Fall 10-2023

the impact of lead corrosion relating to the contamination of drinking water in Canada and in Indigenous communities.

Jessie A. McDonald
Western University, jmcdo65@uwo.ca

Jessie McDonald

Part 1

The Corrosion of Lead Piping and the Contamination of Drinking Water in Canada and Canadian Indigenous Communities

History of Lead Piping in Canada

Lead (Pb) is a metal that has been used in piping for water distribution for centuries, however, the installation of lead pipes in Canada grew large-scale in the 1960s [1]. Lead became the metal of choice for water systems over iron (which was previously used) because it had a longer lifespan and was much more malleable [2]. The widespread installation of lead piping in Canada occurred until 1975 at which point the National Plumbing Code set restrictions on the use of lead piping. In addition, the use of lead-containing solder for new plumbing and repairs occurred until 1986 with the last houses to contain lead piping built in the 1990s [1]. It wasn't until 2011 that a proposal arose to reduce the maximum allowable concentration (MAC) of lead in drinking water from 10 μg/L to 5 μg/L and in 2014 the National Plumbing Code set the standard of lead piping and fixtures to contain a maximum of 0.25% lead [1]. In 2017 the motion of studying the contamination of lead in drinking water was adopted [3].

Corrosion of Lead Piping Resulting in Water Contamination

Corrosion is defined as an irreversible interfacial reaction of a material with its environment which results in the material's consumption or the dissolution of the material into the environment [4]. This process can affect infrastructure integrity, the environment, and public health. The corrosion of materials, in contact with food and drinking water, is specifically an issue when it comes to public health and environmental sustainability. This paper will focus on the impact of the corrosion of lead piping, resulting in the contamination of drinking water in Indigenous communities in Canada and the stakeholders affected by this issue.

Lead corrosion can be described by a redox reaction involving the oxidation of Pb to Pb^{2+} and the reduction of dissolved oxygen to water in acidic conditions. This reaction is shown by the following equation [5]:

$$2Pb_{(s)} + O_{2(aq)} + 2\mathrm{H_2O} \leftrightarrow 2Pb^{2+}{}_{(aq)} + 4\mathrm{OH^-}$$

Additionally, the presence of chlorine disinfectants that are commonly used to remove contaminants from water can also react with lead resulting in further corrosion of lead piping and can be described by the equation below [5]:

$$Pb_{(s)} + Cl_2 \leftrightarrow PbCl_2$$

Orthophosphate is an effective additive to water to reduce lead levels. This chemical compound is often used as a corrosion inhibitor by water supply companies in

an effort to reduce the leaching of lead pipelines [6]. When orthophosphate is added to water, it reacts with lead to form a protective coating inside the lead pipes, preventing metal corrosion [6].

Copper (Cu) was used to partially replace some of the lead piping to decrease the risk of lead contamination, however, this created a galvanic couple between the metals, resulting in the accelerating corrosion of the lead materials [7]. Galvanic corrosion is an electrochemical process that occurs when different metals are electrically connected to each other in an electrolytic solution [7]. The galvanic series is used to describe the dissimilarity of metals, specifically, their differing potentials when submerged in a specific electrolyte [7]. A metal or metal alloy with a lower reduction potential will predominantly act as the anodic site, resulting in the accelerated corrosion of this material when it is electrically connected to a metal of higher potential (predominantly the cathodic site) [7].

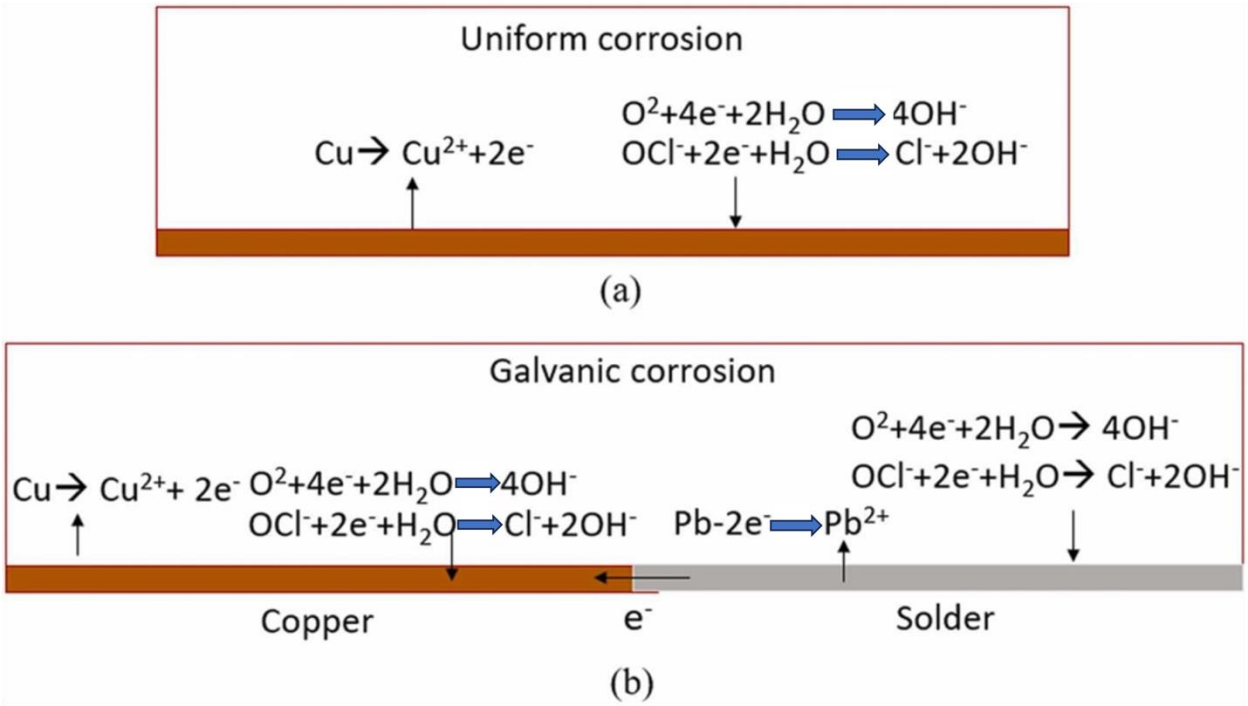

Figure 1: (a) Uniform and (b) Galvanic Corrosion Mechanisms of Cu and Cu-Pb couple [8]. *Copyright © 2023 Elsevier B.V.*

In this scenario, Pb is the favoured anodic site and is oxidized to Pb^{2+} and Cu is the predominant cathodic surface that facilitates the cathodic reaction which is oxygen reduction. In lead systems, the corrosion product may not have strongly adhered to the surface of the bulk material. This can result in the oxide possibly being dislodged from the surface. If this occurs, the anodic reaction will now be more favourable on the bare lead material where the protective coating has been partially removed. Therefore, when you have a preferential corrosion attack on the surface of the bare lead, this results in the accelerated corrosion of that lead material. The lead oxide particulates that are being dislodged from the surface can result in erosion-corrosion.

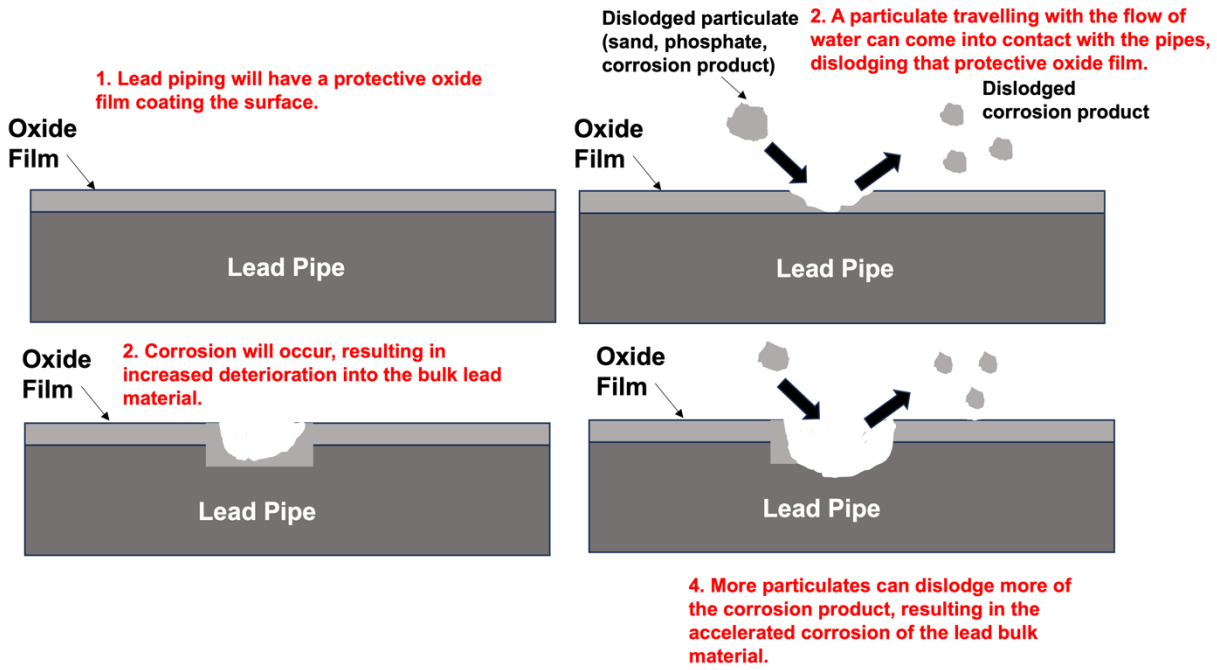

Figure 3: Schematic of Erosion Corrosion Process Involving Lead Pipes.

Figure 3 shows the process of erosion-corrosion. In this scenario, particulates can be dislodged sand, phosphates, corrosion products— the lead oxide film or the orthophosphate coating — resulting in the exposure of bare lead metal. These dislodged particulates can travel down the pipelines with the flow of water, coming into contact with other areas of the pipelines. This mechanical contact of the particulate with the pipeline would again dislodge the loosely adhered corrosion product, exposing more bare lead substrate. This exposure can result in accelerated corrosion of the lead material as it no longer possesses its protective oxide film. Additionally, in a galvanic couple, the bare lead being revealed can further facilitate galvanic corrosion as this situation makes the reaction more thermodynamically favourable. In the case of erosion-corrosion when lead is electrically connected to Cu, the rate of lead dissolution is now much higher than if the pipeline system only consisted of lead piping.

Health Effects of Lead Exposure and Consumption

Lead exposure at any age can have detrimental health effects. For adults exposed to lead levels above 0.01 mg/L, the maximum allowable concentration, can lead to increased blood pressure, kidney damage, digestive issues, anemia, as well as neurological issues [9]. After lead has entered the body through the consumption of contaminated drinking water, it travels to organs such as the brain, the kidneys, liver, and bones [10]. Lead exposure can result in reduced fertility in both men and women, and lead toxicity has been reported to cause other reproductive health issues such as hormone irregularity and issues related to pregnancy such as miscarriage, stillbirth, premature birth, or low birth weight [11]. This is due to the storage of lead in bones; it may be released into the blood during pregnancy resulting in the fetus being exposed to the

lead. However, infants and children are most affected by lead exposure and toxicity as they absorb 4-5 times the amount of lead that adults do [11]. Lead toxicity is especially dangerous in malnourished children as their bodies will absorb even higher amounts of lead if they lack other nutrients such as iron and calcium. Reports have indicated the effects of lead poisoning in children resulting in irreversible neurodevelopmental effects, impaired cognitive development and learning and behaviour issues [12].

The Issue of Lead Contamination in Water in Indigenous Schools

In 2017 tests were conducted by the First Nations Health Authority (FNHA) in 35 First Nations schools located on reserves across the province of British Columbia, Canada. These tests occurred after Trevor Andrew, the water operator for the Adams Lake Indian Band, discovered lead was leaching from a tap in the girls' washroom at T'selcéwtqen Clleq'mel'ten/Chief Atahm School [13]. It was found that all 35 schools possessed unsafe lead levels in their drinking water. The tests revealed that the issue was not just in the lead service lines, the faucet fixtures also contained lead.

There is a long history of discrimination against Indigenous peoples in Canada. Through colonization, the Canadian government forced Indigenous peoples onto reserves, resulting in the diminishment of the sustainability of Indigenous health, education and culture and ultimately leaving these communities without safe drinking water. First Nations reserves are located outside of provincial jurisdiction, resulting in the governments having no authority within these communities. Water utility companies are not responsible for the service lines present on these reserves. In addition to the political implications that led to this catastrophe, economics also played a large role. Lead pipes are expensive to replace, it costs approximately $5,000 to replace private service lines and $10,000 to replace public service lines and Indigenous communities significantly lack financial assistance [13].

The issue of lead contamination was not only an issue within Indigenous schools, non-First Nations public schools within British Columbia were also tested for lead contamination in the drinking water. This study revealed that 26% of public schools within the province had unsafe levels of lead, with some schools having lead levels 100 times higher than the safety limit set by Health Canada. However, action was immediately taken to solve this issue by upgrading the plumbing and installing water filtration systems to remove the lead contaminants. By the end of 2017, the government had made over $7 billion in grants available for the public school systems to combat the lead plumbing issue. The problem is Indigenous communities do not qualify for these grants, as their funding comes from a separate agency, Indigenous Services Canada. This organization is responsible for deciding maintenance budgets and operations that will address the needs of the entire community [13] Trevor Andrew took the independent initiative to replace the faulty faucet fixture, which only cost approximately $300 to $500; however, other communities may face much larger and more expensive issues caused by lead plumbing. In a survey of 122 water operators in First Nations communities throughout Canada, many reported that they felt as though the funding for new infrastructure is extremely limited [13].

First Nations communities have been fighting for years for safe drinking water, with several communities lacking access to clean water for three decades [13]. lead-

contaminated drinking water is especially an issue among communities located on the coast of British Columbia as the primary source of water comes from lakes that contain acidic rainfall water. Once this water enters and travels through the pipelines, it can extract lead and copper from the pipes and into the drinking water [13]. In 2018, it was found that several communities located throughout the province contained highly acidic water, resulting in the accelerating leaching of lead into the water distribution systems [13]. However, it was also indicated that many Water Operators of Indigenous communities fail to test the pH of their water supplies. This lack of knowledge can greatly affect the community and preventative measures could be put in place if low pH water is found to be present.

Conclusions and Next Steps

Lead-contaminated drinking water is an ongoing issue throughout Canada and within Canadian Indigenous communities. There are several stakeholders that are affected by this issue including Indigenous community members, the children attending schools that have tested positive for lead-contaminated water and the community organizations responsible for updating the faulty infrastructure. Indigenous communities have lacked the financial support that the British Columbia government provides for non-Indigenous schools to replace the lead piping systems. The consumption of lead-contaminated water can have detrimental health effects on all members of the public; however, children are the most at-risk.

In the future, the First Nations Health Authority and Indigenous Services Canada should be working together to find a sustainable solution for the replacement of lead piping and fixtures within these communities, as well as infiltrating a proper water filtration system to prevent the possible lead remnants that would still be present in the water wells. However, this will only be done if these communities have access to reliable funding. There should also be regulations in place that call for consistent annual monitoring of lead levels in drinking water, as well as regular pH testing performed by the First Nations Water Operators so that preventative measures can be put in place to decrease the risk of additional corrosion damage of the lead pipes.

Acknowledgement

Acknowledgements are given to Erin Cottrill.

References

1. https://www.canada.ca/en/health-canada/programs/consultation-lead-drinking-water/document.html# (Accessed September 13th, 2023).
2. Rabin, R. The Lead Industry and Lead Water Pipes “A MODEST CAMPAIGN”. *American Journal of Public Health, 98(9),* 1584-1592. (2008). https://doi.org/10.2105/ajph.2007.113555
3. https://www.ourcommons.ca/Content/Committee/421/TRAN/Reports/RP9341762/tranrp21/tranrp21-e.pdf (Accessed September 13th, 2023).
4. Cwaling, B. Biodeterioration of concrete, brick, and other mineral-based building materials. *Understanding Biocorrosion, Fundamentals and Applications,* 281-312. (2014). https://doi.org/10.1533/9781782421252.3.281
5. Triantafyllidou, S. Chemistry of Lead Corrosion in Drinking Water, Environmental Protection Agency. (2021). (Accessed September 14th, 2023).
6. Desantis, M. K., Schock, M. R., Tully, J., Stamper C. B. Orthophosphate Interactions with Destabilized PbO_2 Scales. *Environmental and Science Technology. 54(22),* 14302-14311. (2020). https://doi.org/10.1021/acs.est.0c03027.s001
7. Ng, D. Q., Lin, J. K., Lin, Y. P. Lead release in drinking water resulting from galvanic corrosion in three-metal systems consisting of lead, copper and stainless steel. *Journal of Hazardous Materials, 398,* 122936. (2020). https://doi.org/10.1016/j.jhazmat.2020.122936
8. Chang, L., Lee. J. H. W., Fung, Y. S. Prediction of lead leaching from galvanic corrosion of lead-containing components in copper pipe drinking water supply systems. *Journal of Hazardous Materials, 436,* 129169. (2022). https://doi.org/10.1016/j.jhazmat.2022.129169
9. https://www2.gnb.ca/content/dam/gnb/Departments/h-s/pdf/en/HealthyEnvironments/water/Leade.pdf (Accessed September 16th, 2023).
10. https://www.atsdr.cdc.gov/sites/toxzine/lead_toxzine.html#:~:text=Shortly%20after%20lead%20gets%20into,in%20the%20bones%20and%20teeth. (Accessed September 18th, 2023).
11. https://www.who.int/news-room/fact-sheets/detail/lead-poisoning-and-health#:~:text=Lead%20also%20causes%20long%2Dterm,birth%20and%20low%20birth%20weight.
12. Schwartz, H., Marushka, L., Chan, H.M. *et al.* Metals in the drinking water of First Nations across Canada. *Can J Public Health* **112** (1), 113–132 (2021). https://doi.org/10.17269/s41997-021-00497-5
13. https://www.aptnnews.ca/national-news/tests-in-b-c-find-unsafe-lead-levels-in-water-of-35-first-nations-schools/ (Accessed September 13th, 2023).

Jessie McDonald

Part 2

Lead Contamination: A Look into the Environmental Impact and the Costs of Pipeline Replacement in Canada and Indigenous Communities

Water Pollution

Water pollution is the release of substances, such as microorganisms or chemicals, into water bodies or water sources. This includes subsurface groundwater, lakes, streams, rivers, and oceans. Pollution occurs when the matter released into the water interferes with the beneficial use (ie. drinking water) or with the natural functions of the ecosystems present [1]. Water can be polluted by various sources, such as pathogenic organisms, organic waste, and toxic chemicals such as lead. Domestic sewage is a direct cause of water pollution. Domestic sewage disposal often leads to the contamination of water with pathogens, and if the communities have lead-contaminated drinking water, this will mix with the domestic sewage, and due to the handling procedures of sewage, the now lead-contaminated sewage can be distributed into neighbouring lakes and rivers. The pollution of water bodies with sewage drain-off endangers the aquatic life present. Additionally, lead-contaminated water is often chemically treated with corrosion inhibitors such as orthophosphate, which can further pollute the water bodies and ecosystems that inhabit them. It has been reported that orthophosphate-P can have a detrimental impact on river quality [2].

Figure 1: Lead Pipes Draining into A Body of Water [2].

The Prevalence of Lead in Drinking Water in Canada

Health Canada implemented Health Canada's Guidelines for Canadian Drinking Water Quality (GCDWQ) to regulate the quality of drinking water in Canada [3]. These guidelines were established to dictate the safe levels of trace metals present in consumable water for the public, and they were established based on scientific evidence on how the presence of metals affects human health. Although there is no level of lead that is safe to consume, it was determined that the maximum allowable concentration of lead in drinking water is 5 μg/L or 5 parts per billion (ppb). In 2019, the results from a year-long investigation into the prevalence of lead in drinking water throughout Canada were published. During this study, 12,000 tests that had been taken over the course of 5 years and from 11 different Canadian cities were looked at, revealing that

33% exceeded the maximum allowable concentration of 5 ppb [4]. The results from this investigation detailed that in Ontario, the government had reported 919 instances of exceedance of 5 ppb over a two-year duration, with exceedance rates reaching as high as 50% in some municipalities. Similar results were found in the remaining provinces.

In a separate study, 91 First Nations communities participated in the First Nations Food, Nutrition and Environment Study (FNFNES) [3]. This investigation looked into the levels of trace metals, including lead, present in drinking water in Indigenous communities across Canada. The results obtained from this study are shown in Table 1.

Table 1: Lead Concentrations in First Nations Communities' Drinking Water in Canada [3].

Province	Year	Sample Size	Detection Limit (μg/L)	Mean (μg/L)	Median (μg/L)	75th (μg/L)	95th (μg/L)	Max (μg/L)
British Columbia	2008-2009	300	0.2	1.0	0.6	1.2	3.9	6.3
Manitoba	2010	140	0.2	2.8	1.0	3.1	11.1	24.7
Ontario	2011-2012	318	0.2	3.4	0.7	2.1	13.7	120.0
Alberta	2013	93	0.2	1.2	<0.5	0.7	4.2	45.0
Atlantic	2014	216	0.5	3.3	<1	1.2	18.0	107.0
Saskatchewan	2015	228	0.1	1.2	0.4	1.1	4.6	43.8
Quebec	2016	160	0.1	1.2	0.5	1.1	3.6	25.3

The results shown above indicate that several of the FN communities that participated in this study contain high concentrations of lead in their drinking water. All the maximum concentrations of the metal found exceed the national standard set by Health Canada of 5 μg/L, with the closest being 6.3 μg/L [1]. In the conclusions presented, it was stated that 8.4% of households that participated exceeded the maximum allowable concentration of lead in their water.

Environmental Impact of Lead in Drinking Water

Not only is lead present in drinking water through the usage of lead pipelines and water systems, but it can also contaminate the environment through wastewater and sewage systems. When contaminated wastewater enters waterways or wastewater treatment facilities, lead is able to pollute aquatic and terrestrial ecosystems [5]. Lead exposure can be fatal to aquatic animals due to bioaccumulation. Bioaccumulation is the increased concentration of a pollutant, in this case lead, in an organism [6]. When looking at the effect of lead exposure in fish, it was found that it can cause a variety of health effects on the physiological, behavioural, and biochemical functions of this species [6]. Additionally, when animals are exposed to lead, it can result in damage to the central nervous system, peripheral nervous system, cardiovascular system, and other essential organs [6]. The wastewater run-off into lakes and rivers can also affect the integrity of other aquatic species, such as plant life and microorganisms [7]. When ecosystems are exposed to lead, it results in a decline in biodiversity, growth, and reproduction of species [7]. Regarding plant health, lead prevents seed germination, root elongation, chlorophyll production and water and protein content [8]. These results are most often caused by the obstruction of electron transport, Calvin cycle enzymes and the impaired uptake of essential elements [8].

In addition to the harm to aquatic species, the consumption of lead-contaminated water also has a drastic effect on the health of humans. The ingestion of lead at any age can cause detrimental health effects and impair the proper functioning of several organs. The most affected system in our bodies is the nervous system [9]. Exposure to lead-contaminated drinking water can result in decreased brain function in adults, and lead exposure at a young age has been reported to cause lower intellectual function, attention, focus, emotional regulation, and fine motor skills [9]. Studies have also found that there is a relationship between behaviour and exposure to lead, finding that there may be a link between exposure and attention-related behaviours, such as attention-deficit hyperactivity disorder (ADHD) [9]. In addition to cognitive function, lead exposure can also result in cardiovascular issues such as increased blood pressure, gastrointestinal issues, and bone health [9]. Once lead enters the body, it can accumulate in our skeleton and be released into our blood. This can impact fetuses during pregnancy, possibly resulting in miscarriage, stillbirth, or premature birth [10]. Lead consumption can also affect the reproductive organs in both men and women, leading to infertility [10].

Lead Pipeline Replacement- Cost Benefit Analysis

The only way to ensure there is no lead in drinking water is to act at the root of the problem: replacing all the pipelines that contain lead. However, there are several issues with this process that prevent pipeline replacement programs. The federal government is responsible for certain aspects of public health and the safety of infrastructure; however, safe drinking water often falls under the provincial jurisdiction or even the municipalities [11]. Most government agencies are not forced to direct funding toward the maintenance or replacement of faulty pipelines, especially on private and residential property, resulting in this issue often being ignored. Canada lacks a comprehensive inventory of the lead pipelines throughout the country, meaning that the amount of lead water systems present throughout the nation is relatively unknown, this is due to lost and incomplete records [11].

In a committee hearing conducted by the House of Commons, it was found that the cost of pipeline replacement is a significant source of the lack of action; it costs approximately $5,000 to replace private pipelines and about $10,000 to replace public ones [11]. While some cities have made an effort to assist residents in the costly replacement process, others have not. Ottawa initiated a lead pipeline replacement program to offer financial assistance to homeowners [12]. Residents of the Canadian city are eligible for a rebate of up to $1,000 from the government to put towards lead pipe replacement. Although this may be more than other cities, this only covers approximately 20% of the typical cost. Additionally, there are certain conditions that must be met for residents to qualify for this government grant, such as the following [12]:

- It is only offered to residents who occupy homes consisting of *partial* lead water systems.
- The public line attached to their private line cannot contain lead.
- Reimbursements are not given to those who had replacements done prior to 2019.

Other provinces and municipalities have participated in similar grant programs, such as British Columbia, Toronto, Edmonton, and Halifax, among others [13, 14, 15]. Replacing the lead pipelines throughout the country is not a quick fix, as many of these plans have an estimated end date of more than a decade into the future. Although this evidence of lead pipeline removal is a step in the right direction, there are still several communities at risk that do not have access to the same resources. Indigenous communities in Canada have a long history of discrimination, and it has been reported that there are 618 First Nations communities without safe drinking water [16]. Although it is not clear if all these instances are the result of lead contamination, lead is a significant problem. Indigenous populations do not have access to the government funding that

is available for other Canadians who are affected by the same problem. Instead, funding for maintenance and pipeline removal in First Nations communities comes from Indigenous Services Canada, an agency that possesses limited funding. In the case of lead-contaminated drinking water, it is evident that the risk to human health greatly outweighs the cost of pipeline replacement. Whether assistance comes from the provincial or federal government, there should be more of an effort put towards keeping the Indigenous peoples of Canada safe from leaded water.

References

1. https://www.britannica.com/explore/savingearth/water-pollution (Accessed October 3rd, 2023).
2. https://www.napolilaw.com/article/newark-new-jersey-lead-poisoning/ (Accessed October 10th, 2023).
3. Tapin, A. D., Comber, S., Worsfold, P. J. Orthophosphate-P in the nutrient impacted River Taw and its catchment (SW England) between 1990 and 2013. 2016. https://pubs.rsc.org/en/content/articlehtml/2016/em/c6em00213g#:~:text=Excess%20orthophosphate%2DP%20has%20a,on%20river%20water%20quality%20worldwide
4. Schwarts, H., Marushka, L., Chan, H. M., Batal, M., Sadik, T., Ing, A., Feduik, K., Tikhonov, C. Metals in the drinking water of First Nations across Canada. *Canadian Journal of Public Health, 112,* 113-132. 2021. https://doi.org/10.17269/s41997-021-00497-5
5. https://www.thestar.com/news/investigations/is-there-lead-in-your-tap-water-canada-wide-investigation-exposes-dangerous-levels-of-toxic/article_1352702e-7b6b-5a32-beeb-812e23be35e8.html (Accessed October 6th, 2023).
6. https://samcotech.com/acceptable-lead-levels-in-wastewater-removal/#:~:text=Industrial%20effluents%20can%20contain%20dissolved,into%20aquatic%20and%20terrestrial%20ecosystems (Accessed October 8th, 2023).
7. Lee, J. W., Choi, H., Hwang, U. K., Kang, J. C., Kang, Y. J., Kim, K. I., Kim, J. H. Toxic effects of lead exposure on bioaccumulation, oxidative stress, neurotoxicity, and immune responses in fish: a review. *Environmental Toxicology and Pharmacology, 68,* 101-108. 2019. https://doi.org/10.1016/j.etap.2019.03.010
8. https://ww2.arb.ca.gov/resources/lead-and-health#:~:text=Ecosystems%20near%20point%20sources%20of,and%20neurological%20effects%20in%20vertebrates (Accessed October 9th, 2023).
9. Pourrut, B., Shahid, M., Dumat, C., Winterton, P., Pinelli, E. Lead uptake, toxicity and detoxification in plants. *Rev Environ Contam Toxicol, 213,* 113-136. 2011. https://doi.org/10.1007/978-1-4419-9860-6_4
10. Nordberg, G. F., Costa, M. *Handbook on the Toxicology of Metals, 5th ed.; Volume 2: Specific Metals;* Elsevier, 2022.
11. https://www.who.int/news-room/fact-sheets/detail/lead-poisoning-and-health#:~:text=Lead%20also%20causes%20long%2Dterm,birth%20and%20low%20birth%20weight. (Accessed October 8th, 2023).
12. https://www.ourcommons.ca/Content/Committee/421/TRAN/Reports/RP9341762/tranrp21/tranrp21-e.pdf. (Accessed October 7th, 2023).
13. https://ottawa.ca/en/living-ottawa/drinking-water-stormwater-and-wastewater/drinking-water/drinking-water-programs/lead-pipe-replacement-program#section-efb5a579-eee4-48e0-b7a2-aa4d8655ab00. (Accessed October 8th, 2023).
14. https://www.toronto.ca/services-payments/water-environment/tap-water-in-toronto/lead-drinking-water/priority-lead-water-service-replacement-program/. (Accessed October 8th, 2023).
15. https://www.epcor.com/products-services/water/water-quality/lead-mitigation-strategy/Pages/lead-service-line-replacement.aspx. (Accessed October 8th, 2023).
16. https://www.halifaxwater.ca/get-the-lead-out. (Accessed October 8th, 2023).
17. https://www.theindigenousfoundation.org/articles/indigenous-safe-drinking-water-crisis-in-canada-overview#:~:text=Did%20you%20know%20that%20many,supplied%20with%20safe%20drinking%20water (Accessed October 8th, 2023).