling protocols. Neither flushed sampling nor Schedule 15.1 sampling are designed to detect the presence of LSLs. Profile sampling is the best approach for detecting LSLs, however it is time-consuming, costly, and generates a large amount of data. A flushed sample reduces the staff time associated with sampling, allowing more samples to be collected per day. However, due to the low contact time between the water and the LSL during flushing, lead levels observed from this sampling method are lower than those obtained with stagnation periods. Furthermore, flushed samples are usually used to assess dissolved (and not particulate) lead concentrations.

The following two-tiered verification sampling protocol was developed for Sarnia based on maximizing the number of samples that could be collected per day while collecting enough information to identify the source of lead, where present:

- <u>Tier-1 sampling</u>: Flush the tap until the water runs cold or for five minutes (whichever occurs first). Collect a 1-litre sample for analysis of total lead by ICP-MS[8]. This flushed sample may be collected by the homeowner (using a City-provided water sampling kit) or by City staff (the latter being preferred). Since lead release is significantly reduced at lower temperature, verification sampling will occur in the summer only (e.g., June 15 to October 15, or based on a raw water temperature trigger of 15 °C).
- <u>Tier-2 sampling</u>: If lead is detected in the flushed sample, City staff return to the home to conduct a lead profile consisting of a flush (until water runs cold or after five minutes) followed

[8] Inductively coupled plasma mass spectrometry

by a 30-minute stagnation. During the stagnation, the City staff conducts a plumbing survey. After the stagnation period, the City staff collects the first six litres in individual bottles for analysis of total lead (by ICP-MS) in the premise plumbing and the service line. Sampling will occur in the summer only (e.g., June 15 to October 15, or based on a raw water temperature trigger of 15 °C). Since the Tier-2 sample collection protocol is consistent with that of Schedule 15.1, the first two litres of the profile may be used for Schedule 15.1 reporting.

City staff may need to adjust the profile sample collection protocol at individual homes depending on the results of the in-home plumbing survey. For example, additional 1-L volumes may need to be collected in homes with longer premise plumbing and/or service lines

Threshold value. Based on the review of literature, the flushed sample lead value typically used as a cut-off to identify the presence of an LSL is on the order of 1 to 2 µg/L (for summer sampling); however, this value must be determined based on system-specific testing. Deshommes et al. (2016) recommend carrying out flushed sampling and (full) profile sampling in 10 to 20 houses with confirmed LSLs, to establish a correlation between flushed sample results and stagnated sample results obtained from profiles. The appropriate threshold for flushed samples can then be defensibly established using these site-specific data. Instead of using a threshold value to trigger Tier-2 sampling, to be conservative, the City will carry out Tier-2 sampling if lead is detected at any concentration in the flushed sample. The City intends to confirm the validity of the verification sampling approach through a data analysis activity. Using data collected as part of verification sampling, the City will compare the flushed sample result with profile results in individual homes where a lead profile was collected and the presence of an LSL was subsequently confirmed during replacement activities.

Sampling kits. Regarding the use of water sampling kits for homeowner-collected sampling, it is acknowledged that this may impact data quality due to homeowner error. However, advantages of this approach include:

- More homes can be sampled in a shorter period of time
- Cost savings in terms of staff time
- May provide a higher rate of participation since it does not involve City staff entering the home and scheduling appointments

The City can establish pick-up/drop-off locations for the kits at libraries, community centres, City facilities (such as City Hall, Public Works, and Fire Department), and other locations accessible to the community.

Records review and database refinement. In parallel with the sampling activities, the City's "lead zone" database will continue to be updated based on a records review using construction records, the County's plumbing permits, and operations data. An accompanying map showing the extent of the lead zone is currently under development, based on this database. Overall, it is expected that record review activities will reduce the number of suspected LSLs, however in some cases, addresses may be added to the list. It is expected that this records review process will continue for several years and over time, the quality of these data will improve, resulting in a more realistic estimate of the number of LSLs.

Staffing requirements. Staffing requirements for this program component are anticipated as follows:

- Program management: Coordination with homeowners to schedule appointments; management of data (lead results and plumbing surveys); and communication with homeowners about results.
- Technical staff: To carry out sampling and plumbing surveys. It was assumed that Tier-1 sampling would require approximately 30 minutes per sample (including travel time) and that

Tier-2 sampling would require approximately 1 hour per sample (including travel time), through strategic scheduling of sampling appointments within a reasonable geographic area.

4.6.1.2 LSL Replacement Program

Purpose. The purpose of the LSL replacement program is to reduce the number of LSLs present in the Sarnia Distribution System. Other program components (homeowner support program and public outreach program) will be used to encourage, as much as possible, full LSL replacement.
LSL replacement was included in all of the alternatives.

Prioritization. LSL replacement will focus on the lead zone, and similar to the verification sampling, systematic LSL replacement should initially focus on neighbourhoods with wartime homes. Prioritization will also be based on the City's other objectives, chief among them, sewer separation as required by the MOECC.

Replacement rate. Limited data suggest that as low as 20% of the LSLs encountered during previous sewer separation / watermain replacement projects in the lead zone actually had a public LSL. Until more data can be obtained (e.g., as part of future sewer separation / watermain replacement projects and verification sampling), a conservative assumption was made that 50% of the houses in the lead zone may have a public LSL. The required LSL replacement rate for each alternative was therefore based on replacing 50% of the current estimate of public LSLs in the lead zone over the program duration. Similarly, the replacement rate for private LSLs was based on replacing 50% of the current estimate of private LSLs in the lead zone over the program duration. The alternatives assume that public LSL replacements will occur through a combination of the City's existing "as encountered" approach and targeted replacements. As noted earlier, efforts will be made to encourage private LSL replacement, however the City cannot commit to achieving the targeted private LSL replacement rate because they have no legal authority or mechanism to enforce private LSL replacement.

Replacement of LSLs "as encountered". This refers to replacement of the public side of the LSL during sewer separation / watermain replacement projects or through operations (e.g., watermain breaks, maintenance activities, etc.). Though efforts can be made to prioritize suspected lead areas for the sewer separation / watermain replacement projects, the City cannot control how many LSLs will be encountered during these activities. Therefore the "as encountered" LSL replacement rate was assumed to match current levels. The cost of LSL replacements when combined with other projects was assumed to be $4,000 per replacement, including materials, labour, and restoration (curb gutter, driveway, boulevard, etc.).

Targeted LSL replacement. The remainder of public LSL replacements to achieve the program's necessary replacement rate will be targeted replacements, that is, individual public LSL replacements that occur outside of other projects. These are carried out in response to a homeowner request, who has already replaced or will be replacing the private LSL. For example, replacement of the public LSL would occur at homes where the homeowner receives the LSL replacement loan and replaces the private LSL. Another example would be a situation where an LSL was confirmed (through verification sampling) to be present only on the City-side. The cost of targeted LSL replacements was assumed to be $10,000 per replacement, including materials, labour, and restoration (curb gutter, driveway, boulevard, etc.). Based on experience in other municipalities, it is expected that the unit replacement cost may decrease if targeted LSL replacement is contracted out.

Record-keeping. The City's database will be updated with public and private service line material as observed during sewer separation / watermain replacement projects and LSL replacements. Houses which are found to *not* contain a LSL during these projects can be removed from the suspected lead list. The number of houses in the lead zone suspected to have an LSL will therefore decrease as these projects proceed.

Timing. LSL replacements can occur between April and November (approximately 175 business days), weather permitting.

Staffing requirements. Staffing requirements for this program component are anticipated as follows:

- Program management: Scheduling LSL replacements; coordination with homeowners; updating LSL database.
- Technical staff: To carry out LSL replacements. Staffing requirement estimates in Appendix A do not include labourers/operators for LSL replacements, since staffing costs had been included within the per replacement cost. However, if the City will be relying on their own forces to carry out LSL replacements, this may impact scheduling and/or staffing requirements (FTE).

4.6.1.3 Treatment and Distribution System Maintenance

Member municipality impact study. Previous Schedule 15.1 testing carried out by LAWSS in other member municipalities ten years ago suggested that lead release was not an issue in those systems. A member municipality impact study is required to confirm the following:

- Is lead management needed in the systems of other LAWSS member municipalities? Has this changed, considering the proposed MAC reduction to 5 µg/L? If lead management is required in systems other than Sarnia, this will provide greater support for a corrosion control treatment-based approach.
- Is the implementation of corrosion control treatment at the LAWSS WTP expected to negatively (or positively) impact water quality in the other LAWSS member municipalities (and downstream, non-member municipalities that may receive LAWSS water through interconnections to the LAWSS system)? If so, which impacts are expected? Will ICI customers be impacted?
- Will wastewater treatment upgrades be required if a phosphate-based corrosion control treatment approach is implemented?
- How will O&M activities—such as flushing—be impacted in these systems if corrosion control treatment is implemented?
- Considering the above factors, how should the cost of WTP upgrades be equitably divided among the LAWSS member municipalities?

It was assumed that this member municipality study would be led by LAWSS. The member municipality study was not included in the LSL replacement-based alternatives. Should it be determined through the member municipality impact study that corrosion control treatment at the LAWSS WTP is feasible, the next step would be to conduct treatment investigations (pipe loop study and coagulation optimization study) as described next.

Pipe loop study. Potential corrosion control treatment alternatives were identified through the water quality assessment; however, a pipe loop study will be required to investigate the ability of these treatment alternatives to control lead measured at the tap in the Sarnia Distribution System. A pipe loop study will also confirm key design criteria for a full-scale system, such as the type of treatment chemical, required dosages, and the need for other water quality adjustments (such as pH adjustment to within the optimal range for use with orthophosphate or alkalinity/DIC adjustment to improve buffer intensity).

To carry out the pipe loop study, LSLs must be harvested from the system and used to build pipe test rigs. One option is to set up pipe rigs at the water treatment plant, which would be the case if the pipe loop study was led by LAWSS. It is common for systems conducting pipe loop testing to set up pipe rigs at the plant, since a) water quality is representative of the point at which the treatment chemical would be applied at full-scale, and b) the experiment benefits from the convenience of having access to the plant's lab for carrying out water quality testing. However, disadvantages of operating the pipe loop test at the plant is that the water does not pass through the distribution system, and therefore treatment effectiveness may be overestimated.

Another option is to set up the pipe rigs within the Sarnia Distribution System (e.g., at a pump station or other suitable location owned by the City). This might allow for a more representative assessment of expected lead reduction under actual conditions in the Sarnia Distribution System, considering factors such as iron release from watermains and other water quality interactions within the Sarnia Distribution System, with the caveat that at full-scale, the treatment chemical would be applied prior to passing through the distribution system, and not after. A benefit of this pipe rig arrangement is that, following completion of the study, the pipe rigs can be used by the City as sentinel lead monitoring stations in the distribution system.

It was assumed that the preferred arrangement for the pipe loop study (led by LAWSS at the WTP or led by Sarnia within the Sarnia Distribution System) will be evaluated as part of the pipe loop study design process and determined through discussions and negotiations between Sarnia and LAWSS. The pipe loop study was not included in the LSL replacement-based alternatives; however, was included in the treatment and interim alternatives. In the interim alternatives, it was deemed necessary in the event that, after the three-year interim program, a treatment-based alternative was selected to effectively control lead while LSLs are removed from the system over a period longer than 15 years.

Coagulation optimization study. Treated water aluminum levels at the LAWSS WTP have historically been seasonally high (annual average of 92 µg/L and summer average of 126 µg/L). As confirmed through hydrant sampling carried out in 2017, this contributes to post-precipitation of aluminum in the distribution system and accumulation of aluminum in the distribution system scale deposits. Under a phosphate-based corrosion control treatment approach there is a high likelihood that phosphate would precipitate with the accumulated aluminum (and other metals present in the distribution system such as calcium and iron). As noted in the Washington, DC case study, this precipitate can cause a milky water aesthetic impact and reduces corrosion control effectiveness through the non-targeted consumption of phosphate. Should a phosphate-based treatment approach be identified as preferred through the pipe loop study, a coagulation optimization study would therefore be required to identify treatment optimization strategies for minimizing treated water aluminum levels at the LAWSS WTP. Pre-treatment at the WTP currently uses acidified alum in a direct filtration configuration. Bench-scale coagulation optimization testing can identify suitable coagulant alternatives, assess the applicability of coagulant aids, and evaluate the need for a separate pH adjustment process (ahead of coagulation) to better control aluminum residuals in the treated water. A pilot-scale trial may also be beneficial in evaluating pre-treatment optimization alternatives, which may include a pre-filter orthophosphate dosing location to manage aluminum-phosphate precipitation within the WTP (see Toronto and Hamilton case studies). If it is found that the pre-treatment process cannot be further optimized to reduce treated water aluminum residuals, additional operating and maintenance (O&M) costs related to flushing may be expected if a phosphate-based corrosion control treatment approach is implemented. The coagulation study was not included in the LSL replacement-based alternatives.

Treatment plant upgrades. Estimates of engineering and capital costs were based on the following assumptions:

- Prolonged cessation of corrosion control treatment (e.g., months) may cause lead release. Since there is a low probability of Sarnia requiring emergency servicing from the Petrolia WTP in Bright's Grove (based on historical observations), addition of corrosion control treatment at the Petrolia WTP was not justified. It is therefore assumed that corrosion control treatment would only be implemented at the LAWSS WTP.
- Though there is enough space for a new chemical system at the LAWSS WTP (in the area previously occupied by the fluoride equipment), due to concerns about ventilation and health

and safety, it was assumed that a new building would be required to house the chemical equipment. An allowance was also included in the cost estimate to account for additional footings support for this building due to poor soil quality at the LAWSS WTP site.

- Treatment plant upgrades were not included in the LSL replacement-based alternatives.

Annual treatment chemical costs. Estimates of annual corrosion control treatment chemical costs were based on the following assumptions:

- The selection of treatment chemicals, dosages, and pH targets would need to be confirmed through a pipe loop study however some assumptions were made for the purposes of developing capital cost estimates for the treatment systems. Based on the water quality review and case studies, the initial orthophosphate dose would likely be in the range of between 2 and 3 mg/L as PO_4. Phosphoric acid was assumed as the treatment chemical, at an initial dose of 3 mg/L as PO_4 and a maintenance dose of 1.5 mg/L as PO_4. For the pH adjustment treatment alternatives, sodium hydroxide was assumed as the treatment chemical and a target pH of 8.6 was assumed based on the water quality review.
- Initial dose (first two years) and maintenance dose (from the third year onward) annual chemical costs were based on the LAWSS WTP's average production of 54 ML/d. Projected increases in production rate were not available, therefore the calculation assumes the same production rate for the program duration.
- Annual treatment costs were not included in the LSL replacement-based alternatives.

Annual O&M cost. Additional O&M costs associated with adding a corrosion control treatment process at the LAWSS WTP were included. This cost estimate was provided by LAWSS. Annual O&M costs were not included in the LSL replacement-based alternatives.

Watermain flushing cost. The Sarnia Distribution System is largely comprised of older, unlined cast-iron watermains. The City's previous attempts to carry out unidirectional flushing (UDF) were unsuccessful, since they resulted in uncontrolled velocities that were sufficiently high as to break the watermains. As a result, the City currently practices a quasi-UDF flushing approach, where the distribution system is flushed systematically from a clean source, though valves are not closed to isolate specific stretches of watermain that are being flushed. Existing practices are based on flushing the entire system annually. Though flushing will be especially important to manage secondary impacts expected from the treatment alternatives, it is included under all of the alternatives since UDF can be used to manage existing iron corrosion issues as identified in the water quality assessment.

Wastewater treatment impacts. As noted in the case studies, it is expected that the implementation of a phosphate-based corrosion control treatment approach would impact chemical nutrient removal (for phosphorus) at Sarnia's wastewater treatment plants. Estimated costs were included for additional treatment chemical (alum) use and upgrades to accommodate the higher alum dosing. Wastewater treatment impact costs were only included in the phosphate-based alternative.

4.6.1.4 Homeowner Support Program

Purpose. Due to the concerns associated with partial LSL replacements, there is a need to provide homeowner support programs that will encourage full LSL replacement and that will provide interim protection to vulnerable populations. This will be achieved through two programs: an LSL loan, and POU filters.

LSL replacement loan. The review of case studies identified several options for programs that help offset the costs of private LSL replacement, two such examples being loans and grants. A loan has been identified as a more suitable approach than a grant for Sarnia, since a loan (particularly one that bears interest) places a lesser economic burden on the City, and minimizes perceived injustice issues associated with spending rate-based public funds on private property. Since implementing a loan program has legal and financial ramifications, the City must consult with appropriate internal stakeholders and together develop a suitable structure for its proposed LSL replacement loan program. For the purposes of cost estimation, the following assumptions were made:

- The maximum loan amount is $2,000, and the loan can be repaid to the City by the homeowner over a maximum period of ten years.
- The number of loans offered per year would be reviewed by the City and determined annually based on the previous year's uptake, and the need for allocating new funding would be assessed annually in consideration of unspent funds from the previous year. For cost estimation purposes, it was assumed that on average, a total of 50 loans will be offered per year.
- For simplicity, loan repayment and interest paid by the homeowner was not included in the calculation of program costs. When program details are further defined by the City, these considerations can be factored into the calculation to refine the estimate of program costs.
- A condition of the loan will be that the homeowner must grant the City permission to re-enter the home for post-replacement sampling.
- It was assumed that the loan would be optional in the treatment-based alternatives, and therefore was not included.

POU filters. Point-of-use (POU) filters approved to meet National Sanitation Foundation (NSF) standard NSF/ANSI 53 can remove particulate and dissolved lead. These filters are available in several formats, including pitcher-style, faucet-mounted, and plumbed-in, each with their own advantages and disadvantages. Pitcher filters typically have a lower capacity than faucet-mounted filters, whereas the latter may not be compatible with many modern faucet styles. Plumbed-in filters have significantly higher filtration capacity than faucet-mounted filters, however they are more onerous to install. Higher concentrations of lead will require more frequent filter cartridge replacement.

The City will develop a POU filter program to provide interim protection from lead exposure as follows:

- When lead is detected during the verification program, homes with vulnerable populations (pregnant women; infants; children under 6) may apply for the filter rebate. Similar to the loan program, the City must consult with appropriate internal stakeholders and together develop a suitable structure for the filter rebate program. For cost estimation purposes, it was assumed that the City would offer a maximum of 100 filter rebates annually, each for a maximum amount of $40.
- Filters will be provided to homeowners for free for a period of six months following public LSL replacement (regardless of whether a full or partial replacement is carried out). For cost estimation purposes, it was assumed that the number of filters provided through this program would be the same as the rate of public LSL replacement.

This POU filter program will require the City to purchase large numbers of filters. The City may be able to secure reduced pricing through a filter supply contract. This will also be of benefit in ensuring that a reliable supply of filters is readily available. The POU filter program was included in all of the alternatives.

Staffing requirements. Staffing requirements for this program component are anticipated as follows:

- <u>Program management</u>: Administration of the loan program; administration of the filter rebate program

4.6.1.5 Public Outreach Program

Purpose. The public outreach program is the cornerstone of the lead management strategy. Effective, transparent communication is critical. Key objectives of the public outreach program include:

- Accurately communicating the level of health risk associated with lead
- Informing the public about the City's lead management efforts
- Informing the public as to the actions they can take to protect themselves
- Encouraging the public to participate in the City's programs

The program's objectives will be further refined through a communications plan. Public outreach was included in all of the alternatives.

Current outreach efforts. In partnership with Lambton Public Health, the City's existing outreach efforts consist of the following:

- Letters to homeowners communicating results from lead testing
- Letters to homeowners communicating discovery of a private LSL
- Website content and factsheet available through Lambton Public Health
- News articles in local newspapers
- Press releases

Examples of these materials are provided in Appendix B. It is expected that existing letter templates will need to be updated and new materials created to reflect changes to the City's lead management strategy and current best practices such as those defined in AWWA's new Standard (ANSI/AWWA C810-17: Replacement and Flushing of Lead Services Lines).

Communications plan. In partnership with Lambton Public Health and the City's communications department, a communications plan will be developed specifically for public outreach activities related to the lead management strategy. The plan will define and document key considerations such as:

- Target audiences
- Communication partners
- Key messaging
- Communication formats and mediums
- Timing of communications
- Communications protocols and lines of communication
- Internal training needs

Required materials and programs will be developed in response to needs as defined in the communications plan. The communications plan was included in all of the alternatives.

Initial outreach campaign. An initial outreach campaign will allow the City to inform the public about the updated lead management strategy. This was included in all of the alternatives.

Annual communications. Following initial outreach, annual communication blasts will be required to solicit participation in the verification sampling program and to encourage private LSL replacement. This was included in all of the alternatives.

Staffing requirements. Staffing requirements for this program component are anticipated as follows:

- Program management: Organizing public outreach events and mailouts; targeted communication to vulnerable populations and residents in the lead zone; internal coordination with other aspects of the Lead Reduction Strategy.

4.6.1.6 Monitoring for Effectiveness

Purpose. Monitoring is a key component of the lead reduction approach that will allow the City to assess the strategy's success in reducing lead levels at the tap. Residential lead monitoring programs were included for all of the alternatives. A two-tier distribution system water quality monitoring program (per AWWA's M58 manual of practice) was included for the treatment alternatives.

Residential sampling. Residential lead sampling was based on the Schedule 15.1 protocol, that is, measurement of total lead in the first two consecutive litres obtained from a 5 minute flush followed by a 30 minute stagnation. For the purposes of cost estimation, the following assumptions were made:

- LSL replacement approaches: Post-replacement monitoring is a key component of approaches based on LSL replacement to demonstrate reduction of lead levels measured at the tap and identify the occurrence of lead spikes such that interim protection can be provided. It was assumed that samples would be collected at approximately 6 and 12 months following replacement, and analysed for total lead and total iron. Analysis of iron together with lead will provide valuable information as to the source of lead (e.g., lead service line; galvanized pipe; etc.).
- Treatment approaches: Residential monitoring in these approaches is based on assessing the efficacy of the corrosion control treatment for reducing lead measured at the tap. It was assumed that the City would implement a reduced Schedule 15.1 sampling schedule, that is, 90 residential samples per year collected during the summer sampling period only. Winter sampling was omitted in this case since lead levels are expected to be lower due to the cold water temperature, and therefore winter monitoring does not satisfy the objective of assessing the efficacy of the corrosion control treatment.

Distribution system monitoring. It was assumed that a two-tier distribution system monitoring program (centered on sampling distribution system water quality from sampling stations or hydrants) would be required under the treatment alternatives as a process control tool for corrosion control treatment. For the purposes of cost estimation, it was assumed that Tier-1 sampling would be conducted monthly at 16 sampling sites, and that Tier-2 parameter sampling would occur when a Tier-1 parameter is out of its acceptable range, as defined by a monitoring plan. This monitoring program would include a combination of field parameters (analyzed onsite at time of sample collection) and lab analyses.

Staffing requirements. Staffing requirements for this program component are anticipated as follows:

- Program management: Coordination with homeowners to schedule appointments; management of data including lead results; communication with homeowners about results; preparation of annual report to MOECC.
- Technical staff: To carry out sampling.

4.6.1.7 Re-Evaluation of Alternatives

The interim investigation alternative includes a re-evaluation of alternatives at the conclusion of the three-year study period. This re-evaluation will consider the following factors:

- Based on the updated LSL estimate, can the required rate of public and private LSL replacements be achieved in a reasonable period of time (12 or fewer years)?
- Has LSL replacement been demonstrated to protect public health and achieve regulatory compliance, considering potential changes to lead regulations in Ontario?

- Is corrosion control treatment at the LAWSS WTP feasible?

Similar to this Lead Reduction Plan, it is assumed that the re-evaluation study will be carried out jointly by Sarnia and LAWSS. Any changes to the lead management strategy will be documented in an addendum to the Lead Reduction Plan.

4.6.2 Identification of Preferred Alternative and Rationale

There is currently limited information about the actual number of LSLs in the City of Sarnia. In 2017, an estimate was developed using very conservative assumptions. This 2017 estimate of the number of LSLs in the Sarnia Distribution System is therefore likely much larger than the actual number of LSLs in the system. The City cannot make a defensible decision or financial commitment to carry out accelerated LSL replacements at the rate dictated by the 2017 estimate of LSLs. Further, LAWSS cannot defensibly justify implementing corrosion control treatment to its members without sufficiently identifying and quantifying impacts on the latter, particularly when the LSL replacement alternative is poorly defined due to the conservative estimate of the number of LSLs.

Based on these circumstances, "Option F" describes the first three years of a lead management strategy which is based on eliminating all suspected LSLs within 15 years, either by confirming non-leaded material via available information or, where LSLs are present, actually replacing the LSL. During this three-year period, focus is placed on developing required programs, accelerated LSL verification, and investigating treatment options, with LSL replacement continuing at slightly higher than current rates. This rate of replacement however is lower than that which would be required to replace all LSLs in 15 years, based on the 2017 estimated number of LSLs in the Sarnia Distribution System.

The objective of this interim plan is to collect the information that is needed for the City and LAWSS to defensibly commit to a lead management program for the City of Sarnia, namely:

- Refining the LSL estimate to a more realistic number upon which to build a financially sound plan.
- Confirming the level of homeowner participation in conducting private LSL replacements.
- Confirming the level of public health protection provided by LSL replacement in combination with interim protection measures such as filters (i.e., through reductions in lead measured at the tap).
- Assessing the feasibility of implementing corrosion control treatment at the LAWSS WTP, in terms of:
    - Understanding the impacts of corrosion control treatment on the LAWSS member municipalities.
    - The ability of different corrosion control treatment alternatives to control lead measured at the tap, within the Sarnia Distribution System.
    - The ability to minimize interference with existing water treatment processes at the LAWSS WTP (specifically, coagulation due to seasonally elevated aluminum residuals).

Details for "Option F", including associated tasks, timelines, staffing needs, and costs are described in Section 5. As shown in Figure 4-13, the commitment to replace all LSLs in 15 years (by 2034) will be re-evaluated at the conclusion of the three-year interim period, based on the totality of information collected over the course of this three-year interim plan. If, based on this re-evaluation, it is determined that the remaining LSLs cannot be removed by 2034 (12 years starting in 2022) and/or that LSL replacement on its own does not provide a sufficient level of public health protection, a course correction can be made and corrosion control treatment will be negotiated with the LAWSS Board.

Alternatively, if replacement of the remaining LSLs by 2034 is determined to be feasible, the City can develop a realistic, fiscally sound plan to replace the remaining LSLs in 12 years.

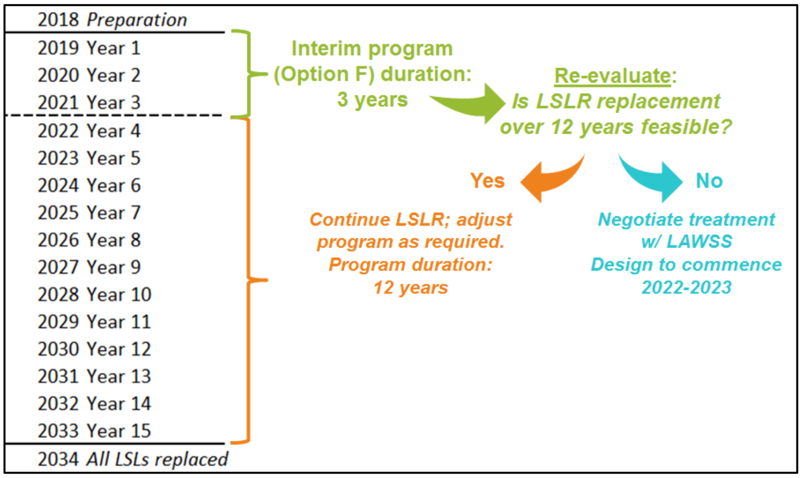


Figure 4-13. Overview of Option F (interim three-year plan)

Advantages of “Option F” include:

- **Protection of vulnerable populations.** By kick-starting the multiple programs that are required in support of lead management, such as public outreach and education, homeowner assistance (loan for private LSL replacement), interim/temporary lead reduction measures (filters), and monitoring, “Option F” provides protection of vulnerable populations during this interim period. These programs would be required regardless of whether the City moves forward with an LSL replacement approach or a treatment approach.
- **Planning for potential future corrosion control treatment.** “Option F” includes background studies in support of a corrosion control treatment approach. Corrosion control treatment can therefore be implemented in 2022-2023 (moving into the design phase) should it be deemed necessary at the end of the three-year period. In other words, “Option F” does not delay the possible implementation of corrosion control treatment relative to what would be possible if a decision was made *today* to implement corrosion control treatment.
- **Adaptable.** By allowing for a course correction (if needed) in 2022, “Option F” provides the City and LAWSS with the flexibility to adapt to upcoming changes to Ontario’s regulatory framework related to lead.
- **Fact-based decision-making.** By focusing on LSL replacement and the collection of required information while protecting vulnerable populations over an interim period, “Option F” sets the City and LAWSS on track to make a defensible decision at the end of the interim period.

SECTION 5

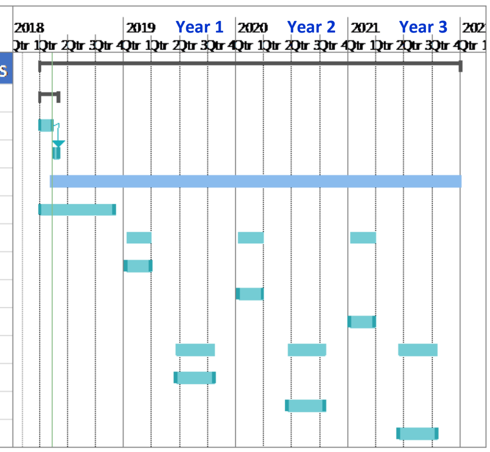
Phased Implementation Plan

Since key program components require a considerable amount of time and effort to develop and implement, the three-year interim plan will commence in 2019 (Year 1), and will conclude at the end of 2021 (Year 3). Details of the plan—including key tasks, schedule, resource requirements, and costs for each year—are described in the following sub-sections. The schedule presented herein is provided as guidance, and may change as the program evolves.

The (previously allocated) lead management budget for 2018 will be used for 2018 program development activities in support of implementing the three-year plan in 2019.

5.1 LSL Verification Program

ID	Task Mode	Task Name	Duration
1		1. LSL Verification Program	980 days
2		**Staffing**	**45 days**
3		Hiring process	6 wks
4		Staff training	3 wks
5		Records review (ongoing activity)	960 days
6		2018 pre-construction verification sampling	175 days
7		**5-min flush sample kit preparation**	**580 days**
8		Sample kit prep for Year 1 (2019)	60 days
9		Sample kit prep for Year 2 (2020)	60 days
10		Sample kit prep for Year 3 (2021)	60 days
11		**Verification sampling (target 1,200 homes annually, June 15 to Oct 15)**	**610 days**
12		Year 1 (2019) verification sampling	90 days
13		Year 2 (2020) verification sampling	90 days
14		Year 3 (2021) verification sampling	90 days



Note: Schedule is provided as guidance, and may change as the program evolves

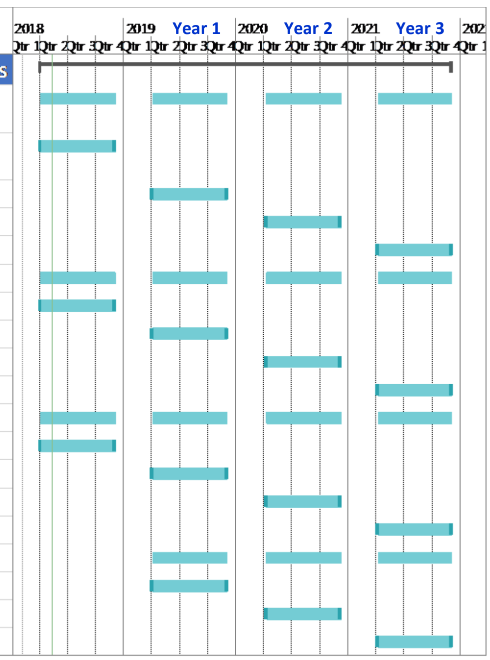
- **Staffing (2018):** One full-time program management/administration person from existing staff and two students will initiate the program. The program management staff and students will support program development activities and data management in 2018, and all program components during Years 1 to 3. This plan assumes that further support will be required in Years 1 to 3, however the need for new staff (versus reassigning existing staff) will be assessed and therefore the exact staffing makeup may change based on availability of existing resources and the need for new resources.
- **Records review (starting summer 2018, ongoing):** The City will continue efforts to update their database of known/suspected LSLs. The objective of this activity is to update the public and private service line material based on construction records, the County's plumbing permits, and operations data. This activity will commence during summer 2018 and will continue on an ongoing basis.
- **Pre-construction verification sampling (summer 2018):** Since the formal verification sampling program will not commence until 2019, the City will conduct some pre-replacement sampling at approximately 40 homes located on the streets scheduled for sewer separation / watermain replacement projects in 2018 (Emma St., John St., Mary St., and Richard St). Ahead of the construction, residential samples will be collected using both a 5-minute flush procedure and the Schedule 15.1 sampling procedure (5-minute flush followed by 30-minute stagnation), and a plumbing survey will be carried out during the stagnation period. During the sewer separation / watermain replacement, any public LSLs encountered will be documented and replaced, and private LSLs documented. This ground-truthing exercise will allow the City to then compare the pre-replacement flushed and stagnation sample lead levels, along with the results from the plumbing

survey, to gain a better understanding of the correlation between the presence of a LSL with lead levels observed with each sampling methods. These data may also support the development of a trigger for Tier-2 sampling, as part of the verification sampling program in Years 1 to 3.

- **5-min flush sample kit preparation (annual, starting in 2019):** Each year, the City will assemble sampling kits that will be used by homeowners for verification sampling. This will be completed prior to the summer sampling period.
- **Verification sampling (annual, starting in 2019):** The City's ambitious target is to verify 1,200 homes annually between June 15 and October 15, in Years 1 to 3. Verification sampling will be carried out either by City staff or by homeowners using free sampling kits that will be provided by the City. If conducted by City staff, a plumbing survey will be carried out at the same time. The objective of verification sampling is to identify locations with LSLs (such that they can be replaced and interim protection provided if required due to presence of vulnerable population residing at that residence) and ultimately to update/refine the estimate of LSLs remaining in the Sarnia system. Since verification sampling depends on homeowner participation, the number of homes verified may vary from year to year. To confirm the validity of the verification sampling approach (use of flushed sample), the City intends to analyse data collected as part of verification sampling, in homes where a lead profile was collected and the presence of the LSL was subsequently confirmed during replacement activities.

5.2 LSL Replacement Program

ID	Task Mode	Task Name	Duration
15		2. LSL Replacement Program	960 days
16		As encountered LSLR – Sewer separation / watermain replacement projects (assume 30 to 40 per year)	960 days
17		2018 ss/wm projects: 1 km (Emma St, John St, Mary St, and Richard St)	175 days
18		Year 1 (2019) ss/wm projects: tbd	175 days
19		Year 2 (2020) ss/wm projects: tbd	175 days
20		Year 3 (2021) ss/wm projects: tbd	175 days
21		As encountered LSLR – Operations (assume 10 per year)	960 days
22		2018 operations projects	175 days
23		Year 1 (2019) operations projects	175 days
24		Year 2 (2020) operations projects	175 days
25		Year 3 (2021) operations projects	175 days
26		Targeted LSLR – As requested by homeowner (assume 10 per year)	960 days
27		2018 homeowner requests	175 days
28		Year 1 (2019) homeowner requests	175 days
29		Year 2 (2020) homeowner requests	175 days
30		Year 3 (2021) homeowner requests	175 days
31		Targeted LSLR – From loan (assume 25 per year)	700 days
32		Year 1 (2019) loans	175 days
33		Year 2 (2020) loans	175 days
34		Year 3 (2021) loans	175 days



Note: Schedule is provided as guidance, and may change as the program evolves

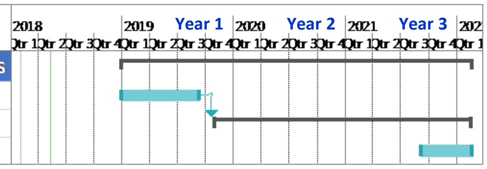
Because the City cannot control how many LSLs will be encountered during sewer separation / watermain replacement projects and operations projects, nor the level of homeowner participation for private LSL replacement, the number of annual LSL replacements is expected to vary from year to year. Assumptions have been made in this plan *for budgeting purposes*, however the City may not meet (or may exceed) these targets. Depending on homeowner participation observed in the first year, the City may choose to budget for a greater number of replacements in Years 2 and 3.

Using the assumptions described below, it is estimated that between 75 to 85 public LSLs, and approximately 60 private LSLs will be replaced annually during the three-year program. LSL replacements can occur each year during the digging season (typically April to November).

- **As encountered LSLR – Sewer separation / watermain replacement projects (annual):** The public side of LSLs encountered during sewer separation / watermain replacement projects will be replaced by the City. For 2018, $2.5M is budgeted for 1 km of sewer separation / watermain replacement projects (Emma St., John St., Mary St., and Richard St). In Sarnia, typical costs for these projects are $3M to $4.5M per kilometre for sewer separation projects, and $1.5M to $2M per kilometre for watermain replacement projects. The annual length replaced and expense incurred will depend on specific projects undertaken in each of 2019, 2020, and 2021 (specific roads to be determined). This plan assumes that 30 to 40 LSLs will be replaced annually through these projects, however more or fewer LSLs may be encountered. The occurrence of public and private LSLs encountered during these projects will be documented: addresses where lead was not found can be eliminated from the “suspected lead” list, which will serve to improve the database, along with verification sampling efforts. When private LSLs are encountered, homeowners will be encouraged to carry out private LSL replacement, and the loan will be offered to them at that time.
- **As encountered LSLR – Operations (annual):** The public side of LSLs encountered during operations projects such as watermain breaks or maintenance activities will be replaced by the City. This plan assumes that 10 LSLs will be replaced annually through these projects, however more or fewer may be encountered. The occurrence of public and private LSLs encountered during these projects will be documented. When private LSLs are encountered, homeowners will be encouraged to carry out private LSL replacement.
- **Targeted LSLR – As requested by homeowner (annual):** In some cases, the homeowner has already replaced or will be replacing the private LSL, and they request that the City replace the public LSL. The City has historically complied in these cases. This plan assumes that 10 LSLs will be replaced annually through these projects, however more or fewer replacements may be requested.
- **Targeted LSLR – From loan (annual, starting in 2019):** As a recipient of the loan, the homeowner will replace the private LSL. The public side of the LSL will be replaced (at the same time as or following private LSL replacement) to prevent a partial LSL replacement. However, in some cases, lead may only be present on the private side of the loan recipient’s service, for example, if the City side had previously been replaced (or will be replaced as part of an upcoming sewer separation / watermain project). The total number of loan-based targeted replacements carried out may therefore be lower than the number of loans awarded. To minimize the number of existing partial LSLs in the system, in Year 1, the City will place greater emphasis on encouraging loan uptake among homeowners where the public LSL has been previously replaced, or will be replaced through the sewer separation / watermain replacement projects. This plan therefore assumes that 25 public LSLs will be replaced annually through the loan (i.e., half of the loans issued each year), however more or fewer replacements associated with loans may occur. Depending on homeowner participation observed in the first year, the City may choose to budget for a greater number of loan-based targeted replacements in Years 2 and 3. All loan-based targeted replacements will be tracked separately from non-loan targeted replacements, to assess the success of the loan program at the completion of the three-year period. (Note: Care will be taken to avoid double-counting these replacements if the loan recipient will have the public portion of their LSL replaced as part of the City’s sewer separation / watermain replacement projects.)

5.3 Treatment and Distribution System Maintenance

ID	Task Mode	Task Name	Duration
35		3. Treatment and Distribution System Maintenance	820 days
36		Member municipality impact study (LAWSS)	9 mons
37		**Pipe loop study (Sarnia/LAWSS; lead entity to be determined)**	**600 days**
45		LRP addendum to re-evaluate alternatives (Sarnia/LAWSS)	6 mons



Note: Schedule is provided as guidance, and may change as the program evolves

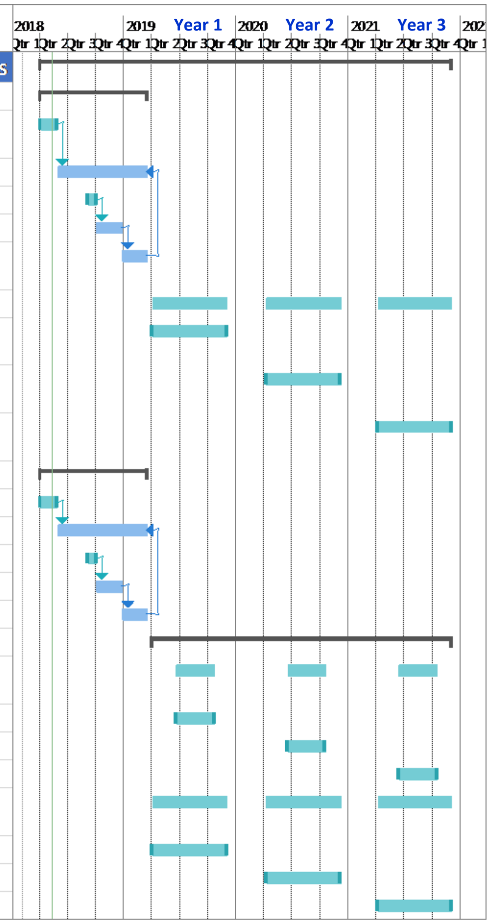
- **Member municipality impact study (Recommended for 2019):** As discussed in Section 4.6.1.3, it is recommended that the City negotiate with LAWSS for the completion of a member municipality impact study. This desktop study will determine whether corrosion control treatment is feasible in the LAWSS system, by assessing and quantifying potential impacts to the member municipalities of LAWSS, associated with the implementation of corrosion control treatment at the LAWSS WTP. The scope should include (but may not be limited to), for each member municipality (except Sarnia, which has been studied in this Lead Reduction Plan): water quality assessments; secondary impacts (including aesthetic); ICI user impacts; wastewater impacts; operation and maintenance impacts (including flushing); and impacts to other interconnected systems. It is recommended that this study take place in Year 1 (2019), such that the feasibility of corrosion control treatment can be confirmed early in the interim program. Since the member municipality study must be negotiated with LAWSS (and is subject to LAWSS Board approval), the timing shown in Gantt chart is tentative and may change.
- **Pipe loop study (Provisionally recommended for 2020 to 2022):** If treatment is determined to be feasible through the member municipality impact study, a pipe loop study will be required to investigate the ability of the treatment alternatives to control lead in the Sarnia Distribution System. The study will also confirm key design criteria for a full-scale corrosion control treatment system, such as the type of treatment chemical, required dosages, and the need for other water quality adjustments such as pH. This study will span several years due to the long time required for planning, acclimation of the pipe scales, and the need to investigate lead control under different seasonal conditions. LSLs will be harvested from the Sarnia system, and will be used to build pipe rigs that will be used for the testing. These rigs can be set up in either the WTP or pump station(s) (or other suitable locations owned by the City), and therefore the first step will be for Sarnia and LAWSS to discuss objectives and select a preferred testing location(s). The number of required pipe loops will be determined during the study design stage. It was assumed that this study will be supported by a consultant. Since the scope, timing, and who will lead (i.e., Sarnia or LAWSS) must be negotiated with LAWSS (and is subject to LAWSS Board approval), the timing shown in Gantt chart is tentative and may change.
- **Coagulation optimization study (Provisionally recommended; timing TBD):** As discussed in Section 4.6.1.3, it is recommended that LAWSS carry out a coagulation optimization study, should results from the pipe loop study indicate that treatment with orthophosphate is the preferred approach. This study will consist of bench-scale testing to identify optimal coagulation strategies to minimize treated water aluminum, which can interfere with phosphate. Since the need for this study (and its timing) are currently unknown, it is not shown in the Gantt chart. If needed, this study would likely be completed following the pipe loop study.
- **LRP addendum to re-evaluate alternatives (2021 to 2022):** As a joint Sarnia/LAWSS study, this will be a re-evaluation of the interim lead management strategy, based on:
    - Updated LSL estimate (from verification sampling) and ability to meet LSL replacement target in 12 years (from rate of homeowner participation in LSL replacement);

- o Ability of LSL replacement to protect public health and achieve regulatory compliance (from monitoring data and changes to lead regulations in Ontario);
- o Feasibility of implementing treatment (from member municipality impact study, pipe loop study, and coagulation optimization study).

Any changes to the lead management strategy will be documented in an addendum to the Lead Reduction Plan.

5.4 Homeowner Support Program

ID	Task Mode	Task Name	Duration
46		4. Homeowner Support Program	960 days
47		Loan program development	250 days
48		Research loan/grant options, private LSLR contractor options, and program configurations	8 wks
49		Consult with internal departments (legal, finance, etc.)	42 wks
50		Select and define approach for loan and private LSLR	4 wks
51		Develop forms/documentation, define administrative processes	3 mons
52		RFP for LSLR contractors --OR-- Negotiate price / develop list of contractors (if required)	3 mons
53		Annual loan administration	700 days
54		Year 1 (2019) loans. Up to 50 loans offered (Assume 25 for full LSLR + 25 for partial LSLR)	175 days
55		Year 2 (2020) loans. Up to 50 loans offered (Assume 25 for full LSLR + 25 for partial LSLR)	175 days
56		Year 3 (2021) loans. Up to 50 loans offered (Assume 25 for full LSLR + 25 for partial LSLR)	175 days
57		Filter program development	250 days
58		Research filter options, program configurations	8 wks
59		Consult with internal departments (legal, finance, etc.)	42 wks
60		Select preferred filter product type	4 wks
61		Develop documentation, define administrative processes	3 mons
62		RFT for filter supply	3 mons
63		Annual filter program administration	700 days
64		Filter rebates for vulnerable populations, following verification sampling (assume 100 per year)	610 days
65		Year 1 (2019) filter rebates	90 days
66		Year 2 (2020) filter rebates	90 days
67		Year 3 (2021) filter rebates	90 days
68		Free filters given following public LSLR (numbers to match public LSLR total)	700 days
69		Year 1 (2019) post-replacement filters	175 days
70		Year 2 (2020) post-replacement filters	175 days
71		Year 3 (2021) post-replacement filters	175 days



Note: Schedule is provided as guidance, and may change as the program evolves

- **Loan program development (2018):** The selected approaches for public and private LSL replacement will affect the structure and conditions of the loan. The City will research and consider various options such as:
  - o Roster of pre-selected contractors to conduct both public and private LSL replacements
  - o City-negotiated/discounted price for private LSL replacement from a list of contractors
  - o City not involved with homeowner's choice of contractor for private LSL replacement

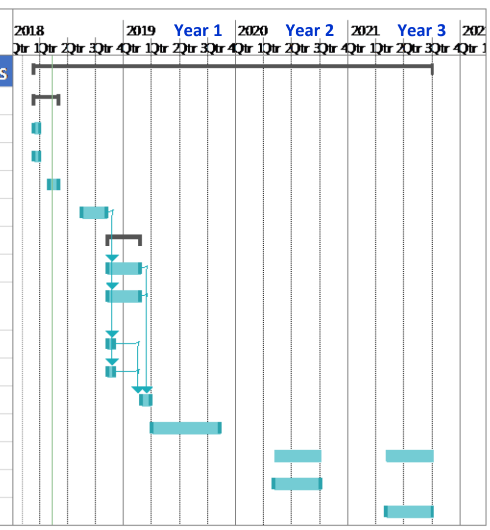
  The loan program will be developed in consultation with the City's internal groups (e.g., legal and finance). Program details such as loan eligibility requirements, maximum loan amount, repayment options, and number of loans issued per year will be defined. The City will develop forms, documentation, and administrative processes to manage the loan program. If a contractor approach is selected, a request for proposals will be required prior to the Year 1 digging season. Development of the loan program will occur in 2018, prior to Year 1.

- **Annual loan administration (annual, starting in 2019):** For budgeting purposes, this plan assumes 50 loans per year at a maximum cost of $2,000 per loan, however this may change when program details are confirmed and refined.
- **Filter program development (2018):** Similar to the loan program development, the City will investigate and select a desired approach for the filter program, in consultation with City departments such as legal and finance. Examples of options that may be considered by the City include:
    - Type of filter (plumbed in; faucet mount; pitcher-style)
    - Rebate program (administered by the City or by filter manufacturer)
    - Conditions under which to provide filters to homeowners for free (eligibility, duration, etc.)

  The City will develop forms, documentation, and administrative processes to manage the filter program. Development of the filter program and issuance of a request for tender for the supply of filters will occur in 2018, prior to Year 1.
- **Annual filter program administration (annual, starting in 2019):** For budgeting purposes, this plan assumes a maximum of 100 filter rebates (for $40 each) will be offered annually to households with vulnerable populations following the detection of lead through verification sampling. Additionally, the plan assumes that filters will be provided to homeowners for free for a period of six months following any public LSL replacement, to reduce exposure to "lead spikes" which are common following service line replacement (both full and partial replacement).

5.5 Public Outreach Program

ID	Task Mode	Task Name	Duration
72		5. Public Outreach Program	930 days
73		**Develop communications materials for immediate needs**	**57 days**
74		Post-replacement flushing and sampling instructions per AWWA C810-	3 wks
75		Advance notice letters for LSLR as part of road projects	3 wks
76		Update "lead detected" and "lead exceeded" letters	4 wks
77		Develop communications plan	3 mons
78		**Develop communications materials for outreach program**	**80 days**
79		Web materials (website / social media / video)	4 mons
80		Targeted communications for sensitive populations (new or expecting mothers / children under 6)	4 mons
81		Letters for targeted verification sampling mailout (lead zone)	4 wks
82		Print ads (newspaper / posters)	4 wks
83		Pre-campaign communication with community partners	5 wks
84		Initial public outreach campaign rollout	8 mons
85		**Annual outreach -- verification sampling and LSL replacement blast**	**370 days**
86		Year 2 (2020) verification sampling blast	22 wks
87		Year 3 (2021) verification sampling blast	22 wks



Note: Schedule is provided as guidance, and may change as the program evolves

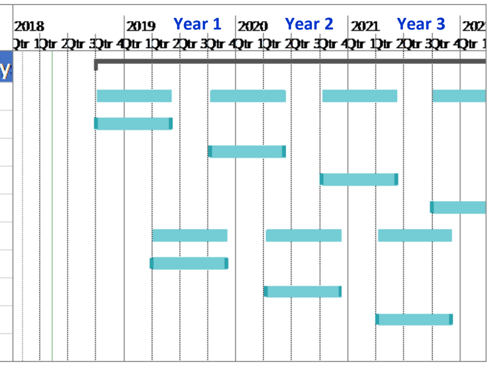
- **Develop communications materials for immediate needs (2018):** Communications in 2018 will be targeted and a number of materials will be developed to meet immediate needs. This will include:
    - Post-replacement flushing and sampling instructions, based on the new AWWA C810-17 standard. Format (door hanger / brochure / letter) to be determined.

  - Advance notice letters for LSL replacement as part of sewer separation / watermain replacement projects to be conducted in 2018. This letter will encourage homeowners to volunteer for pre-replacement sampling and to replace the private LSL.
  - Update the "lead detected" and "lead exceeded" letters previously used for Schedule 15.1 sampling.

- **Develop communications plan (2018):** The City will work with the Public Health unit and the City's communications department to develop a communications plan. This plan will document target audiences, key messaging, communication formats and mediums, the timing of communications, communications protocols and lines of communication, and internal training needs. Development of the communications plan will occur in 2018, ahead of Year 1.
- **Develop communications materials for outreach program (2018 to 2019):** Several communications materials will be developed to support the public outreach campaign, as identified in the communications plan. Examples of materials include:
  - Web-based materials including website content, social media content, and videos
  - A hotline number that residents can call to get more information
  - Targeted communication materials for vulnerable populations (i.e., new or expecting mothers, caregivers of children under 6 years)
  - Letters for targeted/systematic verification sampling, mailed out within the lead zone
  - Print ads (e.g., newspaper, posters)
- **Pre-campaign communication with partners (2019):** Led by the Public Health unit, communication with trusted community partners (one to two months) ahead of the public outreach campaign will help the City build trust and will encourage the public's participation. Examples of partners include:
  - <u>For new/expecting mothers and children under 6</u>: doctors and pediatricians; nurse practitioners; midwives; lactation consultants; early years program coordinators; new mom groups;
  - <u>For targeted geographic areas</u>: councillors; neighbourhood associations;
  - <u>For new or existing homeowners</u>: realtors; plumbers;
- **Initial public outreach campaign rollout (2019):** Rollout of the public outreach campaign is deferred to Year 1 (2019) to allow the City to prepare for responding to inquiries from the public and to establish programs to accommodate their requests to participate. The specific communication mediums for the public outreach campaign rollout will be defined in the communications plan.
- **Annual outreach – verification sampling and LSL replacement blast (annual, starting in 2020):** In Year 1, this will be part of the initial public outreach campaign. In Years 2 and 3, a communications blast will be required to solicit participation in the verification sampling program and LSL replacement program.

5.6 Monitoring for Effectiveness

ID	Task Mode	Task Name	Duration
88		**6. Monitoring for Effectiveness**	**1090 day**
89		**Sampling after 6 months**	**960 days**
90		2018 replacements	175 days
91		Year 1 (2019) replacements	175 days
92		Year 2 (2020) replacements	175 days
93		Year 3 (2021) replacements	175 days
94		**Sampling after 12 months**	**960 days**
95		2018 replacements	175 days
96		Year 1 (2019) replacements	175 days
97		Year 2 (2020) replacements	175 days
98		Year 3 (2021) replacements	175 days



Note: Schedule is provided as guidance, and may change as the program evolves

- **Post-replacement sampling (annual, starting in 2018):** Residential samples will be collected (using the Schedule 15.1 sampling procedure of 5-minute flush followed by 30-minute stagnation) at homes following LSL replacement (both full and partial LSL replacement). This will be conducted at approximately 6 and 12 months following replacement. Samples will be analysed for total lead and total iron. Analysis of iron together with lead will provide valuable information as to the source of lead (e.g., lead service line; galvanized pipe; etc.). Since residential sampling is dependent on homeowner participation, the sampling rate may not be 100%. Entry into the home for post-replacement sampling can be a condition of the loan.

5.7 Resource and Budget Plan

Summaries of estimated phased expenditures and staffing requirements for Option F are presented in Table 5-1 and Table 5-2, respectively.

The (previously allocated) lead management budget for 2018 ($300,000) will be used for 2018 program development activities in support of implementing the three-year plan in 2019. Program costs for Years 1, 2, and 3 are estimated to be approximately $1.14M, $1.12M, and $1.17M, respectively. The City may refine these estimates as the program progresses and more information/experience is gained. For example, additional funding for the loan and for targeted LSL replacements may be sought for Years 2 and 3 if homeowner participation in Year 1 is higher than expected.

The capital projects funding allocated to sewer separation / watermain replacement projects is separate from the lead program cost and is therefore not included in Table 5-1. However since replacing LSLs as encountered is one component of these sewer separation / watermain replacement projects, the funding allocated to the LSL replacement component is included within the costs shown in the table. These renewal projects target sewer separation, as directed by the MOECC.

Table 5-1. Phased Expenditures for "Option F"

Program Component	Preparation (2018)	Year 1 (2019)	Year 2 (2020)	Year 3 (2021)
1. LSL verification program	$40,000	$260,000	$260,000	$260,000
2. LSL replacement program	$100,000	$530,000	$530,000	$530,000
3. Treatment and distribution system maintenance	-	$100,000	$100,000	$150,000
4. Homeowner support program	*staffing cost captured under item 1	$135,000	$135,000	$135,000

5. Public outreach program	$25,000	$60,000	$35,000	$35,000
6. Monitoring for effectiveness	$3,000 *staffing cost captured under item 1	$57,000	$62,000	$62,000
Total—Lead program costs	**$168,000**	**$1,142,000**	**$1,122,000**	**$1,172,000**

The staffing requirements shown in Table 5-2 represent an estimate which will be refined by the City as the program progresses. These staffing estimates exclude full time equivalents (FTEs) for staff that will be carrying out lead service line replacements. It is noted that the staffing requirements shown in this table do not necessarily represent hiring needs; it is assumed that some level of support (if not all) can be provided through existing staff. Where additional staff are required, these gaps may be filled through temporary staff such as students or temporary operators.

To address immediate program development needs, it is assumed that one program management/administration person from existing staff will be trained and two students will be hired and trained in 2018, for the period covering May to December. It is assumed that further support will be required in Years 1 to 3, however the need for new staff (versus reassigning existing staff) will be assessed and therefore the exact staffing makeup may change.

Table 5-2. Phased Staffing Requirements for "Option F"

Staff Type	**Preparation (2018)**	**Year 1 (2019)**	**Year 2 (2020)**	**Year 3 (2021)**
Program management/administration	0.5 FTE	1.13 FTE	1.13 FTE	1.13 FTE
Technical	1 FTE	2.5 FTE	2.5 FTE	2.5 FTE
Student	1.33 FTE	1.75 FTE	1.75 FTE	1.75 FTE
Total	**2.63 FTE**	**5.38 FTE**	**5.38 FTE**	**5.38 FTE**

Appendix A
Alternatives Cost Development

Appendix B
Examples of Existing Public Outreach Materials