



Lead in Plumbing Products and Materials

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18 June 2018

Delivered by email to: Neil.Rech@abcb.gov.au

Mr Neil Rech Project Officer
National Construction Code:
Management and Product Certification
Australian Building Codes Board
GPO Box 2013
Canberra ACT 2601

Re: Lead in Plumbing Products and Materials

Dear Mr Rech

Please find attached our Report for the Australian Building Codes Board in regard to the commissioned review of **'Lead in Plumbing Products and Materials.'**

Yours sincerely

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Summary list of Findings and Recommendations

This Report's comprehensive Findings and Recommendations together with supporting facts and reasons are set out under Section 3 immediately following the responses to each of the six primary questions the Review address as part of its work.

The summary list of Findings and Recommendations to the Australian Building Codes Board below should be read in conjunction with the above-mentioned section of this Report.

Findings

1. The Australian and international research literature shows that brass components containing lead that are used in water supply and plumbing systems can leach lead into drinking water.
2. Where lead service pipes are present they contribute an estimated 50-75% of lead contamination in drinking water collected at the faucet (tap) in homes.
3. There is potential for confusion in regard to the required use of lead-free solder in systems that may be used in contact with drinking water systems.
4. The international research literature shows that multiple factors influence the passivation and release of lead from plumbing products and materials into drinking water.
5. Where water service lines are made of copper, replacement of standard brass-lead taps with 'lead-free' taps results in a relative percentage reduction in the mass of lead delivered in the first litre of dispensed water. However, the use of 'lead-free' taps may not totally eliminate the presence of lead in dispensed water.
6. Galvanic reactions may occur along the length of the pipeline as well as in locations where lead solder has been used on copper pipe – brass fitting joints.
7. Remedial treatment of plumbing systems experiencing persistent problems associated with elevated levels of lead can be achieved via the implementation of a range of physical and chemical strategies.
8. The use of chloramine to disinfect water can result in the release of lead into drinking water systems.
9. Contrary to the approach used in Europe, there is no requirement in the Australian Standards to test for changes in hydraulic flows on the potential release of lead into drinking water systems.
10. The European approach described in EN-15664 (Parts 1 and 2) results in the licencing of materials. This approach permits licenced materials to be used for the construction of appropriate plumbing components without the necessity for further ongoing testing of individual items.
11. Lead contamination of drinking water from plumbing products and materials can also be influenced by:
 - (a) its age – the length of time water has remained unflushed in pipes (water age)



- (b) demand – relatively low use (which can be caused by dead ends in plumbing systems) can result in increased retention time and greater opportunity for corrosive activity and the leaching of lead from in-line and end-of-line fittings to occur.

Recommendations

1. In order to limit the release of lead into drinking water, consideration should be given to recommending that only low lead or preferably lead-free¹ plumbing components should be used during installation of drinking water systems.
2. Water supply authorities in all Australian states should be contacted to confirm the extent of lead water piping still remaining in use.
3. Australian Standard AS 1834.1—1991- Material for soldering: Part 1 Solder Alloys should be amended to explicitly ban the use of solders containing lead in all drinking water systems.
4. In order to more realistically determine the risk of lead leaching from plumbing products and materials it may be necessary to revise the existing test protocols detailed in AS/NZS 4020:2005 – Testing of products for use in contact with drinking water.
5. Notwithstanding the finding that lead can contaminate drinking water from both mains and premise piping, replacement of the tap with a 'lead free' alternative reduces the potential burden of lead at the point of delivery.
6. Where practical, in and end-of-line fittings should be replaced with lead free options.²
7. Review the use of chloramines in drinking water supplies in Australia and undertake new testing to determine its effect on the leaching of lead from plumbing fittings and materials under Australian conditions.
8. Consider adding hydraulic testing as part of the standard approach to testing appliances pursuant to the requirements of AS/NZS 4020:2005.
9. Consider whether adopting the approach of licencing materials as detailed in EN-15664 (Parts 1 and 2) would be more advantageous to Australian manufacturers of plumbing fittings and components than the existing arrangements that relies on product certification.
10. Consider whether there is need for formal guidelines relating to the flushing of water service lines where there is or has been:
 - (a) low water demand
 - (b) standing water in services lines for extended periods, such as at schools following vacation periods.

¹ The Review notes that it does not support the use of the term 'lead-free' as applied in the USA, which permits its use when the lead in brass is < 0.25%wt, calculated across the wetted surfaces of a pipe, pipe fitting, plumbing fitting, and fixture. The Review considers a more accurate term would be low lead. 'Lead-free' should be used only where this is actually the case. However, it accepts that a maximum upper limit would need to apply because lead may be present in minute amounts, significantly below any levels likely to cause harm.

² The Review notes that the replacement of brass-lead fittings that are used in association with the delivery of drinking water in public spaces or those associated with sensitive populations, such as children, should be a priority target for any such replacement strategy.

SECTION 1

Introduction

The Australian Building Codes Board (ABCB) engaged Macquarie University on 30 January 2018 to undertake a literature review to determine to what extent plumbing products and materials may contribute to lead levels in drinking water in excess of those permitted by the Australian Drinking Water Quality Guidelines. The project requirement was that the Review's findings were to be based on historical and up to date research and review of national and international literature, studies and reports. Further there was a requirement to undertake an international comparison of the approaches to controlling lead in drinking water.

1.1 Terms of Reference

The project's research was to have regard to:

- the potential sources of lead in plumbing products/materials
- the effect of water chemistry, quality and temperature on plumbing products/materials
- the cumulative effect of multiple products/materials in a water service
- the interaction of different products/materials within a water service
- consideration of product Standards (not just AS/NZS 4020), hydraulic effects on materials and how products are currently tested; and
- assessment of hydraulic design features in relevant standards on lead released from plumbing materials.

In executing the Review, the project team was required to engage with a range of stakeholders including industry representatives, plumbing regulators and plumbing product and materials manufacturers.

The project requirements specifically excluded assessment of the following matters:

- testing and evaluation of lead content in plumbing products, materials and components to determine compliance with the lead content standards
- testing and evaluation of lead content in drinking water caused by plumbing products, materials and components
- potential sources of lead in drinking water other than as a result of plumbing products, materials and components, e.g. water supply quality.

1.2 Review process

From late February 2018 through to early June 2018, the Review team undertook its research using a range of processes:

- developing search terms for the literature review in consultation with the ABCB Office³
- consulting with stakeholders including plumbing industry personal, plumbing retailers, industry representative organisations and government regulators
- undertaking a literature search of lead in plumbing products and materials
- issuing a survey to stakeholders

³ The ABCB Office 'means the Office, which resides in the Department, is funded by the Parties contributions in accordance with this Agreement', page 4, Inter-Governmental Agreement. available at <http://abcb.gov.au/Resources/Publications/Corporate/2017-Inter-Governmental-Agreement> (accessed 5 June 2018).



- providing the ABCB Office an opportunity to undertake fact checking and content review of the Review's Report
- the final draft document was subject to an internal review process completed by Emeritus Professor Brian Gulson (Macquarie University) who has expertise in the subject matter of this Report.

1.3 Summary of the consultations undertaken for this Report

The Review received advice from the ABCB Office as to suitable organisations, industry and government stakeholders who would likely be able to provide constructive insight with respect to the Review's terms of the reference.

Consequently, the report involved the consultations with a number of industry, government and plumbing regulators to gather information to assist the review. It was made clear to those who participated in the Review's survey and those involved in other consultations that the names of their organisations would not be included in the Report, unless they indicated otherwise. This approach was applied to optimise the likelihood of unfettered responses to the Review's questions, which in turn would assist it in understanding comprehensively all of the issues relevant to the terms of the Review.

The Review also contacted a state plumbing regulator for comment, feedback and any further relevant information with respect to the requirements of the Review. However, this consultation revealed that plumbing regulators undertake no relevant actions that would be pursuant to the terms of the Review.

In addition the Review team were invited by Mr Stuart Henry, CEO of the PPI Group to meet some of its members on 5 April 2018 at Enware, Australia, Caringbah, Sydney, New South Wales, to discuss the Review. The people at the meeting were:

- Dr Steve Cummings, GWA; scummings@gwagroup.com.au
- Adam Degnan, Vice President PPI Group, Enware Australia PTY Ltd; Adam.Degnan@enware.com.au
- Paul Degnan, Enware Australia; Paul.Degnan@enware.com.au
- Michael Drew, Australian Nuclear Science and Technology Organisation; mid@ansto.gov.au
- Dr Paul Harvey, Macquarie University, Sydney; paul.harvey@mq.edu.au
- Jason Hinds, Enware Australia; Jason.Hinds@enware.com.au
- Chris Lacey, Reliance Worldwide Corporation; Christopher.Lacey@rwc.com
- Scott Michaels, President PPI Group, Zetco Valves PTY Ltd; Scott_Michaels@zetco.com.au
- Michael Moriarty, Reliance Worldwide Corporation; Michael.Moriarty@rwc.com
- Nelson Osler, Enware Australia; Nelson.Ostler@enware.com.au
- Konrad Pradzynski, Galvin Engineering; konrad@galvinengineering.com.au
- Nathan Spinner, Enware Australia Pty Ltd; nathan.spinner@enware.com.au
- Professor Mark P. Taylor, Macquarie University, Sydney; mark.taylor@mq.edu.au

In addition to the above consultations, numerous phone calls and e-mail discussions were undertaken with the ABCB Office and other parties to assist in clarifying matters raised during compilation of this Report.

1.4 Acknowledgements

The Review acknowledges and thanks staff from agencies, departments, organisations and industry with whom it consulted for their time and effort in providing information and assistance to the Review. In



particular, the Review acknowledges and thanks the ABCB for accommodating its requests for information and providing time to assist the Review.

1.5 Structure of the report

Pursuant to the terms of reference and the requirements of the ABCB, the Review has limited its findings with facts and recommendations with reasons to Section 3 of this Report. The Review's findings and recommendations to the ABCB are set out below each question addressed as part of the literature review and are then provided in summary at the start of the Report.

The Report structure is set out below.

Section 1	Introduction
Section 2	Industry responses to the Review's questions
Section 3	Literature review

Appendix A	List of abbreviations
Appendix B	Annotated bibliography
Appendix C	PPI Group submission to the Review
Appendix D	Galvin Engineering submission to the Review

1.6 Overview of lead in plumbing products and its impact on drinking water⁴

Metal contamination of drinking water and its potential health effects has impacted human populations for centuries (Bellinger, 2016). Perhaps most famously, albeit controversially, ancient Rome's use of lead in water supply infrastructure has been argued to have caused lead poisoning that contributed to the fall of the empire (Delile et al., 2014; Evans, 1997; Scarborough 1984; Waldron, 1973). Better understanding of the health impacts and consequent corrosion control measures followed the identification of elevated lead and copper concentrations in drinking water resulting from the use of lead service lines in Boston, United States of America (USA), Washington DC USA and also Edinburgh and Glasgow, Scotland (Addis and Moore, 1974; Edwards et al., 2009; Karalekas et al., 1983; Macintyre et al., 1998; Troesken, 2008). Further to these cases of drinking water copper and lead contamination, there has been a multitude of similar examples throughout the world (e.g. Fertmann et al., 2004; Gulson et al., 2014; Renner, 2010; ul-Haq et al., 2009). More recently, in the city of Flint, in Michigan USA, a public health catastrophe has unfolded after 100,000 residents received drinking water via the reticulated town supply contaminated with lead (example of water testing: n = 271 samples, mean – 10.0 µg/L, max – 1050 µg/L, Flint Water Study, 2015) due to the absence of corrosion control measures (Pieper et al., 2017).

Global research of contaminated drinking water supplies has revealed that some contaminants derived from the local environment, such as arsenic and manganese are from bedrock, are widespread and pose a persistent problem (Das et al., 1995; Khan et al., 2011, 2012; Lu et al., 2014; Oulhote et al., 2014). The World Health Organization described the contamination of Bangladesh ground water supplies by the regional arsenic-rich bedrock as a 'public health emergency' (Smith et al., 2000, p. 1093). Its discovery prompted more than a decade of public health research attempting to remedy contamination and prevent further arsenic poisoning (Gardner et al., 2011; Kippler et al., 2016; Rahman et al., 2013, Wasserman et al., 2004).

Previous studies over the last two decades have also revealed drinking water contamination in Australia, mainly from lead used in the roof catchments of tank supplies, historic stabilizer compounds in polyvinyl chloride pipes and corrosion of plumbing fittings (Alam et al., 2008; Cohen, 22nd June,

⁴ The Review notes that the bulk of this section is drawn from Harvey et al. (2016).



2000; Gulson et al., 1994, 1997a, 1997b; Harvey et al., 2015; Huston et al., 2009, 2012; Magyar et al., 2014; NSW DET, 2011; Rajaratnam et al., 2002; Rodrigo et al., 2012; van der Sterren et al., 2013; Yau and Thorne, 2012). However, prior to 2016 there was no single study that had examined the prevalence of contamination of drinking water with lead in the household at the kitchen tap. Harvey et al.'s (2016) study addressed this knowledge gap via assessment of 212 homes across New South Wales. This study showed that almost 100% and 56% of first draw drinking water samples in the 212 homes sampled contained detectable concentrations of copper and lead, respectively. Of the water samples containing detectable concentrations, copper and lead exceeded the Australian Drinking Water Guidelines in 5% and 8% of homes, respectively.

A comprehensive study examining source bulk water supplies from New South Wales has shown that 98% (copper) and 91% (lead) of systems providing drinking water to consumers on a reticulated scheme are free of those contaminants (Li et al., 2009). Nevertheless, source water analysis may be inadequate for the delineation of population exposures because many contaminants, including copper and lead, commonly arise from corrosion of household plumbing infrastructure within the property boundary (Clark et al., 2015; Gulson et al., 1994; Harvey et al., 2015; Pieper et al., 2015).

In Australia, plumbing products in contact with drinking water have received negative attention for their potential to leach lead. Recently, the Perth Children's Hospital (Western Australia) has become a major concern regarding lead leaching from in-line fittings within the drinking water supply (McCafferty, 2017). Indeed, the McCafferty (2017) ChemCentre report on lead leaching from brass fittings with and without orthophosphate treatment showed that water concentrations in untreated drinking water resulted in levels of lead significantly in excess of the Australian Drinking Water Guidelines (ADWG) even after 32 days of a tap water leach trial. These findings are consistent with those detailed in Harvey et al.'s (2016) study of drinking water and plumbing fittings in New South Wales.

In regard to reducing lead exposure, the National Health and Medical Research Council (NHMRC), the peak medical research body in Australia, recommended the following:

The use of products containing lead could be prohibited from use in drinking water or plumbing systems. Even if high lead levels in drinking water are found to be relatively uncommon in Australia, elimination of unnecessary sources of lead would be of benefit in reducing the exposure of children to lead. (Greene et al., 1993) (p. 116).

The NHMRC made the additional recommendation that Australia's governments and policy makers:

Implement [a] pilot program for testing lead in first flush drinking water. Conduct [an] education program to inform home handypersons of the dangers in using lead solder in plumbing. Review drinking water guidelines for lead in context of an overall lead reduction strategy. (Greene et al., 1993) (p. 182).

Internationally, regulations pertaining to the use of lead in plumbing products in contact with drinking water have undergone reform in recent years. In 2014, USA federal legislation commenced that was designed to reduce substantially the permissible lead content of plumbing fixtures and fittings in contact with drinking water. The new legislation prescribed a maximum limit of 0.25% lead calculated across the wetted surfaces⁵ of a pipe, pipe fitting, plumbing fitting, and fixture and 0.2% lead for solder and flux

⁵ The Californian Dept of Toxic Substances Control describes the method for calculating the "weighted average lead content" of a pipe and pipe fitting, plumbing fitting, and fixture as follows: 'the percentage of the lead content within each component that comes into contact with water shall be multiplied by the percent of the total wetted surface of the entire pipe and pipe fitting, plumbing fitting, or fixture represented in each component containing lead.' Available at: <https://dtsc.ca.gov/PollutionPrevention/upload/lead-in-plumbing-fact-sheet.pdf> (accessed 7 June 2018). A worked example is available via the US EPA at: <https://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=P100M5DB.TXT> (accessed 7 June 2018).



on newly manufactured or installed products. The new requirements resulted in substantial reduction in the previously permissible maximum content of lead of 8% (NSF, 2016; Pieper et al., 2017).

1.7 Regulatory framework for plumbing products and materials in contact with drinking water

Plumbing products and materials for use in contact with drinking water inter alia are managed through the WaterMark Certification Scheme.⁶ The WaterMark Administrative Framework details the relationship of key stakeholders and their role in the scheme (Figure 1). Relevantly, the Scheme identifies that it is the responsibility of an 'Approved User' to ensure that only a WaterMark certified product is used in contact with drinking water.

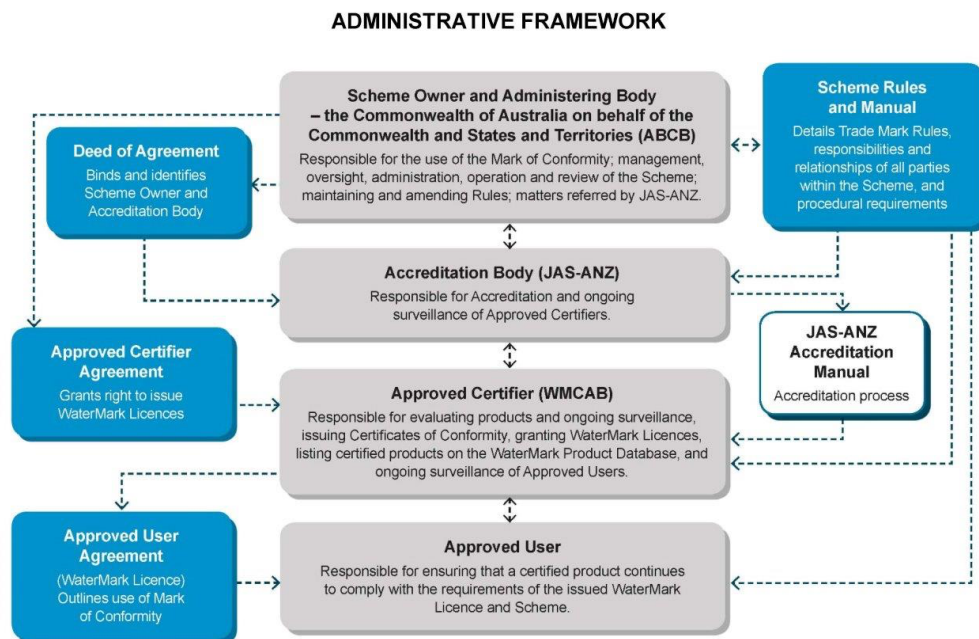


Figure 1. WaterMark Administrative Framework.⁷

Products for use in contact with drinking water in Australia are regulated under the National Construction Code –Volume 3: Plumbing Code of Australia (PCA), the WaterMark Certification Scheme (WMCS)⁸ (Figure 2) and multiple product specifications (Figure 3).

⁶ Information about the WaterMark Certification Scheme is available at: <https://www.abcb.gov.au/Product-Certification/WaterMark-Certification-Scheme> (accessed 10 May 2018).

⁷ Diagram available from the Australian Building Codes Board at: <https://www.abcb.gov.au/Product-Certification/WaterMark-Certification-Scheme/How-it-works> (accessed 10 May 2018).

⁸ The Building Code of Australia, the Plumbing Code of Australia (PCA) and the WaterMark Certification Scheme (WaterMark) are available from the ABCB website: <http://www.abcb.gov.au/> (accessed 16 March 2018).

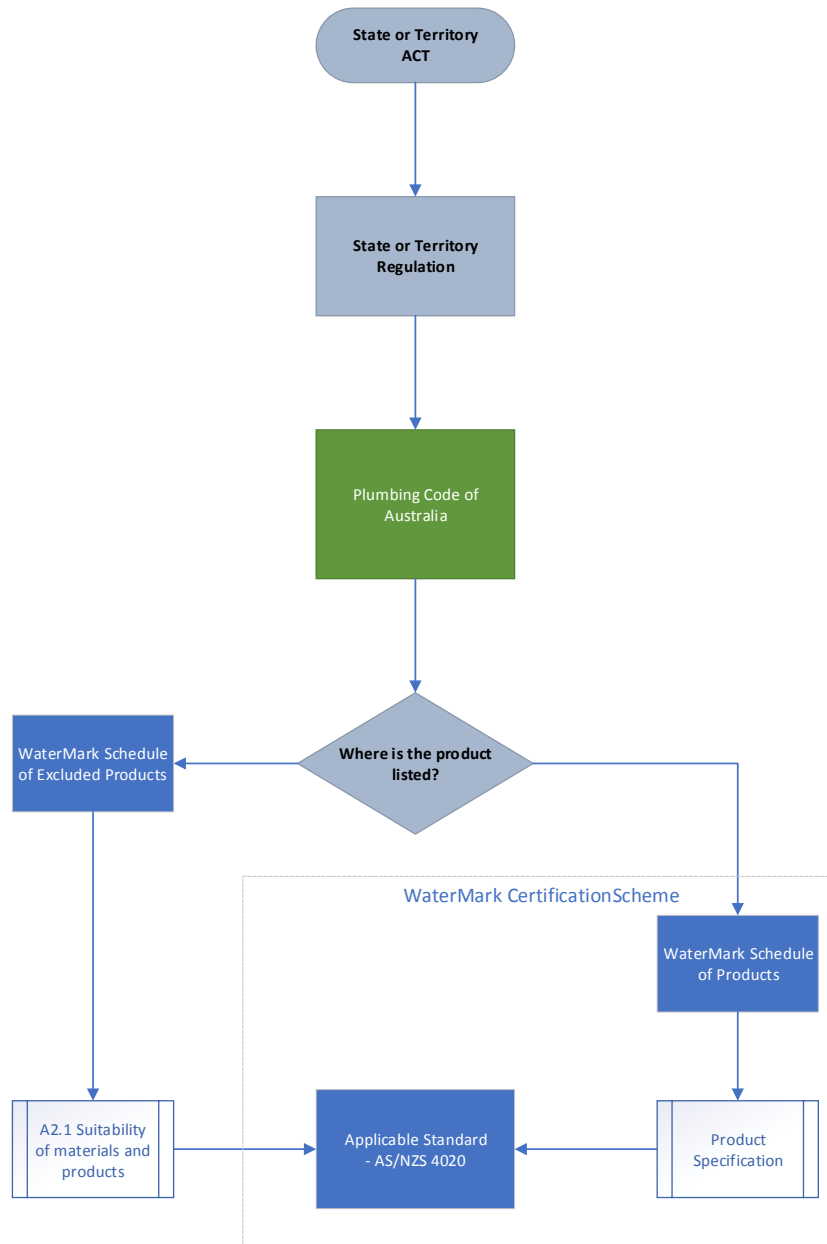


Figure 2. Summary outline of the WaterMark Certification Scheme compliance pathway. Figure supplied by the ABCB.

The PCA and WaterMark Technical Specifications (WMTS) are freely available for use, whereas all other documents such as Australian Standards are restricted by a user pay-wall. The PCA and WMCS concurrently operate as the umbrella regulatory instruments (Figure 3):

Plumbing Code of Australia (PCA):⁹

A2.1 Suitability of materials and products

- (a) Every part of a *plumbing* or *drainage* installation must be constructed in an appropriate manner to achieve the requirements of the NCC, using materials and *products* that are fit for the purpose for which they are intended.
- (b) For the purposes of (a), a material or *product* is fit for purpose if it is—
 - (i) listed on the *WaterMark Schedule of Products*, certified and authorised in accordance with the *WaterMark Certification Scheme*; or
 - (ii) listed on the *WaterMark Schedule of Excluded Products*; and is supported by evidence of suitability provided in accordance with **A2.2**.

Tas A2.1(c)

(c) *****

- (d) A material or *product* intended for use in contact with *drinking water* must comply with **AS/NZS 4020**, and be supported by evidence of suitability in accordance with **A2.2**.

[bold emphasis added]

Tas A2.1(e), (f), (g), (h), (i)

A2.2 Evidence of suitability

- (a) Evidence to support that a material or *product* subject to A2.1(b)(i) has been certified and authorised must be in the form of a **WaterMark Licence**.

[bold emphasis added]

And the Manual for the WaterMark Certification Scheme, Section 1, General:

1.1 Introduction

- 1.1.1. The *WaterMark Certification Scheme (Scheme)* for *plumbing* and *drainage products* is owned by the Commonwealth of Australia, acting on behalf of the Commonwealth of Australia, the State of New South Wales, State of Queensland, State of Victoria, State of South Australia, State of Tasmania, State of Western Australia, the Australian Capital Territory and the Northern Territory (*Scheme Owner*). The **Australian Building Codes Board (ABCB)** has the responsibility for the management and oversight of the *Scheme* on behalf of the *Scheme Owner*.
[bold emphasis added]

The PCA and WMCS both require products to satisfy two primary Australian Standards that prescribe the requirements of a product for use in contact with drinking water:

- AS/NZS 4020:2005 Testing of products for use in contact with drinking water
- AS/NZS 3500.1:2015 Plumbing and drainage water services

The above Australian Standard subsequently require compliance with other additional secondary and tertiary standards¹⁰ and specifications.

The owner of the WaterMark Certification Scheme (ABCB) delegates Accreditation and surveillance of Approved Certifiers (WMCAB) to the accreditation body - the Joint Accreditation System of Australia and New Zealand (JAS-ANZ). The Approved Certifiers are responsible for ensuring that all products are compliant with the WaterMark Product Specifications including but not limited to various Australian Standards.

⁹ Plumbing Code of Australia is available at: <http://abcb.gov.au> (accessed 16 March 2018).

¹⁰ The Australian Standards refer to other minor standards not referred to here.



Australian Standards prescribe maximum allowable lead content of alloys in contact with drinking water. The performance requirements for maximum allowable lead concentrations for metal and metal alloy components in contact with hot and cold drinking water are limited to a maximum of 4.5% (AS 3855 – 1994), with lead solder being limited to 0.1% (AS 3855 – 1994) (Figure 3).

The Review notes that AS/NZS 1565–1996 (Copper and copper alloys—Ingots and castings) contains an additional caveat with respect to the lead content of alloys that are in contact with drinking water:

NOTES:

1 If an alloy is required for use in contact with potable water, the chemical composition is subject to agreement between purchaser and supplier. [p12]¹¹

Additionally, AS/NZS 4020:2005 requires that test water extracts from products in contact with drinking water not exceed 0.01 mg/L (10 µg/L) lead in accordance with the National Health and Medical Research Council Australian Drinking Water Guidelines.

¹¹ It is possible for plumbing products or materials to have a lead content that initially allows it to pass the relevant tests pursuant to AS 4020, but retain potential for leaching its lead content under future *in situ* corrosive conditions—see Section 3 of this Report.

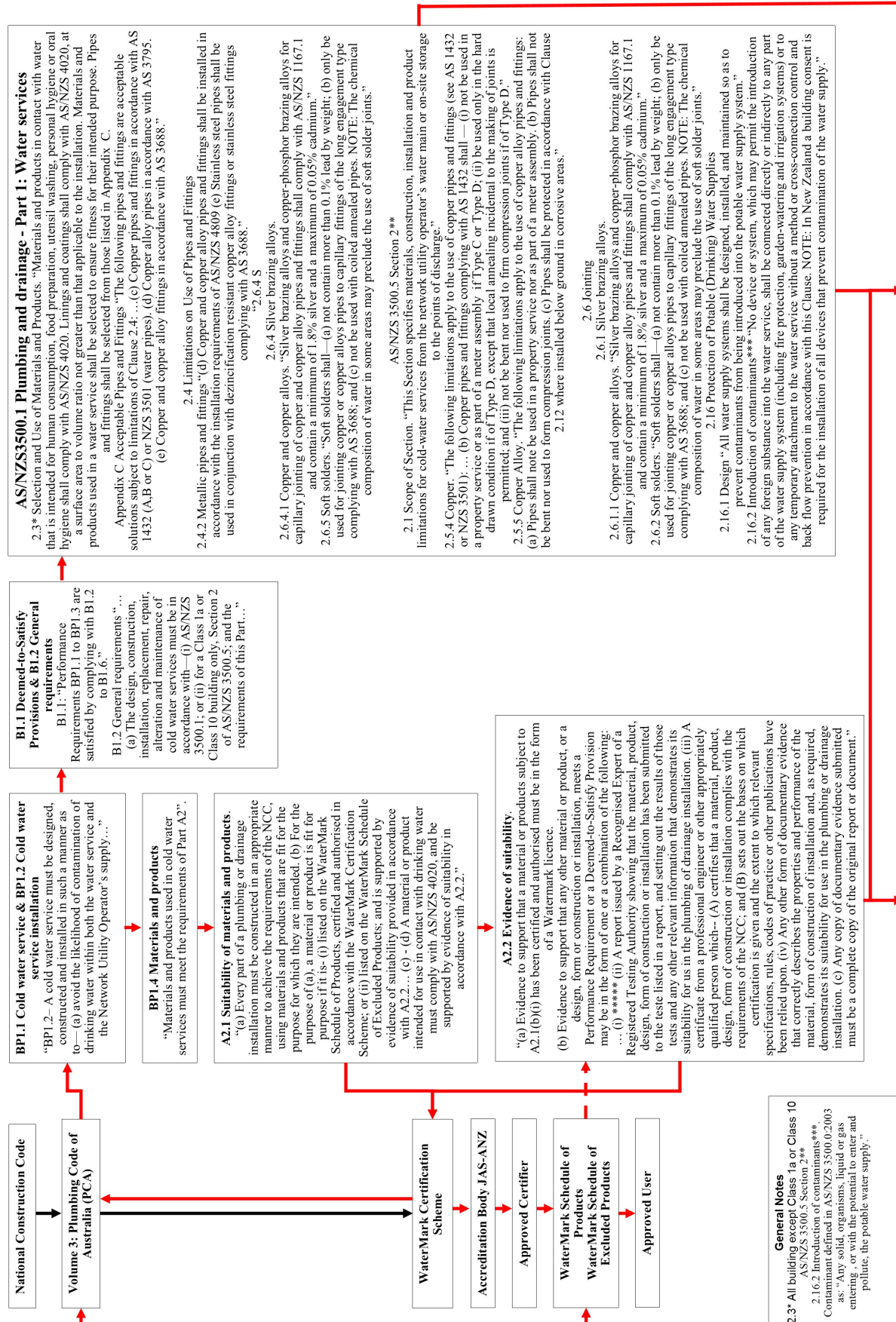
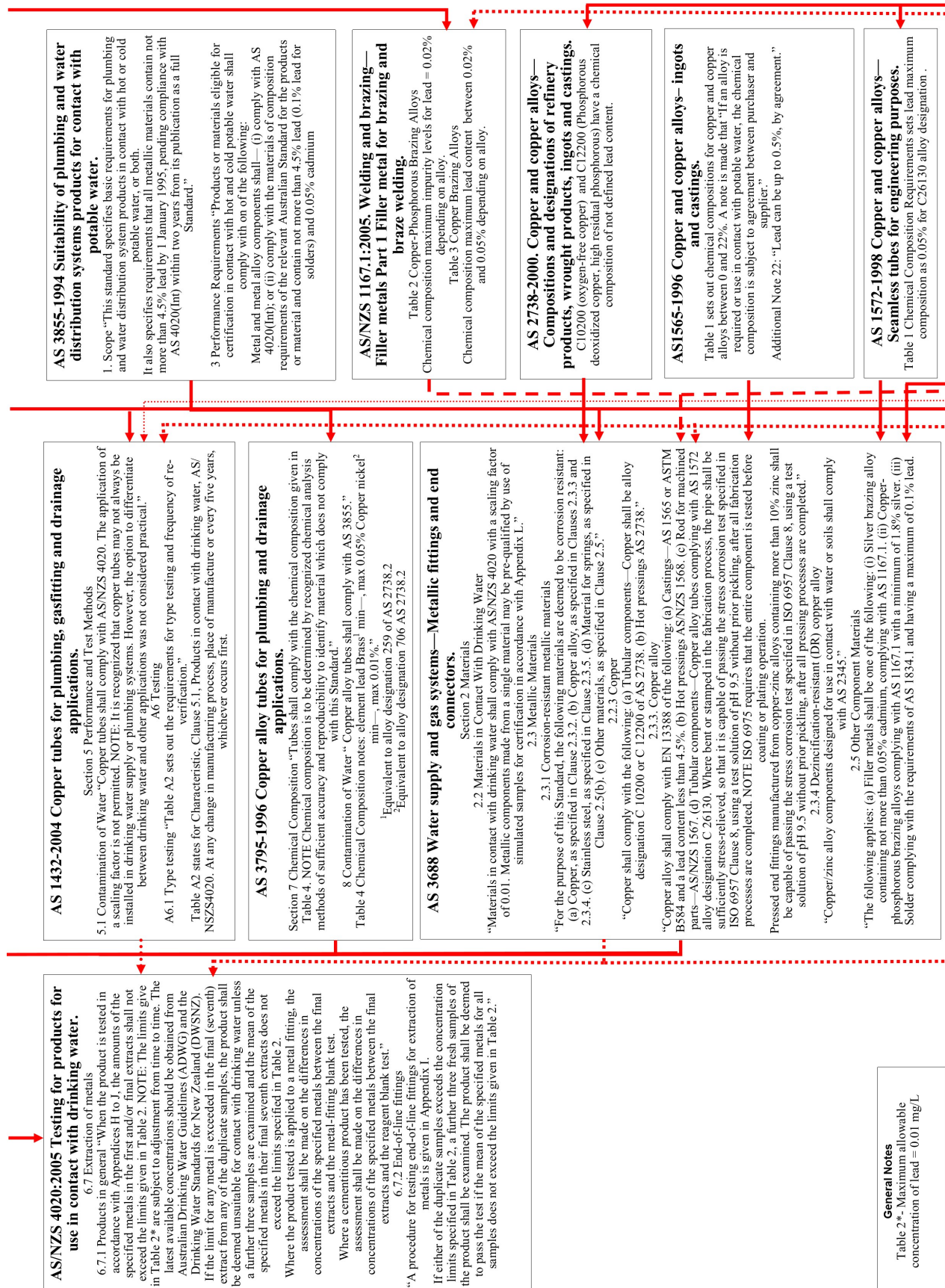
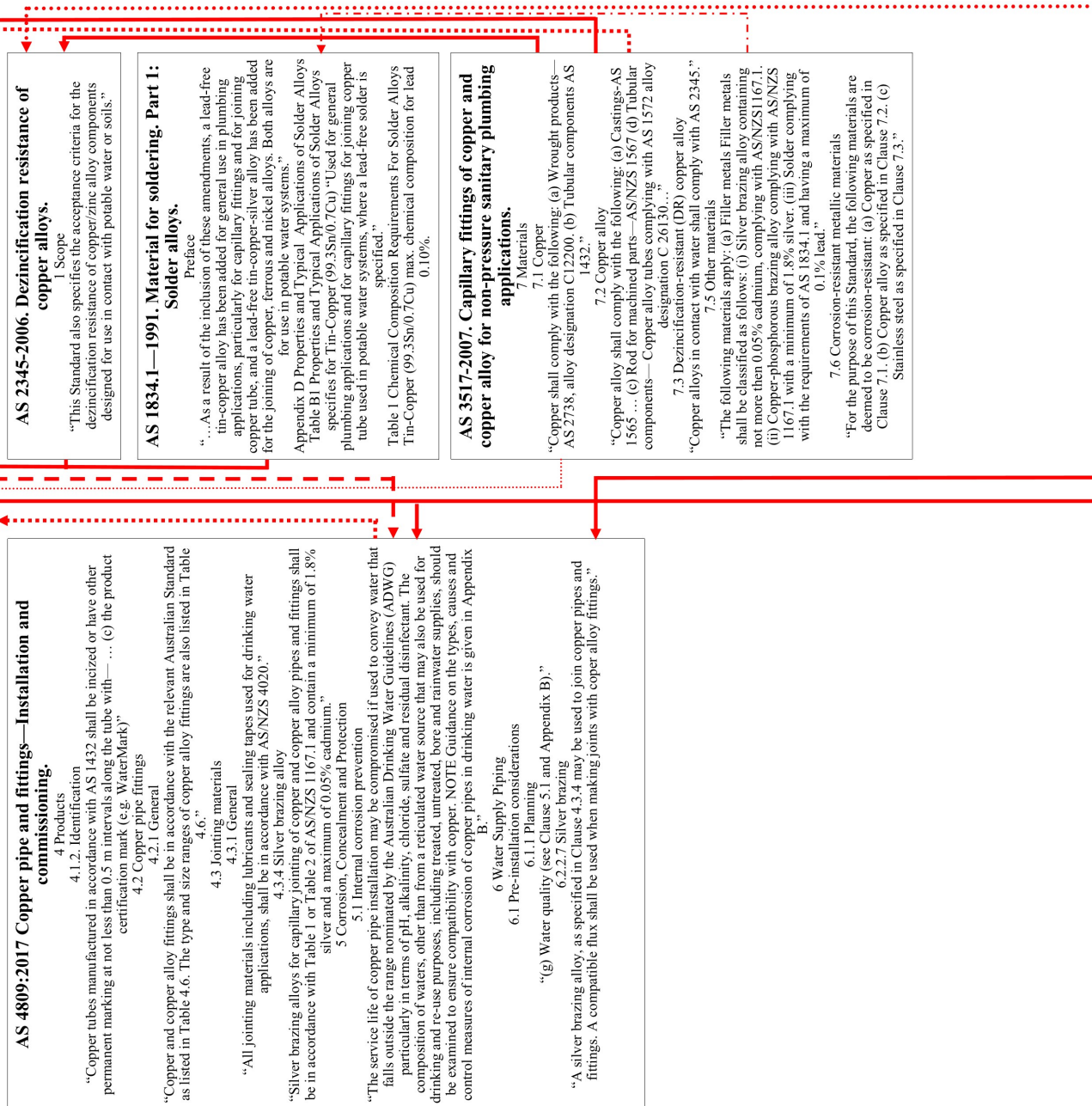


Figure 3. Summary schematic of the main standards relevant for compliance with the WaterMark Certification Scheme.







**AS 5200.007-2008. Plumbing and drainage products.
Part 007: Metal-bodied water hammer arresters**

5 Materials

5.1 Materials in contact with drinking water
"Materials in contact with drinking water shall comply with AS/NZS 4020. Metallic components made from a single material may be prequalified by use of simulated samples for certification in accordance with Appendix P of AS/NZS 3718."

5.2 Metallic materials

5.2.1 Corrosion-resistant metallic materials
"For the purpose of this Standard, the following materials are deemed to be corrosion resistant:

(a) Copper, as specified in Clause 5.2.3. (b) Copper alloy, as specified in Clause 5.2.3. (c) Stainless steel, as specified in Clause 5.2.5. (d) Material for springs, as specified in Clause 5.4 (b). (e) Other materials, as specified in Clause 5.4."

5.2.2 Copper

"Copper shall comply with the following: (a) Tubular components. Copper shall be alloy designation C10200 or C1200 of AS 2738. (b) Hot pressings AS 2738."

5.2.3 Copper Alloy

"Copper alloy shall comply with the following: (a) Castings AS 1565 and a lead content less than 4.5%. (b) Hot pressings AS/NZS 1568. (c) Rod for machined parts AS/NZS 1567. (d) Tubular components Copper Alloy tubes complying with AS 1572 alloy designation C26130. ..."

5.2.4 Dezincification-resistant (DR) copper alloy
"Copper alloys in contact with water shall comply with AS 2345"

5.4 Other component materials

"The following applies:

(a) Filler metals shall be one of the following: (i) Silver brazing alloy containing not more than 0.05% cadmium, complying with AS 1167.1. (ii) Copper-phosphorous brazing alloys complying with AS 1167.1 with a minimum of 1.8% silver. (iii) Solder complying with the requirements of AS 1834.1 and having a maximum of 0.1% lead. (b) Spring materials shall be one of the following: ... (ii) Phosphor bronze to AS 2738 C51000 and C51800. NOTE other materials may be used, provided they meet the performance criteria of this Standard and of the relevant materials Standard."

6 Marking

"Each device shall be permanently and legibly marked with the following: ... (b) WaterMark."

**AS/NZS 1567:1997 Copper and copper alloys—
Wrought rods, bars and sections.**

No specific alloy designation. Table 2 specifies chemical compositions between undefined and 4.5% lead.

9 Dezincification Test

"When required, the dezincification test shall be carried out in accordance with AS 2345."

**AS/NZS 1568:1998 Copper and copper alloys—
Forging stock and forgings.**

No specific alloy designation. Table 1 specifies chemical compositions between undefined and 3.5% lead.

11 Dezincification Test

"When required, the dezincification test shall be carried out in accordance with AS 2345."



SECTION 2

Industry responses to the Review's questions

Company and industry names in the tables below have been retained with the permission of the respective organisation. The Review received advice from the Australian Building Codes Board, the Plumbing Products Industry Group¹² and the Australian Industry Group¹³ about suitable organisations to contact with respect to questions pursuant to the Report. All industry and manufacturing organisations who were contacted provided responses to the Review. These are detailed below.

Review Question 1 – Does your organisation or have you commissioned another authority to routinely test for lead in plumbing products and materials?	
Plumbing organisation type	Response
PPI Group – Industry association for Australian and New Zealand manufacturers and importers of plumbing products	<p>All plumbing products that are connected to the potable water supply are required to obtain WaterMark certification.</p> <p>Therefore, such products that consist of brass should be tested against the appropriate Australian Standard namely AS1565, AS1567 & AS1568. Regular testing of brass material used in plumbing products should be carried out for both chemical composition and dezincification resistance. Given the increase in recycling of materials on a global basis raw material quality can be variable.^[14]</p> <p>PPI Group also consider that product testing and compliance requirements (in particular AS/NZS 4020:2005) with in-field, water sampling testing and guidelines (AS/NZS5667) to remove interpretation and comparison error.</p> <p>The PPI Group is a strong advocate of the WaterMark Scheme. In order to achieve WaterMark Certification, plumbing products need to:</p> <ul style="list-style-type: none"> • be tested by an accredited testing laboratory • comply with an applicable specification • be manufactured in accordance with an approved quality management system; and • clearly state its intended scope of use.¹⁵
Enware, Australia – manufacturer	<p>Yes. To meet the National Construction Code (NCC) / Plumbing Code of Australia (PCA) Performance Requirements Enware test and request test certificates, where required, for products called up in the WaterMark Scheme. WaterMark approval is a Deemed to Satisfy (DtS) provision that satisfies the Performance Requirements of the Code.</p>

¹² The Plumbing Products Industry (PPI) Group's URL is available at: <https://www.ppigroup.com.au/> (accessed 10 May 2018).

¹³ The Australian Industry Group's (Ai Group) URL is available at: <https://www.aigroup.com.au/> (accessed 10 May 2018).

¹⁴ The use of recycled materials in the manufacture of plumbing material and products is referred to by the following organisations, for example: Reliance Worldwide Corporation Limited 2017. Annual Report 2017, page 9. Available at: <http://www.rwc.com/wp-content/uploads/2017/09/2017-Annual-Report-FINAL-small.pdf> (accessed 7 May 2018); Copper Development Association Inc. 2017. Non-Leaded Red Brass and Yellow Brass Casting Alloys. Available at: <https://www.copper.org/applications/industrial/lowlead.html> (accessed 7 May 2018).

¹⁵ Issues raised by the PPI group in relation to the WaterMark Certification Scheme particularly in relation to its policing at the point of sale are detailed in Appendix C. Point of sale regulation for the WaterMark Certification Scheme was the subject of a Discussion Paper compiled by the ABCB in January 2018. The Discussion Paper is available at: <https://www.abcb.gov.au/Resources/Publications/Certification/Feasibility-of-Point-of-Sale-Regulation-for-the-WaterMark-Certification-Scheme> (accessed 5 June 2018).



	<p>AS/NZS 4020 which includes the 'Extraction of Metals' testing is also directly called up in the NCC (p 24):</p> <p>A2.1 Suitability of materials and products</p> <p>(a) Every part of a <i>plumbing</i> or <i>drainage</i> installation must be constructed in an appropriate manner to achieve the requirements of the NCC, using materials and <i>products</i> that are fit for the purpose for which they are intended.</p> <p>(b) For the purposes of (a), a material or <i>product</i> is fit for purpose if it is—</p> <p>(i) listed on the <i>WaterMark Schedule of Products</i>, certified and authorised in accordance with the <i>WaterMark Certification Scheme</i>; or</p> <p>(ii) listed on the <i>WaterMark Schedule of Excluded Products</i>; and is supported by evidence of suitability provided in accordance with A2.2.</p> <p><i>Tas A2.1(c)</i></p> <p>(c) *****</p> <p>(d) A material or <i>product</i> intended for use in contact with <i>drinking water</i> must comply with AS/NZS 4020, and be supported by evidence of suitability in accordance with A2.2.</p> <p><i>Tas A2.1(e), (f), (g), (h), (i)</i></p> <p>For copper alloys, de-zincification resistance testing (AS 2345) is also conducted as part of the WaterMark Scheme product compliance program.</p> <p>Within the Scheme rules and related Australian Standards ongoing testing and reporting is mandatory and is carried out during batch manufacture for DZR and for AS/NZS 4020 during type testing to achieve WaterMark approval and at 5 yearly intervals or any change in material – whichever occurs first.</p> <p>For ongoing supplier verification; test certificates are provided at the time of material delivery. Testing is/can also be commissioned as and when required by material suppliers. Enware also, from time to time, conducted random sample testing of copper alloys to confirm ongoing compliance to AS 2345.</p>
Wholesaler	<p>Yes.</p> <p>We routinely check the lead present in the brass alloy of the plumbing fittings that we import in our dedicated Testing Lab.</p> <p>We have also commenced scheduled 3 monthly DR testing to monitor all brass alloy suppliers that are part of our imported products program.</p>
Designer and Supplier	<p>Testing for lead in the company's plumbing products is conducted internally on a regular basis with results periodically independently check tested by a NATA laboratory.</p>
RBA Group – wholesaler and manufacturer	<p>In a simple answer no we have not set up routine lead testing.</p> <p>Our level of testing has aligned itself with the requirements of the WaterMark and reliance on the traceability of raw materials that</p>



	<p>sub contract suppliers or brand partners produce for us inclusive of AS4020 test requirements.</p> <p>However, there are numerous products that our Group supplies to the market that are Lead Free and are used for the supply of drinking water. These materials are largely either 304 Stainless Steel, 316 Steel or of all plastic / elastomeric construction.</p>
Wholesaler of tapware; manufacturer of pipe fastening systems	No we don't.
Wholesaler	Our Watermarked certified products are tested every 5 years to AS/NZS 4020, as required by the WaterMark Certification Scheme and the applicable Australian standards.
Manufacturer	<p>Yes, product recertification is every 5 years and we would commission AWQC to do this. We also request material certificates from our suppliers.</p> <p>Outside of any recertification or certification of new products, I'm not aware of any regular testing commissioned specifically targeting lead. The only thing remotely close is perhaps regular checking of the MNZ furnace alloy composition we do as part of the service offered by our ingot supplier. This is checking alloy elements are within limits, not any checking of heavy metal leachate.</p>
Galvin Engineering – manufacturer	<p>As part of our QA/QC program, we routinely test materials and components used to manufacture our WaterMarked products using both our in-house laboratory and external NATA approved laboratories. We do this to ensure they comply with our specifications and those set out in the relevant Australian Standards.</p> <p>Whilst some of the testing we perform will identify levels of lead, they are not solely for this purpose, rather to identify the entire chemical composition of the material, as well as other material properties such as susceptibility to dezincification.</p>
Manufacturer – RWC	<p>Under its ISO9001 accreditation, Reliance Worldwide Corporation (RWC) routinely tests the Brass material used in its range of products for both chemical composition and dezincification resistance.</p> <p>Lead levels are monitored on each batch of stock material received.</p>
Manufacturer	The material composition of our raw materials is routinely tested. For DZR brass fittings, lead content is among those tests.
Manufacturer – Rinnai	Yes. Material composition is strictly controlled, which includes lead content. Quality control procedures are in place to confirm material composition, including lead content, on an ongoing basis. Such quality control procedures are carried out by suppliers to Rinnai or by Rinnai itself.

Review Question 2 – If there is no routine testing, has your organisation undertaken or have you commissioned another authority to undertake any testing of lead in plumbing products and materials at any point in time?

Plumbing organisation type	Response
PPI Group – Industry association for Australian and New Zealand manufacturers and importers of plumbing products	WaterMark surveillance requirements during the 5--year term of the WaterMark license need to be strengthened to compare with those that exist in Europe and the USA, for example 6 monthly factory audits to check material composition and production processes are consistent with certification requirements. ¹⁶
Enware, Australia – manufacturer	Routine testing is carried out as described in question 1 to satisfy the requirements of the NCC and the WaterMark Scheme for materials in contact with drinking water.
Wholesaler	The scheduled and spot checking processes that we have in place to test for lead in plumbing products is detailed in the responses to questions 1 and 3.
Designer and Supplier	Refer Question 1.
RBA Group – wholesaler and manufacturer	The testing undertaken for lead has been in accordance with the WaterMark requirements and the reliance on the traceability of raw materials that sub contract suppliers or brand suppliers produce for us inclusive of AS4020 test requirements.
Wholesaler of tapware; manufacturer of pipe fastening systems	No
Wholesaler	No answer provided.
Manufacturer	AS/NZS4020 testing. This applies to any certification of new suppliers or products that exceed previous surface area:volume ratios.
Galvin Engineering – manufacturer	Refer to response for Question #1.
Manufacturer – RWC	N/A – please refer to question 1.
Manufacturer	Refer to question 1.
Manufacturer – Rinnai	Not applicable, see answer to question 1.

¹⁶ Appendix C contains further commentary from the PPI Group about possible improvements to the WaterMark Certification Scheme to ensure raw materials are of consistent quality and are appropriate for the manufacture of plumbing products with respect to lead.



Review Question 3 – How are your plumbing products and materials screened to determine whether they meet the current relevant Australian Standards?

Relevant standards could include the AS/NZS 4020 - Testing of products for use in contact with drinking water; the WaterMark Certification Scheme and the Plumbing Code of Australia.

Plumbing organisation type	Response
PPI Group – Industry association for Australian and New Zealand manufacturers and importers of plumbing products	Accredited WaterMark Conformity Assessment Bodies (WMCAB)[¹⁷] are charged with the responsibility of developing the necessary laboratory test schedules to ensure compliance with Australian Standards, the WaterMark Certification Scheme and the Plumbing Code of Australia. However, this is a decision taken by the WMCAB with respect to assessment, surveillance and timing and some in industry think this process should be more prescriptive to reduce so called CAB shopping to ensure consistency in the process.
Enware, Australia – manufacturer	<p>Sourcing of copper alloys is conducted using Enware preferred suppliers. Enware maintains a database of preferred material suppliers and preferred semi-finished material suppliers. Supplier appraisals and reviews are undertaken as part of ISO 9001 Quality Management System. Product is delivered with accompanying “Certificates of Conformance” to the relevant material specification</p> <p>As the copper alloy global supply chain has matured local supply of raw materials is now limited. To ensure continuity of supply Enware have developed strong relationships with overseas suppliers of raw and semi-finished raw material suppliers. These suppliers have undertaken Enware supplier appraisal reviews and also provide material certificates with deliveries.</p>
Wholesaler	<p>There are 5 important processes that we have commissioned:</p> <ol style="list-style-type: none"> Our Testing Lab: We have a dedicated Testing Lab at our Dandenong South DC facility with 7 qualified staff monitoring the quality and suitability for all of the products in our imported products program. This includes both a dedicated Standards Manager as well as staff skilled in carrying out the testing required across all relevant Australian Standards. Wherever testing is outside the scope of our team we work with NATA certified labs to facilitate this testing. The Watermark Scheme: We enforce a vigilant requirement of only importing fully certified products. As you are aware, the current testing regime to achieve Watermark Standards is comprehensive and rigorous. We work closely with the Australian based Conformance Assessment Bodies and with both our Overseas Buying Team and Overseas Third Part Quality Control agencies to ensure that products we import achieve all relevant Australian Standards. This is a central part of our New Product R&D process.

¹⁷ The role and purpose of the WaterMark Conformity Assessment Bodies for certifying that plumbing and drainage products comply with the relevant approved specifications is provided in brief at: ACBC, 2018. Become a Conformity Assessment Body. Available at: <https://www.abcb.gov.au/Product-Certification/WaterMark-Certification-Scheme/Become-a-WMCAB> (accessed 8 May 2018).



	<p>3. Where we have conducted spot checks of product that have the WaterMark certification we have seldom seen lead leaching into the water supply above the allowable limits giving us significant confidence in the effectiveness of the Watermark Scheme.</p> <p>4. Materials Composition Testing: We have invested in a Mass Spectrometer to investigate the composition of elements within the brass alloy products that we import. We have been conducting this testing in-house for a decade now and regularly assess the level of impurities that may destabilise the structure of the alloy.</p> <p>5. Dezincification Resistant Testing: We conduct scheduled DR testing of products externally to gain a greater level of assurance around the stability of the brass alloy. We also ensure that our supplies send through DR batch testing reports for shipments of stock so that we can analyse the Average Depth of Corrosion in accordance with the testing required by the standard.</p> <p>6. 4020 Testing: Wherever we have been concerned with the performance of products we have worked with the qualified Australian Testing Labs (AWQC) to conduct 4020 testing to ensure the ongoing safety of the products we sell.</p>
Designer and Supplier	<p>Our Company regularly screens our ranges of plumbing products for compliance to relevant Australian Standards. We have an internal NATA laboratory where compliance and check testing is conducted.</p> <p>As our NATA laboratory is not fully accredited to conduct compliance testing across all relevant plumbing product standards such as chemical/material and AS/NZS 4020 testing we use external NATA laboratories where required.</p>
RBA Group – wholesaler and manufacturer	<p>Our current products are screened through the relevant stated methods in each product standard outlining the means for demonstrating compliance. An example of this is with AS/NZS3718 – 2005: Appendix A. In each of the current product categories we sample test against AS4020 at the stated intervals and rely on traceability of material and component suppliers MSDS and mill certificates.</p>
Wholesaler of tapware; manufacturer of pipe fastening systems	<p>Our tap ware is required under certification through WaterMark to be tested for lead content according to Australian standards.</p>
Wholesaler	<p>IAPMO [International Association of Plumbing and Mechanical Officials] is our Conformity Assessment Body and is responsible to provide us with the suitable laboratory test schedules, necessary to verify if our products meet the requirements of the relevant Australian Standards.</p> <p>The WaterMark Certification Scheme and the Plumbing Code of Australia is used by IAPMO to identify the relevant specifications and standards.</p>



Manufacturer	<ul style="list-style-type: none"> AS/NZS 4020 testing of representative products (taps and valves excluding showers) in every five years And audits by our conformity assessment body – SAI Global.
Galvin Engineering – manufacturer	<p>Firstly, we have documented Supply and Manufacturing Specifications that all products and materials must comply with and meet our performance requirements, and the minimum requirements of relevant Australian Standards. Their conformance is routinely verified using several methods, including common ones such as:</p> <ul style="list-style-type: none"> Spectrometer Analysis - to determine conformance to our written specifications and specific material standards such as AS1565, AS1567, AS1568, etc. Dezincification Resistance Testing – to determine conformance to AS2345. Detailed Testing for Materials and Products in Contact with Drinking Water – to determine conformance to AS/NZS 4020. <p>Secondly, we ensure conformance to current relevant standards through internal and external audits of our quality system (ISO 9001:2015), independent annual product certification audits (WaterMark Level 1 requirement), monitoring of Australian Standard changes through our R&D and Compliance Departments, and subscription to online standards databases.</p> <p>Furthermore, new products undergo a full set of tests as prescribed by WaterMark Conformity Assessment Bodies (WMCABs) for materials and performance, which is also conducted at independent NATA approved laboratories.</p>
Manufacturer – RWC	All products sold that appear on the ABCB Watermark Schedule of Products are independently tested to AS/NZS 4020 (through either AWQC or AMS) as part of their respective Watermark certification.
Manufacturer	Our products are Watermark certified based on the relevant product standard, this includes hygiene testing to AS/NZS 4020. All batches are tested to confirm compliance with the requirements of the relevant product standard.
Manufacturer – Rinnai	The only plumbing products Rinnai supplies to the Australian market are water heaters. In the Australian regulatory context, water heaters have to conform with the requirements of the Watermark product certification scheme which includes conformance with AS/NZS4020. The Watermark scheme includes periodic auditing by conformity assessment body (CAB) representatives which includes screening for materials compliance.


Review Question 4 – Does your organisation have alternative fittings that have no or low lead or have knowledge of their availability?

Plumbing organisation type	Response
PPI Group – Industry association for Australian and New Zealand manufacturers and importers of plumbing products	Australian manufacturers and suppliers are generally aware that materials with no lead and with low lead are available and may be used in production however there are challenges in their use around cost and machinability etc. The PPI Group policy position is to see an orderly transition to a 0.25% maximum lead content in copper alloys through the National Construction Code (NCC) cycle of 2018–2022.
Enware, Australia – manufacturer	Sources of materials with no lead and with low lead are known to be available and, where appropriate, these materials are already used in Enware designed, manufactured and distributed products. As an example; low lead copper alloys, stainless steel and composite materials.
Wholesaler	<p>Yes, but there is only a very small selection available to the Australian market at this stage given the breadth of products required by the industry.</p> <p>This includes both brass products, and non-brass alternatives (such as stainless steel). It is, however, extremely important to note that non-brass alternatives, whilst not containing lead, may indeed have limitations that make them inferior to brass products.</p> <p>For example, brass products inherently have a high anti-bacterial quality due to their high copper content which makes it more attractive in healthcare applications than stainless steel alternatives.</p>
Designer and Supplier	Our Company has a limited range of tapware products that has a relatively low lead content ranging between 0.8 to 1.1%. We are aware that some of our overseas suppliers have the ability to produce low lead plumbing products re the US market. Implications of the current requirement for DR brass in combination with a low lead requirement needs to be investigated.
RBA Group – wholesaler and manufacturer	<p>The RBA Group has supplied no lead / lead free products now for around 15 years with an increasing level of product availability since 2010.</p> <p>These product ranges extended to drinking fountains both refrigerated and non-refrigerated models inclusive of accessible design models for public spaces. Timed flow taps manufactured from Stainless Steel since their release to Australia in 2010 that are targeted to schools and public washroom facilities. Pneumatic controls for schools and public washroom along with correctional facilities. These are just some of the lead free products supplied to Australia.</p>
Wholesaler of tapware; manufacturer of pipe fastening systems	It has never been an issue, we have heard of the US “lead -free” brass which could be a great alternative to the current brass if Australian standards changed to it, it would be a good solution.



Wholesaler	Our organization is developing lead free products to meet the specific requests of some customers, regarding the limited release of nickel and lead to drinking water.
Manufacturer	<ul style="list-style-type: none"> • Yes, Ecobass. Some tubular components made from 70/30 brass have very low lead content e.g. alloy 259 stipulated in AS/NZS 1567. <p>Cuphin is an alloy by Deihl Metall in Europe licenced from Mitsubishi Shindoh. This is essentially EcoBrass by another name.</p> <ul style="list-style-type: none"> • Something else to consider is Bismuth. There are alloys commonly used throughout US products that use Bismuth in place of lead for machinability. We have recently seen alloy composition testing from suppliers containing an increased quantity of Bi. • We know when processing EcoBrass that everything, including swarf, must be separated from normal production. If silicon gets mixed in with normal brass it changes the mechanical properties. I fear this is what is happening with Bi – contamination of normal alloys through poor handling. Where this will lead to is anyone's guess, particularly with recycling of unlabelled product. • It must be said of EcoBrass ingot manufacturing by Mitsubishi Shindoh is they only use virgin raw materials or reprocessing known EcoBrass swarf. • If AU is moving to low lead brass as in the US (0.25%), these low lead brasses are unlikely to meet DZR requirements. However, Ecobass can meet both low lead and DZR. Ecobass is an ideal solution to meet global low lead requirement but unfavourable higher price. • We know that in Australia, the retail cost percentage increase across products using Ecobass is overall a detraction from consumer adoption i.e. it is great we can offer it, however the consumer seldom use Ecobass as a purchasing decision.
Galvin Engineering – manufacturer	<p>Yes, we offer several product lines in low lead or lead-free alternatives.</p> <p>We select product lines where it is practical to produce in alternative materials without compromising compliance to current Australian Standards and Watermark requirements, and where we believe there is a willingness from consumers to pay the increased cost of these alternative material products. I have listed two examples below:</p> <ul style="list-style-type: none"> • The Ezy-Drink® GalvinClear range of stainless steel drinking bubbler taps, was designed to offer consumers a choice of a lead-free drinking tap. These are made in our factory in Perth and are ideal for schools, universities and other public areas. It was featured on Channel Seven News late last year on:



	<p>https://www.galvinclear.com.au</p> <p>One of the models can be found on:</p> <p>https://www.galvinengineering.com.au/ezy-drink-galvinclear-316-stainless-steel-piezo-el</p> <ul style="list-style-type: none"> The Conti range of electronic tapware is made for us by a partner in Switzerland. Conti offers a selection of products that not only pass the Australian Standard testing for potable water (AS/NZS 4020), they also comply with s1417 of the Safe Drinking Water Act in the USA (and USA standards NSF61 / NSF372). Therefore, in the USA these taps can be labelled as 'lead free'. <p>In addition, all metallic materials used in these taps are listed on the European Standard (4MS Common Approach), which ensures they meet the strict German Drinking Water Guidelines. One of the models can be found on:</p> <p>https://www.galvinengineering.com.au/conti-electronic-iq-a10-ir-hob-basin-tap-w-temp-mi</p>
Manufacturer – RWC	<p>Yes.</p> <p>RWC push-to-connect (PTC) product sold into the North American market under the SharkBite brand utilises a low-Lead Brass alloy that meets the requirements of both NSF/ANSI 372 and NSF/ANSI 61, albeit at a higher raw material and manufacturing cost.</p> <p>RWC PTC product sold into the US under the EvoPex brand is a polymer product that does not contain Brass (except for a small number of threaded items).</p>
Manufacturer	<p>Our DZR brass raw material has a low lead content compared to the allowable limits. We also offer polymer fittings that are completely lead free.</p> <p>Note – significant fluctuations of lead content appear to be evident in some DZR brass fittings used for plumbing pipe systems sold in the Australian market, with some of them exceeding the allowable limits of the material standard.</p>
Manufacturer – Rinnai	<p>No.</p>



Review Question 5 – Has your organisation or have you commissioned another authority to undertake any testing of dissolution of lead from plumbing products and materials in:

(a) real systems

(b) laboratory simulation of plumbing systems?

Plumbing organisation type	Response
PPI Group – Industry association for Australian and New Zealand manufacturers and importers of plumbing products	<p>PPI Group have no specific response to this question however note that AS/NZS 5667 while providing guidance with respect to water testing and sampling, there are too many variables left to the individual testing facility to implement, which ultimately provide variable and inconsistent test results.</p> <p>A more prescriptive or standardised method of water sampling and testing for lead (and other metals) should be developed for national use which would provide for greater consistency in methodology and ultimately the test results.</p>
Enware, Australia – manufacturer	No to both 5a; 5b.
Wholesaler	<p><i>a. real systems - No</i></p> <p><i>b. laboratory simulation of plumbing systems? – Yes, 4020 testing as detailed above.</i></p>
Designer and Supplier	Our Company has not commissioned another authority to undertake any testing of dissolution of lead from plumbing products and materials in real and simulated laboratory systems.
RBA Group – wholesaler and manufacturer	<p>Simply the answer to this is no, however there has been collaboration with various industry groups who have investigated lead levels and to this resulted in the 4% max limit set many years ago.</p> <p>This study was done back through what was AUSTAP and later changed its name to PPI Group. This study was well ahead of the USA at the time.</p>
Wholesaler of tapware; manufacturer of pipe fastening systems	No to both 5a; 5b.
Wholesaler	No to both 5a; 5b.
Manufacturer	<ul style="list-style-type: none"> No we haven't routinely undertaken any dissolution testing outside of 4020. This does include in-line fittings where scaling factors were used. The only other potential insight here is other global standards – US (max % lead by weight), China (a different dissolution procedure from memory), European 4MS approved materials (pick from a list of approved alloys and some dissolution testing also from memory). I think only China, AU and 4MS take the component post



	<p>production for testing which takes the manufacturing process in to consideration. We know processing affects the dissolution performance, particularly casting. Look at how it affects DZR.</p> <ul style="list-style-type: none"> • We also know lead has a much lower melting point than all other elements in the copper alloy and that the alloy composition of casting will vary throughout the component due the very notion the metal is liquid. When a casting with an internal sand core, the sand has greater insulation properties than the surrounding metal die cavity meaning it is potentially the last area to solidify. It could then be construed that there could potentially be a higher % of lead on the inner surfaces of a casting. • Similarly, the primary reason to add lead to a copper alloy is to provide some lubrication during the machining process. • It could also be construed that lead is smudged across the surface during machining increasing the surface area of lead and thus greater potential for dissolution. • As for real world, can we definitively say that any accelerated testing method is close to being real world?
<p>Galvin Engineering – manufacturer</p>	<p>From time to time we have used independent NATA labs to conduct water composition analysis on products of ours that are installed in the field. We have done this to get a better understanding of how our products perform in different locations and under different operating conditions. This has included testing for recently installed products and for products installed for a longer period. We have also performed in-house testing using our own test rigs.</p> <p>As a side note, the Department of Health in WA does not itself provide a documented procedure for in-field water testing. Instead they publish a list of recommended test labs to use for the analysis of water. After contacting most of these test labs, we were surprised that they could not provide us with a consistent documented procedure for the way water samples should be collected and tested.</p> <p>Through our own experiments, we found five key variables exist when collecting and testing water samples from the field, and that these factors impact the results of the water tests. Therefore, it is reasonable to assume these variables could impact on testing being done by other people in the field, and this could lead to questions as to whether there is compliance to Australian Drinking Water Guidelines. These variables are:</p> <ul style="list-style-type: none"> • volume of sample used in the test • duration of stagnation in the plumbing system being tested (time in which the actual water outlet and other close proximity outlets are not operated) • flush duration and amount used in the test • complexity of the plumbing system being tested • composition (chemical, physical, etc) of the water in the plumbing system being tested. <p>We researched this further to identify correct collection methods and found that whilst AS/NZS 4020 was quite prescriptive in water collection methodology and seems suitable for controlled laboratory conditions, there was little guidance for in-field testing.</p>



	The most relevant Australian standard we could identify for in-field collection, AS/NZS 5667.5, is ambiguous and lacks a lot of detail regarding the variables outlined above. This is likely due to the fact AS/NZS 5667.5 is meant for analysis of the water supply, where AS/NZS 4020 is for the analysis of the effect materials have on water supply. ¹⁸
Manufacturer – RWC	No to both 5a; 5b.
Manufacturer	a. Real systems Yes, overseas b. Laboratory simulation of plumbing systems? Yes, as above.
Manufacturer – Rinnai	With regards to item (a), yes, on real water heating systems. With regards to item (b), no.

¹⁸ The issue of water sampling methods is discussed further in Galvin Engineering's submission to the Review in Appendix D.



SECTION 3

Literature review

3.1 Literature search process

Boolean searches were initially carried out in both PubMed and Google Scholar using terms “plumbing materials” OR “plumbing products” AND “lead” OR “Pb”. This yielded approximately 2700 articles ranked by relevance. Initial scans of the searches suggested large numbers of articles which were irrelevant to the current project. As a result an additional search was also carried out in Web of Science which yielded a further 460 potential articles.

Results from all database searches were then manually interrogated by the researcher to identify articles and papers germane to the current project. Citations and abstracts from relevant articles were then downloaded to an Endnote® database which initially contained 190 journal articles, book sections and web resources. Further items were added to the database when on reading through the resources already identified it became apparent that other information was available which had not been detected by the initial searches. Thus, the final database of literature from which the questions were responded to totalled 228 items.

It was noted by the Review team that Google Scholar, PubMed and Web of Science databases tended to favour results published in the North American literature and that some other relevant results from both the UK and Europe may exist but were not identified from these searches.

The Endnote® database has been included in this report as an annotated bibliography (Appendix B).



3.2 Question 1 – The potential sources of lead in plumbing products / materials

The Endnote® database was interrogated for “sources” of lead in plumbing systems. The search terms included “Lead/Pb in plumbing products/materials”. The literature retrieved from the Endnote® database required a review to identify the most relevant items. This review showed that the major review documents by Sandvig, Kwan et al. (2008), Sandvig, Triantafyllidou et al. (2009) and Triantafyllidou and Edwards (2012) were very relevant for addressing Question 1.

Drinking water complying with the Australian Drinking Water Guidelines (ADWG) is specified to contain maximum lead level of 10 µg/L, but typically contains a concentration of less than 5 µg/L (NHMRC and NRMCC 2011). Lead is not usually at problematic levels in water at the treatment plant or in reticulated water mains in either Australia or indeed in most developed countries (NHMRC and NHMRC 2011, Sandvig, Kwan et al. 2008).

Beyond the supply mains there however exists the potential for lead to be unintentionally added to the drinking water supply from components of the reticulation system, which themselves contain lead. This lead can be added to water in particulate (Triantafyllidou, Parks et al. 2007, Deshommes, Laroche et al. 2010, Xie and Giammar 2011, Clark, Masters et al. 2014) or dissolved form and arises from both interactions of water chemistry (Schock 1989, Harms, Clement et al. 1994) with the plumbing components and hydraulic effects (Sarver and Edwards 2011, Xie and Giammar 2011, Cartier, Arnold et al. 2012). Once added to supplied water and ingested this dissolved or particulate lead can be absorbed directly by consumers adding to their total lead body burden (Gulson, Law et al. 1994, Payne 2008, Edwards, Triantafyllidou et al. 2009, Brown and Margolis 2012, Triantafyllidou and Edwards 2012).

Based on Northern Hemisphere plumbing practice, Triantafyllidou and Edwards (2012) have identified four principal sources of lead additions between the water mains and the point of water consumption. These are:

- lead service pipes
- partially replaced lead service pipes
- lead soldered components
- leaded brass (and bronze) components.

These components and their location in a reticulation system are shown in Figure 4.

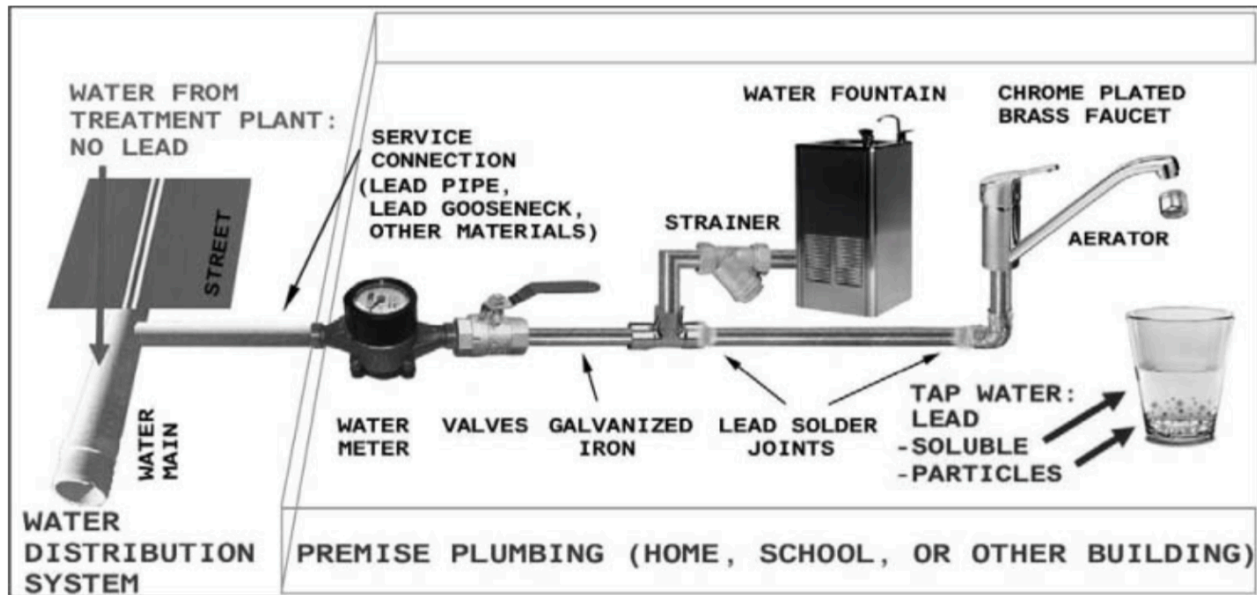


Figure 4. Potential sources of lead additions to reticulated water. Figure from Triantafyllidou and Edwards (2012).

3.2.1 Lead Service Pipe

Lead pipe has been used since Roman times (Potter 1997, Delile, Blichert-Toft et al. 2014) for the distribution of drinking water due to its availability, longevity, malleability and resistance to frost and subsidence (Rabin 2008, Triantafyllidou and Edwards 2012). This use continued in the face of knowledge, from as early as the 1800's, of the potential for such piping systems to contribute to lead poisoning (Rabin 2008). As a result, although the practice of lead pipe installation had been discontinued, there remained in 1997, for example, some 8.9 million homes in England and Wales which had lead water supply pipes (Potter 1997).

As plumbing codes for many large US cities continued to allow lead service line installation into the 1980's the numbers of installed lines nationally in the US is difficult to estimate but is likely to be significant (Rabin 2008). Anonymous surveys of US water authorities in the 1990's suggested the existence of about 3.3 million lead service lines and 6.4 million lead pipe gooseneck¹⁹ connections in the United States (Triantafyllidou and Edwards 2012).

Lead service pipes are estimated to contribute 50-75% of lead contamination (Table 1) at the tap to homes where they are present (Sandvig, Kwan et al. 2008).

Anecdotal information from plumbing practitioners (P. Hobbs, *pers. comm.*) suggests that Australia has relatively few buildings remaining where lead piping is installed, as copper began to replace lead piping throughout the 1930s (Waterlogic Australia Pty Ltd 2018). It would be prudent to ascertain the validity of this statement by contacting water supply authorities in all Australian States and Territories, as if this information were to be incorrect it may significantly change the approach to lead in tap water minimisation in the areas where lead piping was still in use.

¹⁹ A gooseneck is a flexible arched bend (made of lead) in a water service line typically installed between a rigid service pipe and a premise's service line. The bent segments of pipe were traditionally composed of lead had the shape of a goose's neck, hence the name 'lead goosenecks.' This is shown diagrammatically at: LSLR Collaborative (undated). Introduction to Lead and Lead Service Line Replacement. Available at: <https://www.lslr-collaborative.org/intro-to-lsl-replacement.html> (accessed 14 May 2018).



Table 1. Estimated contribution of sources of lead in consumed water when lead service pipes are present. Table from Sandvig, Kwan et al. (2008).

Lead Source	Average % Contribution of Mass of Lead Measured at Tap during Profile Sampling ¹
Lead Service Lines	50% - 75%
Premise Piping	20% - 35%
Faucets	1% - 3%

¹From sites with lead service lines. Based on “mass lead” results at the tap from sequential samples collected for the Sandvig, Kwan et al. (2008) study.

3.2.2 Partially replaced lead service pipe

A common reaction by water authorities to consumer and regulatory concerns with lead in water supplies has been replacement of lead service line piping to premise boundaries with copper pipe. This is done with the expectation that the consumer will be responsible for line replacement beyond that point (Sandvig, Kwan et al. 2008, Arnold Jr 2011). In many cases rather than decreasing lead this pipe replacement has elevated lead levels at the point of consumption. These increases are due to a combination of factors including, disturbance of historic stable lead accumulations on pipe interiors, creation of lead particles during pipe joining and promotion of galvanic effects where copper and lead are in contact (Triantafyllidou and Edwards 2010, Arnold Jr 2011, Cartier, Arnold et al. 2012, Clark, Cartier et al. 2013, DeSantis, Triantafyllidou et al. 2018).

3.2.3 Lead soldered components

Solder is a low melting point alloy that allows the connection of copper based plumbing components with a robust and resilient watertight joint. Historically, the most common solder filler metal used to join copper alloy tube and fittings was 50/50 solder, which is 50% tin and 50% lead (Australian Standards Association 1991).

The amount of lead generated from soldered joints that contributes to lead in consumed tapwater varies depending on the number of joints, age, workmanship, solder area exposed, water volume, temperature and chemistry, and stagnation time (Birden, Calabrese et al. 1985, Sosnin and Thompson 1985, Murrell 1986, Schock 1989, Gregory 1990, Gulson, Law et al. 1994, Sandvig, Kwan et al. 2008). Solder joint dissolution is highest in new installations (Birden, Calabrese et al. 1985, Sandvig, Kwan et al. 2008) and can be accelerated by galvanic interactions with copper tubing and water chemistry, particularly chloride to sulfate ratio (Sosnin and Thompson 1985, Gregory 1990, Lin, Torrents et al. 1997, Nguyen, Stone et al. 2010, Nguyen, Clark et al. 2011, Nguyen, Stone et al. 2011). Lead containing particles in the premise piping that have derived from solder can dissolve over time and have been implicated in cases of childhood poisoning (Walker and Oliphant 1989, Lytle, Schock et al. 1993, Triantafyllidou, Parks et al. 2007).

The permissible amount of lead in solder to be used in conjunction with drinking water plumbing systems was reduced to 0.1% and is detailed in the Australian Standard AS 3855 –1994: *Suitability of plumbing and water distribution systems products for contact with potable water*, following on from a similar restriction in the USA in 1986 (Showman 1994).



The preface to the Australian Standard (AS 1834.1—1991) states:

... a lead-free tin-copper alloy has been added for general use in plumbing applications, particularly for capillary fittings and for joining copper tube, and a lead-free tin-copper-silver alloy has been added for the joining of copper, ferrous and nickel alloys. Both alloys are for use in potable water systems. [p2]

This Tin-Copper solder (composition (%) 99.3Sn²⁰/0.7Cu²¹) is prescribed for use in the Australian Standard (AS 1834.1—1991) as follows:

Used for general plumbing applications and for capillary fittings for joining copper tube used in potable water systems, where a lead-free solder is specified.

However, there is *potential* for confusion with regard to the use of other solders within the Australian Standard (AS 1834.1—1991 - Material for soldering: Part 1 Solder Alloys). For example, the Standard describes the use of a 50Sn solder with lead as the primary remaining component for the following purposes:

Uses include general bit and flame soldering, sweated joints in plain, tinned and galvanized steel, **copper** and **copper alloys**, sheet metal work, **tankmaking**, and **capillary fittings for copper tube**. [p7, bold emphasis added]

Thus, the Australian Standard (AS 1834.1—1991) does not specifically exclude the use of 50Sn lead-bearing solder for applications in contact within drinking water.

Australian Standard AS/NZS 3500.1.2015 (clause 2.6.5) also stipulates that soft solders should not contain more than 0.1% lead by weight. Both AS 1834.1—1991 and AS/NZS 3500.1.2015 are referenced in the WaterMark Technical Specifications WMTS-014:2016 Jointing materials (Australian Building Codes Board 2016), which is the primary standard governing jointing materials.

Nevertheless, as a result of continued availability of high lead there remains potential for some manufacturers and installers to use it in drinking water systems including in Australia and other jurisdictions (Hayes and Hydes 2012, Hill 2014, Hodge 2017, Lodo, Dalglish et al. 2018). Its use has been linked to elevated blood lead levels in residents in newly constructed Scottish dwellings (Ramsay 2003).

3.2.4 Lead brass (and bronze) components

Leaded brasses and bronzes have been historically used in fittings for plumbing systems due to their relatively low production costs, strength, high level of corrosion resistance and pressure tightness. As lead is practically insoluble in solid copper it is present in the cast and wrought materials as discrete particles or phases primarily in the grain boundaries or inter-dendritic regions (Copper Development Association Inc 2017). These lead particles solidify last during the metal casting process in areas where micro-porosity is likely, sealing any porosity and resulting in increased pressure tightness.

Machinability of brass is also improved by lead addition, as it acts both as a tool chip breaker and tool lubricant allowing high production rates with carbon steel cutting tools, with minimal supplementary lubrication (Showman 1994, Morwood 2014). Table 2 gives a listing of brasses and bronzes classified under the UNS system, their common names, uses and lead content.

²⁰ Sn – tin.

²¹ Cu – copper.



Table 2. Common names, uses and lead content of brasses (and bronzes) designated under the Unified Numbering System (UNS) and used for plumbing fixtures and fittings (adapted from Standards Australia 2000, Maynard 2008, Copper Development Association Inc 2017).

UNS grade	Common or trade name	Uses	Nominal copper (%)	Nominal lead (%)	Lead range (%)
C32000	Leaded red brass	Fittings	84.9	1.8	1.5-2.2
C33000	Low leaded brass (Tube)	Plumbing accessories	66	0.5	0.25-0.7
C33200	High leaded brass (Tube)	Plumbing accessories	66	2.0	1.5-2.5
C34000	Medium leaded brass	Fittings	63.5	1.0	0.8-1.5
C34500	Medium leaded brass	Valve stems, fittings	63.5	2.0	1.5-2.5
C35000	Medium leaded brass	Meter parts, sink strainers	61.5	1.1	0.8-2.0
C35300	High leaded brass	Fittings, faucet stems, faucet seats	61.5	2.0	1.5-2.5
C35330	DZR leaded brass	Fittings	61.7	2.5	1.5-3.5
C35350	Leaded brass	Shafts for valves	61.7	3.2	2.0-4.5
C36000	Free-cutting brass	Fittings, faucet stems, faucet seats	61.4	3.1	2.5-3.7
C83600	Ounce metal	Faucets, fittings	84.3	5.0	4.0-6.0
C83800	Hydraulic bronze	Plumbing fixtures	83	6.0	5.0-7.0
C84200	Leaded semi-red brass	Tees, couplings, unions	79	2.5	2.0-3.0
C84400	Valve metal	Fittings	80.2	7.0	6.0-8.0
C84500	Leaded semi-red brass	Faucets, fittings	77.5	6.8	6.0-7.5
C84800	Plumbing goods brass	Faucets, fittings	75.1	6.8	5.5-7.0
C85200	Leaded yellow brass	Fittings	72	3.0	1.5-3.8
C85400	No. 1 yellow brass	Plumbing parts	67	3.0	1.5-3.8
C85700	Leaded yellow brass	Fittings, flanges	60.9	1.0	0.8-1.5
C86400	Manganese bronze	Fixtures	57.6	1.0	0.5-1.5
C87500	Cu-Si Alloy	Fixtures	81.8	0.0	0-0.5
C87800	Cast silicon bronze	Plumbing parts	81.6	0.0	0-0.9
C87850	Cu-Si Alloy	Faucets, fittings, water meter cases	75.8	0.0	0-0.1
C89510	SeBiLOY I (EnviroBrass I)	Lead-free plumbing parts	87	0.1	0-0.25
C89520	SeBiLOY II (EnviroBrass II)	Lead-free plumbing parts	86	0.1	0-0.25
C89530	Cu-Bi-Se Alloy	Lead-free plumbing parts	85	0.1	0-0.25
C89535	Cu-Bi Alloy	Lead-free plumbing parts	86.5	0.1	0-0.25
C89540	Cu-Zn-Bi Alloy	Plumbing castings	61	0.1	0-0.25
C89550	SeBiLOY III (EnviroBrass III)	Plumbing castings	61	0.1	0-0.25
C89836	Cu-Bi Alloy	Plumbing castings	88.2	0.1	0-0.25
C89844	Cu-Zn-Sn-Bi Alloy	Valves, fittings	84.2	0.0	0-0.20

Historically, the most commonly used leaded brasses for cast plumbing applications such as taps and fittings were UNS grades C83600 and C84400 containing respectively 4 – 6% lead and 6 – 8% lead



(Showman 1994). Modern low lead or lead free brass grades are continuing to evolve in response to regulations mandating lead content at the point of water consumption, maximum lead content in alloys used in plumbing components and consumer demand, see Figure 3 (NHMRC and NRMCC 2011, Morwood 2014).

Often these copper and zinc alloys contain bismuth, silicon or selenium additions, or combinations of these elements, in an endeavour to match the machining and casting characteristics displayed by the leaded brasses (Michels 2002, Maynard 2008, Sandvig, Triantafyllidou et al. 2009, Taha, El-Mahallawy et al. 2012). It should be noted that lead is not intentionally added to these lead free grades, but some lead content is inevitable due to recycling of historic material in the manufacturing process (Sandvig, Triantafyllidou et al. 2009).

There is significant evidence to demonstrate the potential for the lead in brass components in drinking water plumbing systems to leach over time into consumed water (Schock and Neff 1988, Kimbrough 2007, Maynard, Mast et al. 2008, Zhang 2009, Sarver and Edwards 2011, Triantafyllidou, Raetz et al. 2012, Harvey, Handley et al. 2016, Lees 2017).

All leaded brass plumbing components including; strainers, check valves, water meters, couplings, fittings, taps, drinking fountains, bubblers, water coolers could be potential lead sources dependent on lead content and water chemistry (Schock and Neff 1988, Dudi, Schock et al. 2005, Maynard, Mast et al. 2008, Elfland, Scardina et al. 2010, Sarver and Edwards 2011, Triantafyllidou, Raetz et al. 2012, Lees 2017). Low lead or lead free plumbing components contribute lead at significantly reduced amounts to drinking water systems when installed (Sandvig, Triantafyllidou et al. 2009).

3.2.5 Other lead sources in drinking water

In Australia, given the widespread use of collected rainwater (Chubaka, Whiley et al. 2018) the use of lead in materials for these systems should also be considered as potential sources of contamination. These sources include inappropriate use of lead solder in rainwater tanks,²² lead roof flashing and roofing and guttering manufactured from galvanised or soldered components containing lead (O'Connor, Mitchell et al. 2009, Magyar, Ladson et al. 2014, Lodo, Dalglish et al. 2018).

Galvanised steel plumbing infrastructure has lead present along with the zinc of galvanising coatings and this can leach into drinking water supplies (Sandvig, Kwan et al. 2008, Clark, Masters et al. 2015). Formation of stable iron oxide/lead phases also occurs as these steel piped systems age, accumulating lead from other sources, these lead phases are vulnerable to dislodgement during renovation or renewal of plumbing systems, at which time they can increase lead at the point of consumption (Kim and Herrera 2010, Schock, Cantor et al. 2014, Wasserstrom 2014, Masters and Edwards 2015, Trueman and Gagnon 2016).

Findings with supporting facts

Findings: Question 1 – the potential sources of lead in plumbing products / materials

1. The Australian and international research literature shows that brass components containing lead that are used in water supply and plumbing systems can leach lead into drinking water.

²² ABC 2013. What's in your rainwater tank? Lead contamination concerns in Tasmania. Available at: <http://www.abc.net.au/local/stories/2013/03/19/3718976.htm> (accessed 14 May 2018).



- 2. Where lead service pipes are present they contribute an estimated 50-75% of lead contamination in drinking water collected at the faucet (tap) in homes.**

Although lead service lines appear to have been used little in Australia, their use along with lead goosenecks are known significant sources of lead contamination in drinking water.

- 3. There is potential for confusion in regard to the required use of lead-free solder in systems that may be used in contact with drinking water systems.**

Although the Australian Standard AS 1834.1—1991 states that lead-free solder is to be used in conjunction with drinking water plumbing systems, the same standard does not specifically exclude the use of 50Sn (which comprises 50% tin, 50% lead) for applications in contact with drinking water, including tankmaking.

Recommendations with reasons

Recommendations: Question 1 – the potential sources of lead in plumbing products / materials

- 1. In order to limit the release of lead into drinking water, consideration should be given to recommending that only low lead or preferably lead-free²³ plumbing components should be used during installation of drinking water systems.**

The evidence from the literature review shows that plumbing fittings and materials including strainers, check valves, water meters, couplings, fittings, taps, drinking fountains, bubblers, water coolers are potential sources of lead. If there is no or very low lead in these fittings the issues of lead-contaminated drinking water from these sources would be resolved.

- 2. Water supply authorities in all Australian states should be contacted to confirm the extent of lead water piping still remaining in use.**

Establishing the extent of the use of lead pipes or goosenecks in water supply networks is a critical first step in eliminating this known source of contamination before water reaches the tap.

- 3. Australian Standard AS 1834.1—1991- Material for soldering: Part 1 Solder Alloys should be amended to explicitly ban the use of solders containing lead in all drinking water systems.**

Clarifying that only lead-free solders should be used in conjunction with all drinking water systems their related plumbing fittings and materials would remove any ambiguity in the interpretation of the relevant standards.

²³ The Review notes that it does not support the use of the term 'lead-free' as applied in the USA, which permits its use when the lead in brass is < 0.25%wt, calculated across the wetted surfaces of a pipe, pipe fitting, plumbing fitting, and fixture. The Review considers a more accurate term would be low lead. 'Lead-free' should be used only where this is actually the case. However, it accepts that a maximum upper limit would need to apply because lead may be present in minute amounts, significantly below any levels likely to cause harm.



3.3 Question 2 – The effect of water chemistry, quality and temperature on plumbing products/materials and Question 4: The interaction of different products / materials within a water service

The Endnote® database was interrogated for the terms “water chemistry”, “quality” and “temperature”. The response to Questions 2 and 4 were combined to improve readability as the overlap of information outcomes would have resulted in a high degree of unnecessary repetition.

Rates of dissolution of lead from plumbing products and materials into water prior to consumption are mitigated by a complex series of electrochemical, geochemical, and hydraulic interactions at the lead / water interface, where ionic composition, pH and temperature, stagnation time and degree of surface passivation can all influence water quality at a consumer’s tap (Schock 1989, Schock 1990, Lytle and Schock 2000, Lytle and Schock 2005, Schock, Cantor et al. 2014). Many of these factors can be influenced by water supply authorities by additions of agents to the water system such as phosphates and orthophosphates,²⁴ chlorides/chloramines (for disinfection), acidifying and alkaline agents to manipulate pH.

3.3.1 pH and alkalinity

Although there is no health based guidance for pH in water, supply authorities generally increase alkalinity and maintain pH slightly higher than neutral to inhibit system corrosion and maintain stability (WHO 2003). Water delivery authorities have to balance corrosion control in their own delivery systems (concrete, iron) with corrosion in the private infrastructure to which they supply which may be of different construction (copper, brass). As a result, these two needs may be in conflict (Edwards 2004). The Australian Drinking Water Guidelines state drinking water should have a pH of between 6.5 and 8.5.²⁵ The following reasons are provided:

One of the major objectives in controlling pH is to minimise corrosion and encrustation in pipes and fittings. Corrosion can be reduced by the formation of a protective layer of calcium carbonate on the inside of the pipe or fitting, and the formation of this layer is affected by pH, temperature, the availability of calcium (hardness) and carbon dioxide.
(NHMRC, NRMMC 2011, p.843)

Soft water supplies (containing low levels of ions, particularly calcium and magnesium and usually low pH) are known to exacerbate lead release from plumbing systems (Moore 1977). By contrast, increases in pH from neutral (7.0) to around 8.0 have been shown to decrease lead release (Raab, Laxen et al. 1993, Ng and Lin 2016). Abrupt changes in water pH and alkalinity may exacerbate lead release from existing plumbing systems. This occurs because historically deposited lead contained in pipe scale (the result of surface passivation) are often sensitive to pH and alkalinity changes, which alters the conditions under which they were formed and can result in the release of significant amounts of lead (Kim, Herrera et al. 2011).

3.3.2 Chlorine and chloramine

Chlorine and more recently chloramines have been commonly added to water supply systems for disinfection control of bacteria and viruses (NHMRC and NRMMC 2011). Both additives result in changes to water chemistry and may alter lead uptake from the pipe, fixtures and solder of plumbing

²⁴ This international research concurs with the findings of the study by the ChemCentre (Western Australia) who examined the potential value of using orthophosphate to passivate lead containing surfaces in plumbing fittings and material associated with the Perth Children’s hospital: McCafferty, P. (2017). An assessment of lead leaching from brass following orthophosphate treatment. Perth, WA, Chem Centre. Available at: http://www.newchildrenshospitalproject.health.wa.gov.au/Libraries/Documents_03052017/ChemCentre_Report.sflb.ashx (accessed 6 February 2018).

²⁵ The Review notes that AS/NZS 4020:2005 ‘Testing of products for use in contact with drinking water’ does not stipulate the pH of water to be used in testing regimes.



systems (Lin, Torrents et al. 1997, Cantor, Park et al. 2003, Edwards and Dudi 2004, Vasquez, Heaviside et al. 2005, Woszczynski, Bergese et al. 2013).

While the use of chloramine has the beneficial effect of suppressing the production of undesirable disinfection by-products and increases in longevity for residual chlorine (WHO 2004), it can also result in significant increases in lead release in vulnerable systems (Dudi 2004, Edwards and Dudi 2004, Vasquez, Heaviside et al. 2005, Switzer, Rajasekharan et al. 2006, Rizzuti and Rogers 2010). Of particular interest is research that has shown the presence of chloramine can result in selective leaching of lead in brass even though the overall corrosion of the brass fittings was reduced in the presence of chloramine (Edwards and Dudi 2004, Edwards, Marshall et al. 2005). This selective leaching can result in brass failure and pinhole leaks with potentially large economic consequences (Edwards, Marshall et al. 2005).

The result of chloramine introduction or continued use may be to require additional water treatment such as the phosphatic additions to increase lead passivation at the surface and to reduce overall lead leach rates (Holm and Schock 1991, Edwards and McNeill 2002, Ng, Strathmann et al. 2012, Wasserstrom 2014, McCafferty 2017). The type of phosphatic addition needs to be carefully selected and monitored as inappropriate additional levels (or choice of additive) can result in increased rather than decreased lead release (Edwards and McNeill 2002) and may need to be adjusted (developed) following pilot plant testing (Schock 1989).

3.3.3 Chloride to sulfate mass ratio

Triantafyllidou (2006) and others (Edwards and Triantafyllidou 2007, Nguyen, Stone et al. 2011, Ng and Lin 2016) have demonstrated that leaching of lead from 50:50 soldered joints and leaded brass fitting can be markedly increased by higher chlorine/sulfate mass ratios ($[Cl]/[SO_4]^{-2}$; CSMR) in contacting water. The mechanism for solder is galvanic corrosion via sacrifice of the lead solder, interestingly, galvanic connection of brass to copper results in decreases in lead release.

Treatments using phosphatic additions have been used to mitigate lead leaching and orthophosphate additions were the most effective treatment for solders and zinc orthophosphate for galvanic brass (Triantafyllidou 2006, Edwards and Triantafyllidou 2007). Abrupt changes in CSMR in water systems, such as by a change from sulfate coagulant to one containing chloride, can result in significant lead releases, as the previously passivated system adjusts to the changed equilibrium of the “new” water chemistry (Edwards and Triantafyllidou 2007).

3.3.4 Temperature and flowrate

Lead release from high-zinc, un-inhibited brass alloy plumbing components exposed to aggressive (chlorinated) water chemistries has been shown to increase when subjected to hotwater and increased flowrates.

In the case of hotwater this appears to be the result of increased selective leaching of lead rather than increases in total metal leaching or increased solubility (Sarver and Edwards 2011). These limited results confirmed the work of McCafferty (1995) who found high levels of lead in 67% of hot drinking water dispensers studied in Perth, but not the earlier work of others who tested a series of complex brass alloys and found no effect for hot water (Paige and Covino Jr. 1992). At increased flow velocity it is suggested that a small overall uniformly increased corrosion of fittings occurs as a result of increased delivery of oxidant to the cathodic surface (Sarver and Edwards 2011).

Findings with supporting facts

Findings: Question 2 – the effect of water chemistry, quality and temperature on plumbing products/materials and Question 4: The interaction of different products / materials within a water service

- 4. The international research literature shows that multiple factors influence the passivation and release of lead from plumbing products and materials into drinking water.**

Factors influencing the leaching of lead from plumbing fittings and materials arises from different pH, chemical composition of the water, galvanic reactions, temperature, disinfection treatment types and flow rates.

Recommendations with reasons

Recommendations: Question 2 – the effect of water chemistry, quality and temperature on plumbing products/materials and Question 4: The interaction of different products / materials within a water service

- 4. In order to more realistically determine the risk of lead leaching from plumbing products and materials it may be necessary to revise the existing test protocols detailed in AS/NZS 4020:2005 – Testing of products for use in contact with drinking water.**

The current requirements set out AS/NZS 4020:2005 in relation to either Metal Extracts (Appendix H) or Extraction Procedures for End-of Line Fittings (Appendix I) does not include a sufficient range of variables that may influence the leaching of lead from plumbing fittings and materials. As a result any tests pursuant to this existing standard may not represent 'real-world' situations.

For example, test water pH values should reflect the composition of natural drinking waters consumed by all Australians. Test pH values used should exceed those specified in the Australian Drinking Water Standards (as referred to in C5.1.1 in AS/NZ 4020:2005). This is because of the potential effects that may arise from corrosivity and leaching actions on plumbing materials and fittings from pH values outside of the range specified for drinking water in the Australian Drinking Water Guidelines at 6.5 to 8.5.



3.4. Question 3 – The cumulative effect of multiple products/materials in a water service

The Endnote® database was interrogated for articles that described information in relation to “cumulative” effects of different plumbing components on lead in end of pipe water. These components might include systems and their components managed by water supply authorities as well as those owned by domestic water consumers i.e. within a residential lot.

Sandvig, Kwan et al. (2008) provide an excellent summary of the sources of lead in the supply system and the factors affecting lead uptake from those sources. This summary is presented in Table 3.

Table 3. Factors affecting uptake of lead from components of the water supply system. Table from Sandvig, Kwan et al. (2008).

Lead Source	Factor Affecting Uptake of Lead from This Source
Lead Service Line	<ul style="list-style-type: none"> Length and diameter of the lead service line (longer lengths and/or smaller diameters may result in higher lead levels) Water quality conditions Water use and hydraulic patterns Disturbance from replacement (short term)
Meter	<ul style="list-style-type: none"> Volume of water contained in meter, and surface area of meter exposed Water quality conditions Water use and hydraulic patterns
Premise	<ul style="list-style-type: none"> Lead solder: <ul style="list-style-type: none"> Number of joints Age of the solder Workmanship of the soldering Surface area of soldered joints exposed to water Water quality conditions Water use and hydraulic patterns Galvanized pipe: <ul style="list-style-type: none"> Length and diameter of piping Surface area exposed to water Water quality conditions Presence of lead service Disturbance from replacement of lead service
Faucet	<ul style="list-style-type: none"> Surface area of faucet exposed to water Physical configuration of the faucet Manufacturing process Water quality conditions Flow conditions Lead from presence of lead service, seeding and uptake of lead from scales

Measurements of the contribution of lead from the various sources in the water supply system before and after lead-free replacement of taps (faucets) are shown in Table 4. These data show that most of the lead is contributed before the tap (faucet) by service and premise piping from the mains.²⁶

²⁶ Harvey et al.'s (2015) study of water supply systems in north-east Tasmania showed that lead in the local drinking water was sourced from a combination of drinking water infrastructure, including lead jointed pipelines, end-of-life polyvinyl chloride pipes and household plumbing.



Of particular interest in the Sandvig, Kwan et al. (2008) study is the system (H1, Table 4), which included copper service piping from the mains (more common in Australia). In this system the contribution from the taps (faucets) are higher as a percentage before replacement (35% *cf.* 5-9% for lead and lead / copper service pipes) than after replacement (12% *cf.* 12-15%). What should be emphasised from Table 4 is that the overall mass concentration of lead in the first litre of dispensed tap water for the H1 copper piped system is 3-9 times lower than that in systems supplied with lead or lead /copper service pipes.

Table 4. Comparison of mass and relative percent contributions of tap (faucet) and premise piping to first-litre lead levels before and after replacement with 'lead-free' taps. Table from Sandvig, Kwan et al. (2008).

Site	Service line material	Faucet (first 125 mL)		Premise (second 875 mL)	
		Mass of lead (µg)	Relative % contribution to first-litre lead mass	Mass of lead (µg)	Relative % contribution to first-litre lead mass
F-1					
Before	Pb/Cu service	0.5	5%	10.1	95%
1 month after	Pb/Cu service	1.6	15%	8.8	85%
F-2					
Before	Pb service	2.4	9%	23.4	91%
1 month after	Pb service	3.7	12%	28.2	88%
H-1					
Before	Cu service	0.75	35%	1.4	65%
1 month after	Cu service	0.38	12%	2.9	88%

3.4.1 Galvanic Interactions

The potential for enhanced corrosion and increased lead release caused by the galvanic interaction of different metal components (iron/copper/lead) in water delivery systems is well documented (see Figure 5; Gregory 1990, Dudi 2004, Arnold Jr 2011, Nguyen, Clark et al. 2011, Triantafyllidou 2011, Clark, Cartier et al. 2013, DeSantis, Triantafyllidou et al. 2018).

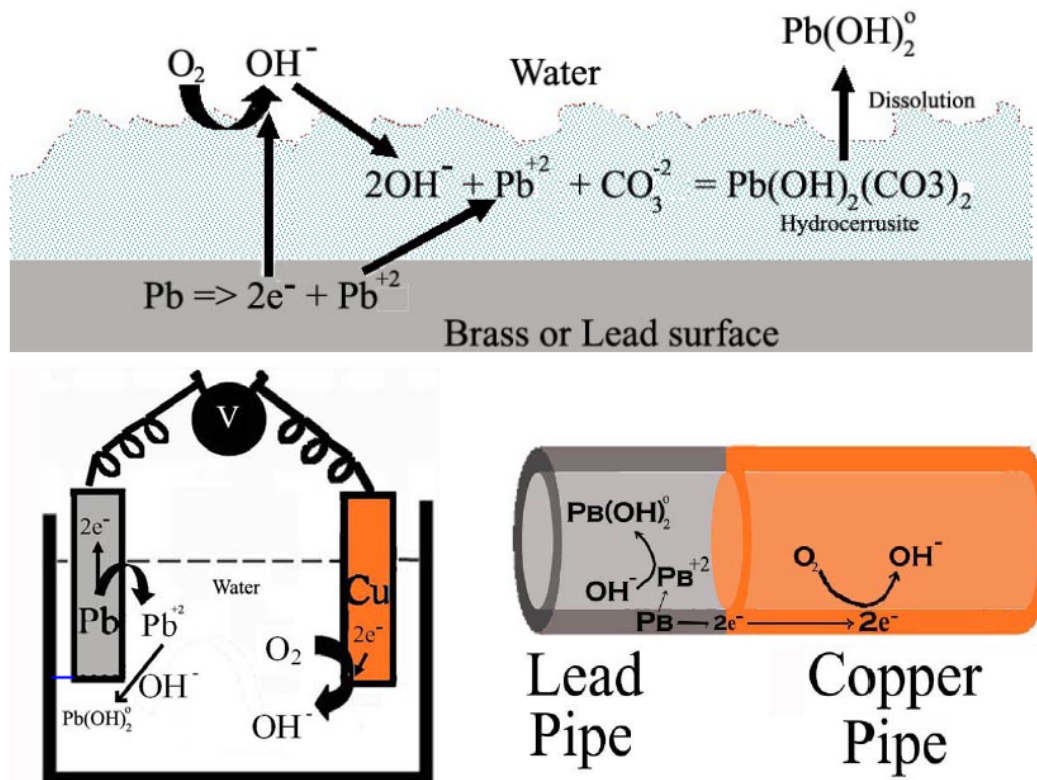


Figure 5. For corrosion of pure lead pipe, anodic reactions (lead corrosion) and cathodic reactions (e.g. dissolved oxygen reduction) occur in close proximity over the pipe surface (top), resulting in either no change or an increase in water pH. Galvanic corrosion driven by coupled lead and copper separates anodic and cathodic reactions, accelerating the corrosion of the lead, dropping pH near the lead surface and increasing pH near the copper surface (bottom). Diagram from Triantafyllidou (2006).

3.4.2 Lead / copper piping systems

In particular, it has been shown definitively that partial replacement of lead service pipes with copper piping between the premise boundary and the water mains results in increased lead at the point of consumption in the short term and may not provide any long term benefit in terms of lead reduction (Triantafyllidou and Edwards 2010, DeSantis, Triantafyllidou et al. 2018).

Lead in water concentration increases following partial replacement are attributed to both disturbance of existing high lead corrosion/passivation scales (Sandvig, Kwan et al. 2008) and lead release being maintained by galvanic interaction between the lead/copper piping systems (Hu, Gan et al. 2012, Clark, Cartier et al. 2013, St Clair, Cartier et al. 2016).

3.4.3 Copper piping / brass systems

Galvanic reaction between copper piping and screwed brass fittings should not occur (Triantafyllidou 2006). However, at joints when lead soldered brass joints are used galvanic reactions between the lead solder and copper pipe can occur resulting in the release of lead into drinking water supplies (Gregory 1990, Triantafyllidou 2006, Nguyen, Stone et al. 2010).

3.4.4 Case Study – University of North Carolina

Elfland, Scardina et al. (2010) document an interesting case of lead release from corrosion of brass fittings in a new building installation at the University of North Carolina during February-March 2007,



where very high lead in water levels at taps were measured post-construction (several >100 µg/L and one 1120 µg/L). Prior to building occupation the plumbing had been flushed to remove construction debris, hyperchlorinated (200 mg/L) and then flushed again. Supplied water had low levels of lead (<1 µg/L) and there was no indication that other lead sources (such as solder containing lead) were the cause of elevated lead levels.

Elfland, Scardina et al. (2010) concluded that lead leaching problems were worst when: (1) drinking water is moderately corrosive to brass; (2) the leaded brass has a high lead level on its surfaces; and (3) the premise plumbing lines have relatively low water demand and high water age. The lead levels were reduced to acceptable levels by implementing a commissioning protocol which involved fine-tuning the corrosion control strategy of phosphatic additions and implementing 1-3 days of remedial flushing to condition the in-line brass fittings and fixtures; identification and removal of high-lead brass devices and high-lead particles trapped in strainer mesh. Without these latter source removals the authors suggested that the high lead levels could have persisted for years.

Findings with supporting facts

Findings: Question 3 – the cumulative effect of multiple products/materials in a water service

- 5. Where water service lines are made of copper, replacement of standard brass-lead taps with 'lead-free' taps results in a relative percentage reduction in the mass of lead delivered in the first litre of dispensed water. However, the use of 'lead-free' taps may not totally eliminate the presence of lead in dispensed water.**

While the most significant contributions of lead to drinking water arise where lead is used in service lines (see Finding 2), further additions of lead to water also occur at the tap, which can be reduced by replacement of plumbing and fitting materials with lead-free alternatives.

- 6. Galvanic reactions may occur along the length of the pipeline as well as in locations where lead solder has been used on copper pipe – brass fitting joints.**

Galvanic reactions can result in the release of lead (and other metal contaminants) into drinking water supplies. In addition, where drinking water is moderately corrosive to brass fittings, any lead present in that fitting is subject to leaching and could contaminate drinking water.

- 7. Remedial treatment of plumbing systems experiencing persistent problems associated with elevated levels of lead can be achieved via the implementation of a range of physical and chemical strategies.**

Intervention strategies that have been shown to reduce lead in water at the tap include flushing to condition (passivate) lead-rich surfaces, removal of in-line and end-of-line brass-lead fittings and fixtures, and the removal of high-lead particles trapped in strainer mesh. The addition of phosphate compounds²⁷ can also reduce the leaching of lead from plumbing fittings and materials. With the exception of the replacement of brass-lead fittings, the other strategies require on-going application to ensure lead does not re-contaminate drinking water.

²⁷ The international literature examining the efficacy of phosphatic compounds to mitigate the leaching of lead from plumbing products and materials corresponds with the findings of McCafferty (2017) who examined the use of orthophosphate as suitable way of treating brass fittings *in situ* at the Perth Children's Hospital, Western Australia.

Recommendations with reasons

Recommendations: Question 3 – the cumulative effect of multiple products/materials in a water service

- 5. Notwithstanding the finding that lead can contaminate drinking water from both mains and premise piping, replacement of the tap with a 'lead free' alternative reduces the potential burden of lead at the point of delivery.**

The use and fitting of lead-free plumbing products and materials, which are available for purchase, will contribute to reductions of lead to drinking water at the point of consumption.

- 6. Where practical, in and end-of-line fittings should be replaced with lead free options.²⁸**

Permanent replacement of in-line and end-of-line brass-lead fittings with lead-free alternatives eliminates the requirement to conduct repeated application of non-permanent management strategies to ensure that lead does not re-contaminate drinking water.

Moreover, if there is no lead present associated with in-line and end-of-line fittings any lead contamination issues cannot be attributed to these plumbing materials and products. This would help resolve issues related to drinking water being contaminated at the point of delivery.

²⁸ The Review notes that the replacement of brass-lead fittings that are used in association with the delivery of drinking water in public spaces or those associated with sensitive populations, such as children, should be a priority target for any such replacement strategy.



3.5 Question 5 – Consideration of product Standards (not just AS/NZS 4020:2005), hydraulic effects on materials and how products are currently tested

In order to address Question 5 an examination of the relevant standards was supplemented by examination of commentary on other relevant standards identified during the literature search process.

This question was addressed in three parts:

- (a) a brief review of existing relevant standards from Australia, USA and Europe
- (b) an assessment of whether the standards consider hydraulic effects on the liberation of lead from allowable materials used in plumbing fittings
- (c) whether current standards for testing the liberation of lead incorporate hydraulic effects.

3.5.1 A brief review of existing relevant standards from Australia, USA and Europe

Tables 5, 6 and 7 summarise the testing regimes contained within the relevant Australian, USA and European standards for the assessment of leaching and liberation of lead from plumbing components.

The tables provide a comparison of Australian Standard 4020:2005, USA standard NSF/ANSI 61-2016 and EU standard (EN 15664-1 and EN 15664-2). The Review provides discussion of the EU's approach to the assessment of leaching and liberation of lead from plumbing components.

**Table 5.** Summary of the AS/NZ Standard 4020:2005, Testing of products for use in contact with drinking water.

Test Authority	Product	Test Procedure	Test water	Lead compliance
AS/NZS 4020:2005 Appendix H–Extraction of Metals—for products in contact with drinking water	In-line Products not installed within 250 mL draw-off point. Includes pipes, fittings for metals making up more 30% of wetted area.	Static exposure, of wetted area to test water, over 24 hrs, can be hot and/or cold or both. Can be in-product or emersion exposure as appropriate.	Drinking quality ¹ , prepared from distilled or de-ionised water with hardness of 50 mg/L (as calcium carbonate). Can be either chlorine- free or chlorinated ² (1 mg/L).	0.01 mg/L
AS/NZS 4020:2005 Appendix I–Extraction procedures for end-of- line fittings	End-of-line Any product, or part of a product, installed within 250 mL draw-off of a drinking water delivery point. May include taps, tap components, fittings, flexible tubes, drink dispensers, boiling water dispensers, drinking fountains, water treatment appliances, hose- connection vacuum breakers, ball- valves and flow control valves	Static exposure, of wetted area to test water, over 24 hrs, can be hot and/or cold or both. Can be in-product or emersion exposure as appropriate.	Drinking quality, prepared from distilled or de-ionised water with hardness of 50 mg/L (as calcium carbonate). Can be either chlorine-free or chlorinated (1 mg/L)	0.01 mg/L

¹ No specific specification, but if was to be drinking water quality then water of the ADWG Guideline value for pH of 6.5-8.5 could be used (NHMRC and NRMCC 2011).

² There is a specific note in the section on test water preparation (Section C5.1.3) that '*chloraminated water has been tested and has no effect on results* [including the leaching of lead] (Standards Australia/Standards New Zealand 1995). This appears contrary to many of the findings presented in the research literature on the changes that chloramines can have on the release of lead (see for example, Edwards and Dudi 2004, Edwards, Marshall et al. 2005, Vasquez, Heaviside et al. 2005, Switzer, Rajasekharan et al. 2006, Miranda, Kim et al. 2007, Rizzuti and Rogers 2010, Woszczynski, Bergese et al. 2013).

Comment: The test procedure appears benign to the product being tested and does not subject them to what might occur with “aggressive” waters (see in particular Chapter 2 in Triantafyllidou (2006).



Table 6. Summary USA standard for drinking water systems (NSF/ANSI 61-2016, Drinking Water System Components – Health Effects).²⁹

Test Authority	Product	Test Procedure	Test water	Lead compliance
NSF/ANSI 61-2016 Drinking Water Components–Health Effects Section 8 – Mechanical Devices (NSF/ANSI 2016).	In-line Products used in treatment/transmission system in contact with drinking water intended for human consumption. Not for point-of-use devices and includes pipes, fittings.	Static exposure of wetted area to test water, over 24 hours, after 14 days conditioning in test water.	Water pH8 prepared from distilled or de-ionised water with hardness of 500 mg/L (as calcium carbonate), plus inorganic carbon 122 mg/L and chlorinated (2 mg/L).	0.005 mg/L normalised to use.
NSF/ANSI 61-2016 Drinking Water Components–Health Effects Section 9 – Mechanical plumbing ¹ (NSF/ANSI 2016).	End-of-line Any product, or part of a product, installed within 1L draw-off of a drinking water delivery point intended for human consumption. May include taps, tap components, fittings, flexible tubes, drink dispensers, boiling water dispensers, drinking fountains, water treatment appliances, hose-connection vacuum breakers, ball-valves and flow control valves.	Static exposure of wetted area to test water, over 24 hrs, after ≤19 days conditioning in test water. Can be in- product or emersion exposure as appropriate.	Water pH8 prepared from distilled or de-ionised water with hardness of 500 mg/L (as calcium carbonate), plus inorganic carbon 122 mg/L and chlorinated (2 mg/L).	0.005 mg/L normalised to 1L (this was lowered from 0.015 mg/L in July 2012) (Estelle 2016).

¹ Certification to NSF 372 is required to demonstrate compliance with a 0.25% lead content maximum for wetted surfaces from January 4, 2014.

² Contains specific restriction against the intentional use of lead containing materials (Section 3.5) – brass, bronze and solders all to be “lead free” from January 4, 2014.

²⁹ NSF International Standard / American National Standard 2016. Drinking Water System Components – Health Effects. Available at: https://www.nsf.org/newsroom_pdf/NSF-ANSI_61_watermarked.pdf (accessed 27 April 2018).



European Union (EN 15664 Parts 1 and 2)

Estelle (2016) describes the present situation with development of a testing standards for water supply components in the European Union as:

Pursuant to the [European Union] DWD [Drinking Water Directive], work began to establish a single European scheme for the hygienic assessment of materials in contact with drinking water known as the European Acceptance Scheme. However, the Scheme lost support from the European Commission in 2006 and the effort was subsequently taken up by a dedicated group of four member states (France, Germany, the Netherlands and the United Kingdom) known as the 4MS (Portugal later joined the 4MS in 2014). Due to the vast amount of materials used in drinking water systems, each member of the 4MS was assigned responsibility for a subgroup of materials. Germany assumed responsibility for metallic materials, France for cementitious materials, the Netherlands for organics and the United Kingdom for other materials. For metals, the 4MS developed a 'Common Approach' that established a procedure for acceptance and a common composition list of metals that are suitable for contact with drinking water. Eventually, the intent is for the 4MS approach for metals to be accepted throughout the E.U., but the timeline for implementation in other member states is not clear.

Dynamic testing beyond six months is described in EN 15664-1 and the three water types used for testing in EN 15664-2:

To determine the suitability of metallic materials, the results of a long-term 'rig-test' outlined in European standard EN 15664 Parts 1 and 2 are evaluated and assessed in accordance with a separate standard, DIN 50930 Part 6, developed by the German standardisation body (Deutsches Institut für Normung). 42–44 Part 1 of the EN standard describes **test procedures which simulate the consumption behaviour of a four person household**. Part 2 defines three different natural water qualities used in the test to represent the broad range of waters distributed in E.U. countries. The final step is to interpret the data produced by EN 15664 using the DIN standard as a basis for assessment. DIN 50930 Part 6 is the standard used to determine if leached levels of lead and other elements (e.g. Cu, As, Ni) meet the 4MS acceptance criteria adapted from the parametric values established in the DWD. **For lead, the 4MS compliance level is 5 µg/L**, which is 50% lower than the maximum limit set by the DWD. From a compliance perspective, the German Federal Environmental Agency (Umweltbundesamt (UBA)) is responsible for ensuring that metals in contact with drinking water meet the legislative and regulatory requirements mutually accepted by the 4MS.

Table 7. Summary of EN 15664 Parts 1 and 2.

Test Authority	Product	Test Procedure	Test water	Lead compliance
European Union (EN 15664 Parts 1 & 2).	Pipe or cylindrical test pieces representative of a plumbing construction material.	Dynamic exposure , samples are exposed to a 5 L/min flow of the test water. The test is based on alternating periods of once through flow and stagnation, simulating the conditions of a domestic drinking water distribution system. Tests take place over 6 month period.	Three water types for testing reference materials: (i) very hard, neutral; (ii) soft, weakly acidic; (iii) soft, alkaline. In addition alternative local waters sources can be used for: (a) comparative testing; and (b) interaction of a local water with materials.	Results evaluated according DIN 50930 Part 6, for lead this requires Pb < 5 µg/L ; (see comments from Estelle 2016, above).



Assessment is based on an assumed contact surface area for metallic materials shown in Table 8) (after Estelle 2016).

Table 8. Product groups for metallic materials – EN 15664-1.

Product Group	Examples of products of parts of products	Assumed contact surface “a”
A	Pipes in buildings installation. Uncoated pipelines in water supply systems.	100%
B	Fittings, ancillaries in buildings installations (e.g. pump bodies, valve bodies, water meter bodies used in buildings installations).	10%
C	1. Components of products of product group B (e.g. the spindle of a pump or the moving parts in water meter in building installations). The sum of the surfaces in contact with drinking water of all of these components has to be less than 10% of the total wetted surface of the product. 2. Fitting, ancillaries in water mains and water treatment works with permanent flow (e.g. pump bodies, valve bodies used in water supply systems).	1%
D	Components of fittings and ancillaries in water mains and in water treatment works (C2).	—

3.5.2 Assessment of whether the standards consider hydraulic effects on the liberation of Lead from allowable materials used in plumbing fittings

Neither the Australian or American standards make any attempt at simulating any hydraulic effects as both test in static systems (Standards Australia/Standards New Zealand 1995, NSF/ANSI 2016). The Europeans (including UK) have however adopted a dynamic approach using a German designed test rig through which the test waters flow for extended periods of 6 months or more (4MS Joint Management Committee 2016), other countries Japan, Canada use variations of American Standard for certification (Estelle 2016).

3.5.3 Do current standards for testing the liberation of lead incorporate hydraulic effects

Only in the case of the European standard (EN 15664-1 and EN 15664-2) is there any attempt at simulating the dynamic piping environment. The European approach described in EN 15664 (4MS Joint Management Committee 2016) results in the licencing of materials (rather than particular plumbing fittings or appliances), these materials can then be used for the construction of appropriate plumbing components without the necessity for further ongoing testing of individual items.

Findings with supporting facts

Findings: Question 5 – consideration of product Standards (not just AS/NZS 4020:2005), hydraulic effects on materials and how products are currently tested

- 8. The use of chloramine to disinfect water can result in the release of lead into drinking water systems.**

Notwithstanding the disinfectant benefits of using chloramine in drinking water supplies, the use of chloramine in water in Australia and its impact on the leaching of lead needs to be re-evaluated. This work is required because the international research literature is contrary to the statement in AS/NZS 4020:2005 at section C5.1.3 that states: 'Chloraminated water has been tested and found to have no effect on results'.

- 9. Contrary to the approach used in Europe, there is no requirement in the Australian Standards to test for changes in hydraulic flows on the potential release of lead into drinking water systems.**

The European standard, EN 15664 (Parts 1 and 2), requires dynamic flow testing of waters for extended periods of 6 months or more to simulate the conditions in a domestic distribution system.

- 10. The European approach described in EN-15664 (Parts 1 and 2) results in the licencing of materials. This approach permits licenced materials to be used for the construction of appropriate plumbing components without the necessity for further ongoing testing of individual items.**

Recommendations with reasons

Recommendations: Question 5 – consideration of product Standards (not just AS/NZS 4020:2005), hydraulic effects on materials and how products are currently tested

- 7. Review the use of chloramines in drinking water supplies in Australia and undertake new testing to determine its effect on the leaching of lead from plumbing fittings and materials under Australian conditions.**
- 8. Consider adding hydraulic testing as part of the standard approach to testing appliances pursuant to the requirements of AS/NZS 4020:2005.**

Inclusion of hydraulic testing as part of product or material testing would more clearly determine the likely outcomes associated with the normal use of plumbing products and materials. This would eliminate uncertainty about product performance over a longer period of time.



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- 9. Consider whether adopting the approach of licencing materials as detailed in EN-15664 (Parts 1 and 2) would be more advantageous to Australian manufacturers of plumbing fittings and components than the existing arrangements that relies on product certification.**

The licencing of materials could be one of the means of ensuring compliance via the WaterMark Certification Scheme, in addition to other product compliance testing.

3.6 Question 6 – Assessment of hydraulic design features in relevant standards on lead released from plumbing materials

The search terms used to compile information relevant to Question 6 were “Hydraulic design” AND “Water supply design” AND “Lead/Pb”. However, there was no specific response to the literature search using the specified terms. Nevertheless, particular guidance on Question 6 is available from the Case study at University of North Carolina (UNC), which is described in the answer to Question 3.

The UNC case study showed that the following situations should be avoided:

- (a) Water aging-cumulative changes in chemical and biological properties are associated with higher "water age" in distribution systems. This may, in some cases, negatively impact water corrosivity and regulatory compliance for metals take up resulting in elevated lead and copper levels (Masters, Parks et al. 2015).
- (b) The UNC study also suggested high lead levels occurred in new premises when the plumbing lines had relatively low demand and high water age (Elfland, Scardina et al. 2010).

Findings with supporting facts

Findings: Question 6 – assessment of hydraulic design features in relevant standards on lead released from plumbing materials

11. Lead contamination of drinking water from plumbing products and materials can also be influenced by:

- (a) its age – the length of time water has remained unflushed in pipes (water age)
- (b) demand – relatively low use (which can be caused by dead ends in plumbing systems) can result in increased retention time and greater opportunity for corrosive activity and the leaching of lead from in-line and end-of-line fittings to occur.

Recommendations with reasons

Recommendations: Question 6 – assessment of hydraulic design features in relevant standards on lead released from plumbing materials

10. Consider whether there is need for formal guidelines relating to the flushing of water service lines where there is or has been:

- (a) low water demand
- (b) standing water in services lines for extended periods, such as at schools following vacation periods.

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Appendix A – List of abbreviations

Term	Abbreviation
Accredited WaterMark Conformity Assessment Bodies	WMCAB
Australian Building Codes Board	ABCB
Australian Standard / New Zealand Standard	AS/NZS
bismuth	Bi
Building Code of Australia	BCA
copper	Cu
European Union	EU
International Association of Plumbing and Mechanical Officials	IAPMO
lead	Pb
National Association of Testing Authorities, Australia	NATA
National Construction Code	NCC
Plumbing Code of Australia	PCA
Plumbing Products Industry Group	PPI Group
selenium	Se
silicon	Si
tin	Sn
zinc	Zn

Appendix B – Annotated bibliography

4MS Joint Management Committee (2016). Acceptance of metallic materials used for products in contact with drinking water: 4MS Common Approach; Part A – Procedure for the acceptance Part B – 4MS Common Composition List-2nd Revision: 07.03.2016 Bundesministerium für Gesundheit (Deutschland).

Council Directive 98/83/EC on the Quality of Water Intended for Human Consumption (DWD) establishes a high level of protection for the consumer and requires Member States to ensure that substances and materials used in preparation and distribution of drinking water do not reduce that level of protection. The Directive's point of compliance is at consumers' taps. This implies a need for control of all products in contact with drinking water (PDW), including pipes and fittings within consumers' premises. Most of the metals used in metallic PDW are controlled as parameters by the DWD.

Monitoring carried out by Member States provides evidence that metallic pipes and fittings can increase concentrations of metals in drinking water. Metal release into drinking water is caused by corrosion. This is a long term process and leads to the build-up of corrosion product layers which influence further metal release. Two different periods of metal release from a PDW can be distinguished. The initial period about three months (short term behaviour) is mainly influenced by the surface characteristics of the product (e.g. lead film on the surface), whereas the long term behaviour is characterized by the corrosion of the bulk metallic material. As it is the bulk metallic material that defines the long term behaviour of products, it is possible to accept metallic materials for use with drinking water. For the acceptance of metallic materials other factors affecting the interaction between metals and water have to be taken into account, such as:

- chemical and physical characteristics of water
- design and construction of the distribution system (e.g. density of use of fittings, design of products)
- flow regime, as determined by the water consumption habits of consumers
- contact time of the metallic material with water.

The procedure described in this document for accepting metallic materials takes reasonable worst case situations of the above mentioned factors into account. The procedure refers to EN 15664-1 as the testing method for metallic materials. The testing conditions specified in this standard simulate the use of metallic materials in plumbing systems within buildings. The interpretation of test results can be very complex in some cases and it is recommended to get advice from a "Committee of Experts" during the decision making process.

The acceptance will lead to a listing of the accepted materials on a Composition List (Material List). The acceptance of materials and their listing in the Composition List requires a clear definition of the material's composition and test methods to identify the complete composition.

Arnold Jr, R. B. (2011). New insights into lead and copper corrosion: Impacts of galvanic corrosion, flow pattern, potential reversal, and natural organic matter. Environmental Engineering. Blacksburg, Virginia, Virginia Polytechnic Institute and State University MSc: 79.

The EPA Lead and Copper Rule set Action Limits for lead and copper concentrations in potable water, but accelerated corrosion of lead in potable water systems due to a galvanic connection to copper remains a significant health risk to consumers. In addition to elevated lead release due to galvanic corrosion of lead-tin solder and leaded brass fixtures, partial lead service line replacements with copper pipe present long-term health concerns.

Prior research has demonstrated that the effects of galvanic corrosion can be controlled by water chemistry, and the interplay between alkalinity, natural organic matter (NOM), and orthophosphate (added as corrosion inhibitor) may have a significant influence on corrosion of common lead plumbing materials. Results of bench-scale experiments demonstrate that in some waters galvanic corrosion can multiply lead release from lead pipe by up to 60 times, but other waters curtail the galvanic current and alleviate the effects of galvanic corrosion. Measurements of pH at the lead surface demonstrate that a corrosive micro-environment forms during stagnation in which the local pH drops to 3.0 or lower, demonstrating that the worst-case scenario for galvanic corrosion of lead occurs during long stagnation periods.

In addition to water chemistry, flow pattern also has an impact on galvanic corrosion of lead. Conventional wisdom regarding lead release indicates that continuous flow results in the greatest mass of lead release, but reports of anomalously high lead concentrations after long periods of stagnation point to the contrary. In this experiment, continuous flow of chlorinated water through a Pb-Cu galvanic couple promoted Pb(IV) formation and resulted in potential reversal that caused lead pipe to become cathodic to copper and minimized lead release to water. In contrast, intermittent flow resulted in sustained galvanic attack, and a mass balance of Pb release indicated that a greater total mass of lead was released with intermittent flow.

These results have important implications for assessing lead risk at the tap, especially considering long stagnation periods at facilities such as schools and increasing efforts for water conservation.

Elevated copper release in potable water can cause aesthetic problems and mild health concerns and often occurs in new plumbing systems prior to the formation of a protective scale layer on the pipe surface. While solubility in new copper pipes tends to be controlled by an amorphous solid of high solubility, over time, the natural copper aging process results in the formation of a protective scale of much lower solubility, but the transition can be inhibited in waters with high levels of NOM. Experiments demonstrated that GAC treatment to remove NOM accelerates the aging process to a protective scale that provides a long-term reduction in copper release even after GAC treatment is terminated. Therefore, compared to pH adjustment and orthophosphate addition, which must be continued perpetually, GAC treatment may be a more holistically pleasing method of copper corrosion control. This approach could be useful in the commissioning of new buildings to facilitate rapid aging and avoid potential long-term copper corrosion problems.

Arnold, R. B., Jr. and M. Edwards (2012). "Potential reversal and the effects of flow pattern on galvanic corrosion of lead." Environmental Science and Technology 46(20): 10941-10947.

Simplistic conventional models predict that a greater mass of lead will be released from lead pipes exposed to higher velocity and flow durations. However, if galvanic Pb-Cu connections are present, or if a highly protective Pb(IV) scale can be formed, reduced flow can markedly increase the mass of lead release to water and resultant consumer exposure. Three chemical mechanisms were identified that can reduce lead release at higher flow

including (1) formation of Pb(IV), (2) potential reversal of Pb:Cu couples, after which galvanic corrosion sacrifices copper and lead is protected, and (3) reduced formation of corrosive microenvironments at lead surfaces in galvanic couples. Potential reversal occurred only in the presence of free chlorine with continuous flow, and it did not occur with chloramine, with intermittent flow, or if orthophosphate was present. For both disinfectants, electrochemical measurements supported a mass balance of lead release demonstrating that a greater total mass of lead release occurred with intermittent flow than with continuous flow.

Australian Standards Association (1991). AS1834.1—1991 Material for soldering: Part 1 Solder Alloys. Homebush, NSW, Standards Australia.

This Standard was prepared by the Standards Australia Committee on Lead and Lead Alloys under the direction of the Metals Standards Board, to supersede AS1834.1—1986, Solder alloys. The revised Standard is technically the same as the previous edition except that it incorporates the two amendments. As the result of the inclusion of these amendments, a lead-free tin-copper alloy has been added for general use in plumbing applications, particularly for capillary fittings and for joining copper tube, and a lead-free tin-copper-silver alloy has been added for the joining of copper, ferrous and nickel alloys. Both alloys are for use in potable water systems. This Standard is one of a proposed series of Standards covering materials for soldering. Currently, the only other Standard in the series is AS1834.2—1986, Flux-cored solders.

Berkowitz, M. (1995). "Survey of New Jersey schools and day care centers for lead in plumbing solder - Identification of lead solder and prevention of exposure to drinking water contaminated with lead from plumbing solder." Environmental Research 71(1): 55-59.

Levels of lead in drinking water can be high enough to pose a potential health threat to very young children, primarily from the use of lead solder for indoor plumbing. In February 1987, New Jersey banned lead solder for use in the installation or repair of drinking water plumbing systems. However, because lead solder continued to be available for purchase in the state, New Jersey Department of Health staff sought to (i) determine the extent to which schools and day care centers were in compliance with the ban, and (ii) determine the effectiveness of a solder analysis test kit commonly used by plumbing inspectors in the field. Samples of solder were collected from 53 day care centers and 37 schools known to have been constructed or renovated after the ban took effect. Samples from 24% of those facilities constructed or renovated just after the lead ban (1987-1988) tested positive for lead content. However, for those facilities constructed or renovated in later years (1989-1992), there was a decline in the percentage of samples that tested positive for lead content. For this period of time, 13% of the samples tested positive for lead. In total, more than 10% of facilities with new plumbing installed between 1987 and 1992 had solder samples that tested positive for lead. A lead in solder test kit commonly used by inspectors proved to be an effective screening tool for the field. The New Jersey Department of Health recommends continued enforcement of the lead solder ban through inspection and encouragement of behaviors that minimize consumption of potentially lead-contaminated drinking water. In order to assess patterns of water use, staff at the day care centers were asked to complete a questionnaire. Sixty-seven percent of the respondents reported that they "always" use water from the cold tap when preparing drinks or food for the children. In addition, 57% reported that they always first flush the tap before using the water for drinking or food purposes. Posters and pamphlets developed by the department and containing recommendations for how to minimize consumption of lead-contaminated drinking water were also provided. (C) 1995 Academic Press, Inc.

Birden, H. H., et al. (1985). "Lead dissolution from soldered joints." Journal-American Water Works Association 77(11): 66-70.

Levels of lead in tap water exceeding the US Environmental Protection Agency primary drinking water standard of 0.05 mg/L have been reported in several communities in Connecticut. Investigation revealed that the lead originates from leaching of soldered joints in recently constructed plumbing systems, not from source water supplies. This study examined the phenomenon quantitatively with plumbing runs fabricated from the most commonly used plumbing materials and solder formulations. Tests of two groundwater sources of different corrosivity run through soldered copper piping demonstrated levels of lead well in excess of the USEPA standard. The levels of lead declined with time and varied with the type of solder used and the corrosivity of the water. Elimination of lead in solders and education of the public are suggested as countermeasures.

Boyd, G. R. (2008). "Lead release from new end-use plumbing components in Seattle public schools (vol 100, pg 105, 2008)." American Water Works Association Journal 100(4): 167-167.

Field sampling and laboratory studies were conducted to investigate lead release from new end-use components used in drinking water fountains in Seattle (Washington) Public Schools. Analysis of sequential small-volume samples collected at 22 sources found high lead concentrations in water that was left standing overnight. Results showed significant lead release at or near bubbler heads and at another location upstream of the bubbler head in the end-use plumbing. Laboratory testing of new end-use components were used to estimate the relative contribution of each component to the total lead release in a first-draw sample. Results of the field sampling and laboratory testing programs helped develop mitigation strategies for reducing overall exposure of Seattle's students and staff to lead in drinking water.

Boyd, G. R., et al. (2009). "Effects of Changing Disinfectants on Lead and Copper Release (vol 100, pg 75, 2008)." Journal American Water Works Association 101(2): 10-10.

Utilities face new challenges as they strive to comply with multiple, simultaneous regulations aimed at enhancing drinking water quality. For example, many utilities must comply with regulations for both corrosion control and residual disinfection. Today utilities are considering converting from free chlorine to chloramines for greater residual stability and better compliance with the Total Coliform Rule as well as the more stringent requirements of the Disinfectants/Disinfection Byproducts Rule. This article identifies several key issues for predicting the effects of disinfectant change on lead and copper corrosion and release into drinking water supplies based on information currently available in the literature. The key issues associated with a change in disinfectant that potentially could affect corrosion and lead and copper release in drinking water systems are identified in order to provide a better understanding of potential water quality effects associated with a change in disinfectant. This information can help utilities assess their systems' potential risk of lead and copper release after implementing a change in disinfectant.

Boyd, G. R., et al. (2008). "Lead release from new end-use plumbing components in Seattle Public Schools." Journal American Water Works Association 100(3): 105-114

Field sampling and laboratory studies were conducted to investigate lead release from new end-use components used in drinking water fountains in Seattle (Washington) Public Schools. Analysis of sequential small-volume samples collected at 22 sources found high lead concentrations in water that was left standing overnight. Results showed significant

lead release at or near bubbler heads and at another location upstream of the bubbler head in the end-use plumbing. Laboratory testing of new end-use components were used to estimate the relative contribution of each component to the total lead release in a first-draw sample. Results of the field sampling and laboratory testing programs helped develop mitigation strategies for reducing overall exposure of Seattle's students and staff to lead in drinking water.

Boyd, G. R., et al. (2008). "Lead variability testing in Seattle Public Schools." Journal (American Water Works Association) 100(2): 53-64.

Following a lead remediation program in Seattle (Washington) Public Schools, a field testing program was undertaken to assess the variability of lead at school drinking water sources. Results from 768 samples (384 first-draw and 384 flushed samples) found that the mean lead concentration was 3 µg/L, considerably less than the 21 µg/L measured before the remediation. The highest lead levels and greatest variability in sampling results were observed for end-use plumbing that contained standard brass components with ~3-8% lead. Relatively low lead concentrations and sampling variability were observed for water sources with low-lead water fountains and plumbing components. Study results showed that implementation of a program involving replacement of end-use plumbing with non-leaded materials significantly reduced lead levels in drinking water sources within Seattle Public Schools. These findings also indicated that the likelihood of lead release in school drinking water fountains can be assessed on the basis of the characteristics of end-use plumbing configuration at each source.

Boyd, G. R., et al. (2000). "Lead pipe rehabilitation and replacement techniques for drinking water service - Survey of utilities." Tunnelling and Underground Space Technology 15: 59-63.

The purpose of this technical note is to summarize results from a survey of water utilities regarding preferred lead pipe rehabilitation and replacement techniques for small diameter (< 25 mm) water service pipes. The survey results are based on responses from 23 water utilities ranging in size from 26,500 to 4,656,000 m³/d in North America, Europe and Japan. In North America, survey respondents indicated preferences for the open-trench, pull-through, and moling technologies. In Europe, respondents indicated preferences for the open-trench and moling technologies. In Japan, respondents indicated overwhelming preference for the open-trench technology. Results from this survey were used to identify factors affecting the performance, advantages, and limitations of each technology. (C) 2001 Elsevier Science Ltd. All rights reserved.

Boyd, G. R., et al. (2000). "Lead pipe rehabilitation and replacement techniques for drinking water service: review of available and emerging technologies." Tunnelling and Underground Space Technology 15: 13-24.

The purpose of this paper is to describe currently available and emerging technologies regarding the rehabilitation and replacement of small diameter (< 25 mm) lead pipes for water service. Numerous techniques currently are available and can be classified into five technology categories: open trench, replacement on new route (e.g. moling), replacement using existing route (e.g. pull through), pipe coating, and slip lining. Each technology has its own particular advantages and limitations. As such, water utilities should be prepared to use a range of techniques applicable to site-specific conditions. (C) 2001 Elsevier Science Ltd. All rights reserved.

Brown, M. J. and S. Margolis (2012). Lead in drinking water and human blood lead levels in the United States, US Department of Health and Human Services, Centers for Disease Control and Prevention.

Lead is a pervasive environmental contaminant. The adverse health effects of lead exposure in children and adults are well documented, and no safe blood lead threshold in children has been identified. Lead can be ingested from various sources, including lead paint and house dust contaminated by lead paint, as well as soil, drinking water, and food. The concentration of lead, total amount of lead consumed, and duration of lead exposure influence the severity of health effects. Because lead accumulates in the body, all sources of lead should be controlled or eliminated to prevent childhood lead poisoning. Beginning in the 1970s, lead concentrations in air, tap water, food, dust, and soil began to be substantially reduced, resulting in significantly reduced blood lead levels (BLLs) in children throughout the United States. However, children are still being exposed to lead, and many of these children live in housing built before the 1978 ban on lead-based residential paint. These homes might contain lead paint hazards, as well as drinking water service lines made from lead, lead solder, or plumbing materials that contain lead. Adequate corrosion control reduces the leaching of lead plumbing components or solder into drinking water. The majority of public water utilities are in compliance with the Safe Drinking Water Act Lead and Copper Rule (LCR) of 1991. However, some children are still exposed to lead in drinking water. EPA is reviewing LCR, and additional changes to the rule are expected that will further protect public health. Childhood lead poisoning prevention programs should be made aware of the results of local public water system lead monitoring measurement under LCR and consider drinking water as a potential cause of increased BLLs, especially when other sources of lead exposure are not identified.

Brown, S. M. (2008). "Nitrification in Premise Plumbing: Role of Phosphate, pH, and Pipe Corrosion." Environmental Science and Technology 42(21): 8170-8170.

Nitrification in PVC premise plumbing is a weak function of pH over the range 6.5–8.5 and is insensitive to phosphate concentrations 5–1000 ppb. Lead pipe enhanced nitrification relative to PVC, consistent with expectations that nitrifiers could benefit from ammonia recycled from nitrate via lead corrosion. Relatively new copper pipe (<1.5 years old) did not allow nitrifiers to establish, but nitrifiers gradually colonized over a period of months in brass pipes when copper concentrations were reduced by pH adjustment or orthophosphate. Nitrifiers were inhibited by trace copper, but not by lead levels up to 8000 ppb. In some systems using chloramines, brass in plastic plumbing systems might be more susceptible to lead/copper leaching, and accelerated dezincification, due to lower pH values resulting from nitrification.

Burton, R. D. (2010). "Plumbing - vital to global health." Perspectives in Public Health 130(5): 205-206.

In this paper, Robert Burton, Deputy Chairman of the World Plumbing Council (WPC), outlines the mission and objectives of that organisation (established in 1990) and stresses the importance of plumbing as a contributor to global health, citing historic and recent examples of the way in which plumbing and public health are linked. It suggests that the connection between plumbing and health has been largely forgotten in many developed countries. The paper refers to the joint publication by WPC and the World Health Organisation (WHO) of "Health Aspects of Plumbing" which aims to assist developing countries tackle the issues relating to the improvement of health through water supply and sanitation. The paper refers to the importance of both industry and public education and

refers to a number of initiatives being carried out to share good practice in the field of plumbing training. These include the WPC's annual Lecturers'/Trainers' Scholarship. Reference is also made to the need for appropriate registration and licensing arrangements. The paper concludes with some suggestions for future action in pursuit of this goal, I suggest the following actions:

- Water supply, health and plumbing officials in every country should establish a formal dialogue to find ways of cooperating to promote the public health role of plumbing.
- Discussions should take place with governments to treat plumbing as part of the wider health remit of the country in question.
- "Health Aspects of Plumbing" should be promoted on a wider basis.
- The World Plumbing Council should explore further ways of working with organisations such as the World Health Organisation to enable good practice in areas of education, training, licensing and registration to be shared with particular emphasis on the creation of appropriate training programmes in countries where none currently exist.
- Plumbing and water industry organisations not already involved in WPC activities should be encouraged to join and to play an active role.
- Educational authorities should be encouraged to include references to the link between plumbing and public health in all school curricula.

Cantor, A. F., et al. (2003). "Effect of chlorine on corrosion in drinking water systems." Journal (American Water Works Association) 95(5): 112-123.

Efforts by utility managers, especially of some small water systems, to comply with the US Environmental Protection Agency's (USEPA's) new Ground Water Rule may soon include the addition of chlorine to their systems for disinfection. However, depending on water quality characteristics and the type of pipe metal, the addition of chlorine may increase internal corrosion of the distribution system. This, in turn, may push a system out of compliance with USEPA's 1991 Lead and Copper Rule for system corrosion. If corrosion does increase, pH adjustment or the addition of orthophosphate as a corrosion inhibitor, can help control the problem. No matter the situation, the authors stress the need for routine monitoring of the system so that chemical levels can be adjusted appropriately in the event of corrosion.

Cartier, C., et al. (2012). "Effect of flow rate and lead/copper pipe sequence on lead release from service lines." Water Research 46(13): 4142-4152.

A pilot experiment examined lead leaching from four representative configurations of service lines including: (1) 100% lead (Pb), (2) 100% copper (Cu), (3) 50% Pb upstream of 50% Cu, and (4) 50% Pb-downstream of 50% Cu using a range of flow rates. The cumulative mass of lead release indicated that a typical partial replacement configuration (50% lead downstream of copper) did not provide a net reduction in lead when compared to 100% lead pipe (85 mg for 50% Pb-downstream versus 83 mg for 100%-Pb) due to galvanic and deposition corrosion. The partially replaced service line configuration also had a much greater likelihood of producing water with "spikes" of lead particulates at higher flow rates, while tending to produce lower levels of lead at very low flow rates. After the first 214 days the galvanic current between copper and lead was only reduced by 34%, proving that galvanic impacts can be highly persistent even in water with optimized corrosion control by dosing of zinc orthophosphate. Finally, this experiment raises concern about the low flow rates used during some prior home sampling events, which may underestimate exposure to lead during normal water use, especially when galvanic Pb:Cu connections are present.

Cartier, C., et al. (2013). "Impact of treatment on Pb release from full and partially replaced harvested Lead Service Lines (LSLs)." Water Res 47(2): 661-671.

Release of lead from 80% partially replaced service lines was compared to full lead service lines using harvested-stabilized lead pipes and field brass connectors. After more than a year of stabilization, lead release was consistent with field samples. Over the relatively short duration partial replacement of lead pipe by copper pipe (3 months), generated high lead release, attributed to galvanic corrosion, resulting in a final outcome for lead release that was even worse than for a full lead pipe. Increased lead release was especially evident at higher flow rates. Orthophosphate reduced lead release from full lead pipes by 64%. For partially replaced samples with copper, lead concentrations were unchanged by phosphate dosing at moderate flow (103 +/- 265 vs 169 +/- 349 mug/L) and were increased to very high levels when sampled at high flow rates (1001 +/- 1808 vs 257 +/- 224 mug/L). The increase lead release was in the form of particulate lead (>90%). In comparison to the condition without treatment, increased sulfate treatment had little impact on lead release from 100%-Pb rigs but reduced lead release from partially replaced lead pipes with copper. Our results also raise questions concerning protocols based on short 30 min stagnation (as those used in Canada) due to their incapacity to consider particulate lead release generated mostly after longer stagnation.

Casteloes, K. S., et al. (2015). "Decontaminating chemically contaminated residential premise plumbing systems by flushing." Environmental Science-Water Research & Technology 1(6): 787-799.

Recent large-scale drinking water chemical contamination incidents in Canada and the U.S. have affected more than 1 000 000 people and involved disparate premise plumbing decontamination approaches. In this study, past premise plumbing decontamination approaches were reviewed and a mass balance water heater model was developed and tested. Organic contaminants were the sole focus of this work. Thirty-nine contamination incidents were identified and contaminants had a wide range of physiochemical properties [i.e., log K_{ow}, water solubility, vapor pressure]. Minimal data was available pertaining to flushing protocol design and effectiveness. Results showed that premise plumbing design, operational conditions, contaminants present and their properties, as well as building inhabitant safety have not been fully considered in flushing protocol design. Results indicated that flushing could decontaminate some, but not all plumbing systems. Several modeling scenarios showed contaminant levels exceeded drinking water health limits after flushing following recent large-scale water contamination incidents. Water saving fixtures and devices, water heater size, and flow rate affected contaminant removal efficiency. Modeling did not consider service lines or piping. This study provides a first step in the development of science based premise plumbing flushing protocols for organic contaminants.

Cheng, Z. and K. A. Foland (2005). "Lead isotopes in tap water: implications for Pb sources within a municipal water supply system." Applied Geochemistry 20(2): 353-365.

Residential tap waters were investigated to examine the feasibility of using isotopic ratios to identify dominant sources of water Pb in the Columbus (Ohio, USA) municipal supply system. Overall, both the concentrations, which are generally low (0.1–28 µg/L), and isotopic compositions of tap water Pb show wide variations. This contrasts with the situation for a limited number of available service lines, which exhibit only a limited Pb-isotope variation but contain Pb of two very different types with one significantly more radiogenic than the other. Most tap water samples in contact with Pb service lines have Pb-isotope ratios that are different from the pipe Pb. Furthermore, the Pb isotope compositions of

sequentially drawn samples in the same residence generally are similar, but those from separate residences are different, implying dominant Pb sources from domestic plumbing. A separate pilot study at two residences without Pb service lines shows isotopic similarity between water and solders in each house, further suggesting that the major Pb sources are domestic in these cases and dominated by Pb from solder joints. Although complicated by the broad range of overall Pb-isotope variations observed and limited by sample availability, the results suggest that Pb isotopes can be used effectively to constrain the sources of Pb in tap waters, especially for individual houses where multiple source candidates can be identified.

Chubaka, C. E., et al. (2018). "A Review of Roof Harvested Rainwater in Australia." Journal of Environmental and Public Health 2018: 14.

To address concern regarding water sustainability, the Australian Federal Government and many state governments have implemented regulatory mechanisms and incentives to support households to purchase and install rainwater harvesting systems. This has led to an increase in rainwater harvesting in regional and urban Australia. This review examines the implementation of the regulatory mechanisms across Australia. In addition, the literature investigating the potential health consequences of rainwater consumption in Australia was explored. Studies demonstrated that although trace metals such as arsenic, cadmium, chromium, lead, and iron were present in Australian rainwater, these metallic elements were generally found below the health limit guideline, except in high industrial areas. In addition, pathogenic or indicator microorganisms that include, but are not limited to, *Escherichia coli*, total and faecal coliforms, *Campylobacter*, *Salmonella*, *Legionella*, *Pseudomonas*, *Cryptosporidium*, *Enterococci*, *Giardia*, *Aeromonas*, and *Mycobacterium avium* Complex (MAC) have been detected in rainwater collected in Australia. However, epidemiological evidence suggests that drinking rainwater does not increase the risk of gastrointestinal disease. It was also identified that there is a need for further research investigating the potential for rainwater to be a source of infection for opportunistic pathogens.

Clark, B., et al. (2013). "Effect of connection type on galvanic corrosion between lead and copper pipes." Journal American Water Works Association 105(10): 69-70.

Pipe connectors can influence galvanic corrosion between lead and copper pipes by distancing the lead from copper pipe, introducing a third metal, and forming crevices. In this study, the effects of distance, connector material, and crevices on galvanic corrosion were examined, and benchscale comparison testing of commercial connectors was conducted using real tap waters. Brass connectors only slightly decreased (<25%) the galvanic current that sacrifices lead pipe, with higher reductions for new brasses with higher zinc content. Crevices in brass connectors contained water with extremely high levels of lead (up to $9.4 \times 10^6 \mu\text{g/L}$), and in bench-scale tests, connections with crevices caused approximately four times more lead release to water than did direct connections.

Clark, B., et al. (2014). "Profile sampling to characterize particulate lead risks in potable water." Environmental Science and Technology 48(12): 6836-6843.

Traditional lead (Pb) profiling, or collecting sequential liters of water that flow from a consumer tap after a stagnation event, has recently received widespread use in understanding sources of Pb in drinking water and risks to consumer health, but has limitations in quantifying particulate Pb risks. A new profiling protocol was developed in which a series of traditional profiles are collected from the same tap at escalating flow rates. The results revealed marked differences in risks of Pb exposure from one consumer

home to another as a function of flow rate, with homes grouped into four risk categories with differing flushing requirements and public education to protect consumers. On average, Pb concentrations detected in water at high flow without stagnation were at least three to four times higher than in first draw samples collected at low flow with stagnation, demonstrating a new "worst case" lead release scenario, contrary to the original regulatory assumption that stagnant, first draw samples contain the highest lead concentrations. Testing also revealed that in some cases water samples with visible particulates had much higher Pb than samples without visible particulates, and tests of different sample handling protocols confirmed that some EPA-allowed methods would not quantify as much as 99.9% of the Pb actually present (avg. 27% of Pb not quantified).

Clark, B. N., et al. (2015). "Lead Release to Drinking Water from Galvanized Steel Pipe Coatings." Environmental Engineering Science 32(8): 713-721.

Problems identified with elevated lead in drinking water associated with galvanized steel pipes were recently hypothesized to result from lead accumulation on galvanized steel pipe surfaces from upstream lead service pipes. However, historical research documents that the grade of zinc typically used for galvanizing contains a minimum of 0.5% lead and can itself be a significant long-term source of lead, which may explain some recent lead contamination problems associated with galvanized steel. Surface analysis of various galvanized steel pipes and fittings installed from 1950 to 2008 demonstrated that the concentration of lead in the original zinc coating can range from nondetect to nearly 2%, dependent on the manufacturer and fitting type. Since cadmium is also present in many zinc coatings, but not in lead pipe, leaded solder, or brass, correlation of zinc concentration to both lead and cadmium concentrations in water was considered as a possible fingerprint implicating the coating on galvanized steel as a lead source; bench-scale tests of metal leaching from harvested galvanized steel pipes were used to validate this approach. Using profile sampling, individual homes with galvanized steel pipes as a primary lead source were identified in Washington, DC, Providence, RI, Chicago, IL, and a city in Florida. In some cases, the levels of lead from this source were very significant ($>100 \mu\text{g/L}$) and can be exacerbated by installation of a copper pipe upstream during partial service line replacements.

Clement, J., et al. (2001). "Flowcharts for the selection of lead and copper corrosion control strategies." Journal NEWW A December: 289.

In 1996, the Office of Ground Water and Drinking Water of the U. S. Environmental Protection Agency was interested in developing some simple guidance that could be used by regulators, small water systems, and their engineers to aid in initially determining what treatment approaches for lead and copper control would have the best chance of success. The original document was prepared for Peter Lassoosky, U. S. Environmental Protection Agency Office of Ground Water and Drinking Water in January of 1997. The manual was developed under USEPA Contract 68-C4-0007 by Black & Veatch under subcontract to The Cadmus Group. The primary author of the manual was Jonathan Clement (Black & Veatch), with assistance from Michael Schock (U. S. Environmental Protection Agency, National Risk Management Research Laboratory, Water Supply and Water Resources Division) and Wendy Marshall (U. S. Environmental Protection Agency, Region 10). In the four years since the completion of the manual, many water systems have successfully employed corrosion control treatment to achieve compliance with the Lead and Copper Rule. However, the information in the manual is still timely and relevant, because some systems still have difficulty in sufficiently reducing lead and copper corrosion, and other systems may need to change water treatment approaches because of other regulatory issues or changes in water sources. Thus, corrosion control for lead and copper

will need to be revisited in the context of these changes. Rather than exactly reproducing the manual as originally printed, it was decided to take advantage of the considerable experience in New England and elsewhere throughout the past four years to refine (or even sometimes correct) the recommendations for treatment selection. Thus, this version of the manual has been slightly revised and edited by a collaboration of many members of the New England Water Works Association Committee on Corrosion and Its Effects on Water Quality, to help provide readers with the best general screening-level guidance current knowledge permits.

Coles, R., et al. (2014). ""Lead Leached into Water from Select Plumbing Fixtures" Could Lead to Health Hazard." Journal of Krishna Institute of Medical Sciences University 3(1): 49-56.

Background: Lead is an inert metal and is resistant to corrosion. It also increases tensile strength of many common materials in daily use. Lead was used during the Roman period to transport water (hence the name plumbing/plumber is common terminology even in the present day). Lead enters the biological system through the air, water, and dust. Fine particles of lead, having diameter less than 5 nm are directly absorbed by lungs. Inorganic lead is absorbed by the gastrointestinal tract, and organic lead is absorbed by the skin. Lead has long been known to be a toxic heavy metal and exposure is associated with many deleterious health effects. Still, lead remains a popular ingredient in products ranging from paint to batteries. The lead content in any given material is estimated using various methods. The least cumbersome method is found to be X-Ray Fluorescence technique (XRF). A portable XRF device was used in the present study. Aim: The main aim of this study to investigate whether lead is present in various commonly used plumbing materials. Material and Methods: All types of branded and commonly used pipes were gathered from a market in Bangalore and tested using the XRF machine. In order to evaluate to what extent lead from the pipes could leach into water, seven pipes were randomly selected and filled with Aquafina water (having undetectable level of lead) for a 24 hour period. This water was tested at an NABL accredited laboratory in Bangalore, India for lead content. Result: It was determined that lead was present in many of the samples, at an unacceptable levels ranging from, well above the globally accepted level of 0.01 mg/L proof that lead was able to leach from the samples into water. Conclusions: As lead in drinking water represents a direct pathway for human exposure, the authors recommend that significant measures be taken to prevent use of lead in the plumbing industry for prevention of it's deleterious effects. Authors have also recommended non expensive solution to prevent the lead from water getting in to biological or environmental system.

Copper Development Association Inc (2017). "Leaded brasses: An Overview." Retrieved 10 April, 2018, from

https://www.copper.org/resources/properties/microstructure/lead_brasses.html.

Leaded Brasses-Overview

Lead brasses are used for their high machinability and atmospheric corrosion resistance. The machinability of brass is increased by the addition of lead because it acts as a microscopic chip breaker and tool lubricant. The leaded brasses are used for copper base screw machine material. The alloys have excellent machinability, good strength and corrosion resistance. Lead can be added to any brass to increase machinability and provide pressure tightness by sealing the shrinkage pores. There are low, medium and high leaded brasses, with lead contents up to 3.5%. The lead brasses are used for architectural hardware, general purpose screw machine parts, screws, valves, fittings, bearings and specialty fasteners. The wrought lead brasses are designated by UNS C31200 through

C38500. The cast lead brasses are grouped with their unleaded counter parts, and fall in the range of alloys between C83600 through C97300.

The microstructure of the leaded brasses is similar to that of the unleaded brasses. The microstructure of the leaded brasses contain discrete lead particles primarily in the grain boundaries or inter-dendritic regions. Lead is practically insoluble in solid copper and is present in the cast and wrought materials as discrete particles that appear dark in the structure. The microstructure of the as cast lead brasses is a function of the zinc content. The lower zinc containing alloys are single phase solid solution alpha dendrites, with lead particles dispersed throughout the interdendritic regions. Those with a higher zinc content have a two phase structure, consisting of alpha and beta. The higher zinc containing alloys have a microstructure of all beta. The lead appears as discrete particles, appearing dark in the microstructure. The microstructure of the wrought low zinc leaded brasses consists of twinned grains of alpha with lead particles throughout the matrix. The higher zinc containing alloys contain a mixture of alpha and beta phases and lead particles.

Davis, W. F. (1990). "A case study of lead in drinking water: protocol, methods, and investigative techniques." American Industrial Hygiene Association Journal 51(12): 620-624.

A comprehensive study was performed to determine whether lead (Pb) in drinking water exceeded acceptable levels at a manufacturing and research site. Recent research indicates the possibility of abnormal adolescent development if the mother's blood lead levels exceed 15 µg lead per dL of whole blood. Using Environmental Protection Agency (EPA) estimates of average consumption and ratios combating the amount of lead consumed to blood lead levels, a level of 10 µg/L of lead in water was determined to be acceptable. Water samples were collected from each type of water cooler and from faucets in every bathroom on site. Samples were collected that represented worst case exposures. Novel methods were used to identify the source of lead at those locations that exceeded the acceptable limit for lead. Control techniques are discussed. A laboratory study was performed to determine if lead could be prevented from leaching into drinking water from existing plumbing systems by treating the system with carbon dioxide gas.

DeBoer, J. (2011). "Article reporting on lead contamination from brass plumbing devices in new buildings sparks discussion." Journal American Water Works Association 103(1): 8.

As chairman of the NSF Joint Committee on Drinking Water Additives, which oversees the ongoing development of NSF/ ANSI Standard 61 (NSF 61) I read with interest the article by Elfland and colleagues that was published in the November issue. The article addressed several problems, one of which NSF 61 was designed to avoid - high leaching of lead from new plumbing products. The article raises several significant issues, including the fact that the current Lead and Copper Rule does not require testing of new plumbing. It also points out that design, especially in new buildings with low water use, and construction practices must all be carefully monitored by building owners to avoid practices that may lead to high lead levels in drinking water. In this case, debris with high lead content was found to have collected on strainers and screens in the premise piping of new buildings. After reading the article I contacted the various product certification organizations that are on the Joint Committee to see if they were aware of complaints on the faucets or ball valves associated with the incident at UNC. I was told by one organization that they had been contacted by the authors with the make and model number of one of the suspect ball valves and the certifier followed up with the manufacturer and determined that the product had never been certified to NSF/ANSI Standard 61. This highlights a problem that is not unique to this particular incident. Despite plumbing and water utility regulations across the majority of US states and Canadian provinces that require products to comply with NSF 61, few people

know how to verify whether products are certified or submit complaints if certified products do not perform as claimed. Several organizations are accredited by ANSI and the Standards Council of Canada (SCC) to certify products to NSF 61. These organizations have listings of products certified to NSF 61 on their websites: CSA International (www.csa-international.org), International Association of Plumbing and Mechanical Officials (www.iapmo.org), NSF International (www.nsf.org), UL (www.ul.com), and WQA (www.wqa.org). These listings are updated daily, and anyone can log in to these databases to verify whether products are certified. If a product is certified and a problem arises with that product, the certification organization should be contacted immediately. Once the certification organization verifies that a product does not comply with the standard, the certification organization can issue a public notice and initiate a product recall by the company. I encourage the authors and UNC to pursue investigation of these specific products with the respective certification organizations, if indeed they are certified. If the products were not certified, then an investigation should be launched to determine why uncertified products were used. If the authors' conclusion is that the products were certified and meet the requirements of NSF 61 but still contributed excessive levels of lead to drinking water, then that information needs to be shared with the NSF 61 Joint Committee. The standard is under continuous maintenance and is updated regularly to address consistency in its interpretation and application. This is critical in the evaluation of products for lead release or other contaminants potentially exceeding drinking water regulations. In addition, the NSF 61 Joint Committee has made several changes to NSF 61 over the past 20 years to further restrict the leaching of lead. This includes reducing the allowable amount of lead leachate by two thirds (from 15 to 5 µg/L for products such as ball valves) and also adding a verification method to determine compliance with weighted average lead content below 0.25% (to meet current requirements in California and Vermont and proposed US federal legislation). The NSF 61 committee encourages research to determine better ways to evaluate lead leaching from products, but it seems very inappropriate to indict NSF 61 as unworthy if noncertified products were used and the investigators have not actually tested the products to the requirements of the standard.

Jon DeBoer Chairman NSF Joint Committee on Drinking Water

Del Toral, M. A., et al. (2013). "Detection and Evaluation of Elevated Lead Release from Service Lines: A Field Study." Environmental Science and Technology 47(16): 9300-9307.

Comparative stagnation sampling conducted in 32 homes in Chicago, Illinois with lead service lines demonstrated that the existing regulatory sampling protocol under the U.S. Lead and Copper Rule systematically misses the high lead levels and potential human exposure. Lead levels measured with sequential sampling were highest within the lead service lines, with maximum values more than four times higher than Chicago's regulatory compliance results using a first-draw sampling protocol. There was significant variability in lead values from different points within individual lead service lines and among different lead service line sites across the city. Although other factors could also influence lead levels, the highest lead results most often were associated with sites having known disturbances to the lead service lines. This study underscores the importance and interdependence of sample site selection, sampling protocol, and other factors in assessing lead levels in a public water system.

Delile, H., et al. (2014). "Lead in ancient Rome's city waters." Proc Natl Acad Sci U S A 111(18): 6594-6599.

It is now universally accepted that utilization of lead for domestic purposes and water distribution presents a major health hazard. The ancient Roman world was unaware of

these risks. How far the gigantic network of lead pipes used in ancient Rome compromised public health in the city is unknown. Lead isotopes in sediments from the harbor of Imperial Rome register the presence of a strong anthropogenic component during the beginning of the Common Era and the Early Middle Ages. They demonstrate that the lead pipes of the water distribution system increased Pb contents in drinking water of the capital city by up to two orders of magnitude over the natural background. The Pb isotope record shows that the discontinuities in the pollution of the Tiber by lead are intimately entwined with the major issues affecting Late Antique Rome and its water distribution system.

DeSantis, M. K., et al. (2018). "Mineralogical Evidence of Galvanic Corrosion in Drinking Water Lead Pipe Joints." Environmental Science and Technology.

Galvanic corrosion as a mechanism of toxic lead release into drinking water has been under scientific debate in the U.S. for over 30 years. Visual and mineralogical analysis of 28 lead pipe joints, excavated after 60+ years from eight U.S. water utilities, provided the first direct view of three distinct galvanic corrosion patterns in practice: (1) no evidence of galvanic corrosion; (2) galvanic corrosion with lead cathode; (3) galvanic corrosion with lead anode. Pattern 3 is consistent with empirical galvanic series (lead brass copper in order of increasing nobility) and poses the greatest risk of Pb exposure. Pattern 2 is consistent with galvanic battery reversion. The identification of copper-sulfate minerals (Pattern 2), and lead-sulfate and lead-chloride minerals (Pattern 3) in galvanic zones illustrated the migration of chloride and sulfate toward the anode. Geochemical modeling confirmed the required pH drop from the bulk water level to at least pH 3.0-4.0 (Pattern 2) and pH < 5.5 (Pattern 3) in order to form these minerals. Despite joints being over 60 years old, galvanic zones in Pattern 3 were active and possibly posed an important source of lead to drinking water. Importantly, Pattern 3 was not observed in samples from systems representing water qualities favoring PbO₂ formation.

Deshommes, E., et al. (2010). "Source and occurrence of particulate lead in tap water." Water Research 44(12): 3734-3744.

Lead samples were collected at the tap from homes with lead service lines (LSLs) in a full-scale utility using both random daytime (RDT) and particulate stimulation sampling (PSS) protocols. Analysis of the results revealed two sources and occurrences of particulate lead. A first source is due to corrosion of lead-bearing elements in the premise plumbing (PP) and occurs mostly at low to moderate concentrations <3 µg/L, with some sporadic higher concentrations (4–12 µg/L). These spikes were consistently observed and considerably increased using PSS, showing that current sampling protocols may miss a significant portion of particulate lead. The second source results from the adsorption of dissolved lead onto iron deposits in LSL/PP, and is continuously present at low to moderate concentrations. Statistical analyses were validated by physical analyses of: (i) lead scales from LSLs; and (ii) lead particles from tap aerators.

Deshommes, E., et al. (2010). "Lead removal from tap water using POU devices." American Water Works Association. Journal 102(10): 91.

Test 1: Pour-through POU devices, lab-scale study on the reduction of Pb and other metals. Four identical pour-through POU devices (devices X) were tested for total Pb, chromium (Cr), Cu, cobalt (Co), nickel (Ni), and Ag before and after filtration at time 0 and after 40, 80, 120, and 150 L (POU recommended lifetime) in duplicate and over three days in the laboratory. The delay between each batch of water put through the filter was as recommended by NSF-53 (15-60 s).

Common point-of-use (POU) devices that met NSF/ANSI-53 certification standards for lead removal before July 16, 2007, were evaluated for the reduction of lead and other trace metals in drinking water. Systematic testing and evaluation of various POU devices focused on particulate and dissolved lead removal efficacy, under conditions different from those addressed in the NSF-53 testing protocol (particle type, water tested, lead levels). Tap mounted and under-the-sink POU devices showed, globally, adequate removal performance, although the NSF threshold value for lead of 10 µg/L was occasionally slightly exceeded. Pour-through POU devices failed to remove particulate lead, decreased pH, did not reduce turbidity, and were the least efficient for chlorine removal. Copper removal was effective for any concentration tested, and silver was detected in effluent water. Nitrification did not increase the dissolution of lead particles trapped in the filters.

Point-of-use (POU) devices can contribute to the improvement of water quality and safety (USEPA, 2006a). A recent nationwide survey on the household domestic water use patterns in the United States conducted by the US Environmental Protection Agency (USEPA) showed an increase in the use of water treatment devices between 1995 and 2002 (37% of the household respondents in 2002; USEPA, 2003). POU devices are commercially available in various forms, including under-the-sink, tap-mounted, and pour-through devices. The most widely used POU devices are the pour through (pitcher-style filter) and tap-mounted treatment systems. Under-the-sink devices are more expensive and not easy to install (USEPA, 2006b). POU devices are widely used to remove taste and odour compounds from drinking water. They can also be used as a temporary remediation strategy to reduce lead (Pb) exposure during the establishment of adequate corrosion control treatment, or during lead service line replacement. In Canada, some provincial public health authorities have issued advisory notices recommending that pregnant women and children under six years old use bottled water or NSF/ANSI-certified filtration devices if a lead service line is in use or when total or partial replacement does not result in lead levels below the Canadian drinking water threshold of 10 µg/L total lead (WDGPH, 2007; MPHD, 2006). Tens of thousands of filters were also distributed to residents of Washington, D.C., to mitigate hazards from high lead levels in drinking water (Edwards et al, 2009).

Dresher, W. H. and D. T. Peters (1992). "Lead-free and reduced-lead copper-base cast plumbing alloys - Evaluation of candidate United States compositions-1." Metal 46(11): 1142-1146.

Several lead-free and reduced-lead cast copper alloys were evaluated as possible alternatives for conventional leaded plumbing materials. Evaluations were based on the candidates' castability, machinability, solderability, finishing and plating characteristics and cost. Silicon brasses and a reduced-lead version of a standard red casting brass were found to be adequately castable and machinable to warrant consideration, although production processes may require some technological development. Compared with conventional leaded alloys, raw material costs will be higher, and production costs will rise, for these lead-free materials. An alternative approach is to create lead-free internal surfaces in cast leaded brass plumbing products. A chemical stripping process capable of achieving this condition was developed. The relatively simple process reduces lead leaching from conventional leaded brasses to concentrations below detectable limits in laboratory work.

Dresher, W. H. and D. T. Peters (1993). "Lead-free and reduced-lead copper-base cast plumbing alloys - Evaluation of candidate United States compositions-2." Metal 47(1): 26-33.

Several lead-free and reduced-lead cast copper alloys were evaluated as possible alternatives for conventional leaded plumbing materials. Evaluations were based on the candidates' castability, machinability, solderability, finishing and plating characteristics and cost. Silicon brasses and a reduced-lead version of a standard red casting brass were found to be adequately castable and machinable to warrant consideration, although production processes may require some technological development. Compared with conventional leaded alloys, raw material costs will be higher, and production costs will rise, for these lead-free materials. An alternative approach is to create lead-free internal surfaces in cast leaded brass plumbing products. A chemical stripping process capable of achieving this condition was developed. The relatively simple process reduces lead emissions from conventional leaded brasses to concentrations below detectable limits.

Dudi, A. (2004). Reconsidering lead corrosion in drinking water: product testing, direct chloramine attack and galvanic corrosion. Blacksburg, Virginia, Virginia Tech. MSc (Env. Eng): 116.

The ban on lead plumbing materials in the Safe Drinking Water Act (1986) and the EPA Lead and Copper Rule (1991) have successfully reduced lead contamination of potable water supplies. The success of these regulations gave rise to a belief that serious lead contamination was an important past problem that had been solved, and that additional fundamental research was therefore unnecessary. This work carefully re-examined the lead contamination issue from the perspective of 1) new regulations causing a shift from chlorine to chloramine disinfectant, 2) assumptions guiding sampling strategies, 3) existing performance standards for brass, and 4) galvanically driven corrosion of lead bearing plumbing materials. The results were instrumental in uncovering and understanding a serious problem with lead contamination in Washington, D.C.

A critical reading of the literature indicates that chloramines can accelerate corrosion of lead bearing materials and increase lead contamination of water. When a new sampling protocol was conceived and used in Washington homes to assess the nature of the problem, hazardous levels of lead were found to be present in some drinking water samples. Contrary to the conventional wisdom, lead was not always highest in first draw samples, but often increased with flushing. This has several important implications for monitoring and public health. For instance, well-intentioned public education materials were causing consumers to drink water containing very high levels of lead in some circumstances. Laboratory and field-testing proved that chloramines were causing serious lead corrosion problems. That testing also discovered that, unbeknownst to scientists and utilities, free chlorine itself can act as a corrosion inhibitor, reducing lead solubility and contamination of water. The net result is that changing disinfectant from free chlorine to chloramine can sometimes trigger serious lead contamination of water.

While the worst problems with lead in Washington, D.C. came from the lead services, significant levels of lead were occasionally sampled from homes with solders or brass as the lead source. This prompted re-evaluation of the ANSI/NSF 61, Section 8 standard, which is relied on to protect public health from in-line brass plumbing devices that might leach excessive lead to potable water. In-depth study of the standard revealed serious flaws arising from use of a phosphate buffer in the test waters and a failure to control carbonate dissolution from the atmosphere. Due to these deficiencies, small devices made of pure lead could actually pass the performance test. The public therefore has no assurance that devices passing NSF Section 8 testing are safe and reforms to the standard are obviously needed.

Other problems arise from connecting copper pipe to lead bearing plumbing in practice. The copper is cathodic and dramatically accelerates corrosion of the lead anode via a galvanic current. Corrosion and hydrolysis of released Pb^{+2} can lower pH near the surface of the lead and increase its solubility. A similar galvanic effect can arise from cupric ions present in the water via deposition corrosion mechanism. In cases where part of a lead service line is replaced by copper pipe, the galvanic corrosion effect can create a serious long-term problem with lead contamination. Such partial lead service line replacements are occurring in many US cities and the practice should be stopped.

Lead contamination of potable water is not only a problem of the past but also of the present. While additional research is necessary before regulators, utilities and homeowners can anticipate and mitigate such problems with confidence, this work provides sound fundamental basis for future progress.

Dudi, A., et al. (2005). "Lead leaching from inline brass devices: A critical evaluation of the existing standard." Journal American Water Works Association 97(8): 66-78.

The American National Standards Institute/NSF Standard 61, Section 8, is intended to protect the public from inline brass plumbing products that might leach excessive levels of lead to potable water. Experiments were conducted to examine the practical rigor of this test. Contrary to expectations, the test was not highly protective of public health. In fact, results indicated that small devices made of pure lead-which pose an obvious public hazard-can easily pass the leaching protocol. Reforms are needed to help prevent such unacceptable outcomes in the future. Brass devices passing the test can contribute to lead levels at the tap in residences, schools, and other buildings.

The presence of phosphate in the NSF pH 5 water decreased lead leaching, but its effects on copper were complex in comparison with both field and laboratory experience (Schock & Fox, 2001; [Michael Schock] et al, 1995). In this test, the presence of phosphate increased copper leaching by 14 times, relative to the same samples for pH 5 without phosphate buffer (Figure 6).

Duranceau, S. J., et al. (2010). "Effects of orthophosphate corrosion inhibitor on lead in blended water quality environments." Desalination and Water Treatment 13(1-3): 348-355.

This study evaluated the effects of orthophosphate (OP) inhibitor addition on corrosion of lead/tin coupons exposed to different blends of groundwater, surface water, and desalinated seawater. Four different doses of OP inhibitor, from zero (control) to 2 mg/L as P, were investigated and non-linear empirical models were developed to predict lead release from water quality and OP doses. Surface characterization evaluations were conducted using X-ray Photoelectron Spectroscopy (XPS) for each lead coupon tested. A theoretical thermodynamic model was developed to predict lead. OP inhibitor addition was found to reduce lead release for the OP dosages evaluated and water blends evaluated compared to pH adjustment alone. Empirical models showed increased phosphorus and pH reduced lead release while increased alkalinity, chloride, and temperature contributed to lead release. Thermodynamic modeling suggested that hydroxypyromorphite is the controlling solid that forms on lead surfaces, regardless of blend, when OP inhibitor is added for corrosion control.

Durowoju, M. and O. Kolapo (2013). "Producing Lead-Free Copper Alloys for Plumbing Fittings; A Case Study of Nigerian Taps." International Journal of Engineering Research and Applications 3(4): 408-411.

Inclusion of lead in pipe fittings brings about good machinability, lubricity and filling of pores created after casting. The leaching of lead into drinkable water exposes people particularly children to harmful effects of lead. In view this, it is necessary to search for other elements that can eventually replace lead and offering the advantages provided by lead.

Nigerian taps (Brass Tap1, Brass Tap 2 and Cast Iron Tap) were considered in the study and it was observed that the lead compositions are 2.14%, ~ 5.81% and 0.011% respectively. The first two taps have percentages of lead which is above the allowable value of 0.25% given by most of the regulatory bodies. This brings the urgent need to consider alternative elements to replace lead.

Edwards, M. (2001). Role of phosphate inhibitors in mitigating lead and copper corrosion, American Water Works Association.

Surprisingly, although phosphate-based inhibitors are used at utilities serving more than half the U.S. population, at the time this work was undertaken, many fundamental questions remained unanswered regarding their effect(s) on lead and copper corrosion. This research successfully answered some questions and provided some new insights as to important reactions occurring in pipes as well. Finally, some additional questions were raised that should be addressed in future research. At the outset, we note the potential limitations of the work.

First, there is no guarantee that trends noted in this study for inhibitors will be directly transferable to other waters of similar pH and alkalinity. Although it is believed that pH and alkalinity are two of the most important factors influencing corrosion and inhibitor behaviour, other factors, such as chloride, hardness, disinfectant type and dose, stagnation and flow, and temperature, are undoubtedly important.

Second, with respect to lead release, it is well known that mechanisms of release differ based on the source of lead (brass, pure lead, solder, etc.), whether the material is galvanically coupled to a more noble metal such as copper, and other factors. This work exclusively examined the effects of water quality on pure lead pipes. Given the lack of information regarding corrosion of other lead containing plumbing materials, it is often assumed that trends noted for pure lead apply. Although this assumption provides some basis for decision making, we note that the validity of this hypothesis has not been rigorously tested, and in fact there is reason to believe that it is not valid in many circumstances. Thus, as with any research report, results described below must be interpreted and applied with caution.

In sum, the previous practical research has demonstrated that phosphate-based inhibitors profoundly impact lead and copper by-product release. In research done to date, researchers rarely have been able to draw conclusions demonstrating cause and effect relationships, much less identify how inhibitors actually work. Moreover, the existing literature cannot be revisited to compare and contrast inhibitor effects because key data such as temperature, pH and alkalinity usually were not reported.

Because inhibitors can act through a variety of water quality dependent mechanisms, an important first step towards improved understanding would be to investigate inhibitor impacts in detail for a few important water qualities. When coupled with additional laboratory work designed to examine fundamentals of polyphosphate reversion, complexation, dissolution and precipitation, a foundation for improved understanding may be provided.

Edwards, M. (2004). "Controlling corrosion in drinking water distribution systems: a grand challenge for the 21st century." Water Science and Technology 49(2): 1-8.

It is argued that the water distribution system will be a key public health battlefield of the 21st century. Corrosion in private plumbing is deserving of special attention, since the health and economic impacts are probably of equal or greater magnitude compared to public systems, and there has not been an advocate working on behalf of the consumer to solve these problems. To better serve society in this endeavour we will need educational programs, aggressive research to minimize the unsustainable costs of corrosion, and to consider our legacy to future generations when making decisions on materials use.

Edwards, M. and A. Dudi (2004). "Role of chlorine and chloramine in corrosion of lead-bearing plumbing materials." Journal American Water Works Association 96(10): 69-81.

A switch from free chlorine to chloramine disinfectant triggered problems with excessive lead in Washington, D.C., drinking water. High levels of lead originated in the service lines, but excessive lead was also derived from solder or brass plumbing materials. In many cases, the highest lead concentrations emerged from the tap after about 1 minute of flushing, a troublesome outcome, given that routine public notification recommended that consumers flush for about a minute to minimize lead exposure. Bench-scale testing found that chlorine reacts with soluble Pb^{+2} to rapidly precipitate a red-brown-colored lead solid that was insoluble even at pH 1.9 for 12 weeks; this solid did not form in the presence of chloramine. Further experiments indicated that chloramines sometimes dramatically worsened lead leaching from brass relative to free chlorine, whereas new lead pipe was not strongly affected.

Edwards, M., et al. (1999). "Desktop guidance for mitigating Pb and Cu corrosion by-products." American Water Works Association. Journal 91(5): 66.

Utility experiences were examined to assess the reliability of solubility models and decision trees in forecasting control of lead (Pb) and copper (Cu) corrosion byproducts. Such approaches cannot quantitatively predict effectiveness of corrosion control. For example, even the best fit solubility models explain only about 35 and 18 percent of the quantitative variation in 90th percentile Cu and Pb release, respectively. However, the decision trees and solubility models are qualitatively consistent with utility experience and are thus useful when promising water quality changes are identified to mitigate corrosion byproduct release. Utility experiences confirm that an optimal alkalinity range (20-40 mgf/L as $CaCO_3$) exists for Pb corrosion control above pH 8.5, a higher mass ratio of chloride to sulfate tends to worsen Pb byproduct release, and detectable color can signal a natural organic material content that may adversely affect compliance with the Cu action limit.

Edwards, M., et al. (2005). "Unintended consequences of chloramine hit home." proceedings of the Water Environment Federation 2005(1): 240-256.

The known drawbacks of chloramination include nitrification, elastomer decay, and required pre-treatment steps for fish culture and dialysis patients. To date, there has been no explicit consideration of adverse consequences of chloramination on property and water quality in buildings. Specifically, the effect of chloramine on re-growth of bacteria during stagnation, plumbing failures and lead leaching are poorly understood.

Potential problems with bacterial re-growth can arise in building plumbing systems after chloramines decay and form free ammonia. Autotrophic nitrifying bacteria convert the free ammonia to nitrite and nitrate while creating organic carbon in the form of biomass and

soluble microbial products. The levels of organic carbon created by nitrifiers are sufficient to support the growth of heterotrophic (HPC) bacteria. In one water tested with long stagnation times, HPC reached 106-107 cfu/ml using chloramines, whereas HPC was 1000x less when chlorine disinfectant was used. The decay of chlorine does not release nutrients for bacterial growth—a significant advantage relative to chloramine in situations with low flow and long detention times. Because the water within home plumbing is rarely sampled for bacteria, the true extent of the problem is not detected by routine distribution system monitoring using flushed samples.

A switch to chloramine may increase lead leaching, brass failures and pinhole leaks under at least some circumstances. Of these problems, pinhole leaks and brass failures have the largest potential economic consequence. For instance, a single re-plumb can cost an individual consumer 500x more than the median annual projected cost of the Stage 2 regulation. The adverse public health impacts of mold growth from pinhole leaks, lead leaching and bacterial re-growth deserve consideration. While these problems may eventually prove to be rare events, they have significant consequences for the unfortunate consumers who are impacted. If these events prove to be widespread, alternatives to chloramine will become more attractive despite higher initial cost to utilities.

Edwards, M. and L. S. McNeill (2002). "Effect of phosphate inhibitors on lead release from pipes." Journal (American Water Works Association) 94(1): 79-90.

This paper examines the relative effects of polyphosphates versus orthophosphates on tap water in pipes of various ages (three years, six months, and two weeks in age). Although orthophosphate dosing reduced soluble lead release by about 70% in most cases, increased lead release was observed in the new pipes. Hexametaphosphate increased soluble lead release over a broad range of water qualities, with each milligram per liter of residual hexametaphosphate increasing soluble lead release by about 1.6 mg/L, compared with orthophosphate. On the basis of these results and other researchers' findings, polyphosphate cannot be recommended for lead corrosion control. Polyphosphate still offers important benefits for preventing scaling and precipitation of iron or manganese and facilitating certain types of iron corrosion control. However, utilities may want to determine the minimum polyphosphate dose that achieves these goals because detriments to maximum soluble lead in pipes during stagnation are proportional to the residual polyphosphate.

Edwards, M., et al. (2001). The role of pipe ageing in copper corrosion by-product release. Pipe Material Selection in Drinking Water Systems. B. Berghult, A. E. Broo and T. Hedberg. 1: 25-32.

The presence of sulphate, bicarbonate and orthophosphate can change the type of solid present in systems containing cupric ion or cupric hydroxide solids. In some cases, a short-term reduction in copper solubility is realized, but over longer periods of time formation of basic cupric sulphate (brochantite) and even cupric phosphate can ultimately prevent the formation of very insoluble tenorite or malachite phases. To the extent that this occurs, the presence of sulphate and phosphate in water can increase copper solubility over much longer time periods. The relative effect can depend on the anion concentration and the rate of solids precipitation. Low levels of sulphate tend to hasten the transition from cupric hydroxide to tenorite, whereas higher levels of sulphate can interfere with that transition. These possible effects should be considered when attempting to reduce copper corrosion by-product release from consumer plumbing and similar transitions are likely important for other plumbing materials such as zinc, iron and lead.

Edwards, M., et al. (1996). "Alkalinity, pH, and copper corrosion by-product release." Journal American Water Works Association 88(3): 81-94.

Contrary to expectations, higher bicarbonate concentrations exacerbate copper corrosion rates and by-product release. In fact, as illustrated by monitoring experiences of large utilities and by laboratory data, the concentration of copper corrosion by-products in drinking water increases linearly with bicarbonate concentration at constant pH. This relationship implicates cupric hydroxide solubility in control of copper release from relatively new (less than a few years old) copper plumbing. Decision-making guidance from a traditional Larson's ratio or Langelier index approach can aggravate copper corrosion problems; consequently, their use should be discontinued for copper corrosion mitigation. In contrast, aeration CO₂ stripping is a particularly attractive strategy because benefits from higher pH are realized without adverse effects from higher alkalinity.

Edwards, M. and S. Triantafyllidou (2007). "Chloride-to-sulfate mass ratio and lead leaching to water." Journal American Water Works Association 99(7): 96-109.

Experimental tests and utilities' practical experience highlighted the importance of chloride-to-sulfate mass ratio (CSMR) in the control of lead leaching to potable water. The effect of higher CSMR was demonstrated in bench-scale experiments using brass coupons and lead solder-copper pipe joints, with the amount of lead leaching to water increasing by factors of 1.2-2.7 and 2.3-40.0, respectively. Anion exchange treatment, a switch in coagulant type, and other seemingly innocuous treatment steps can result in significant changes in CSMR. Practical data collected at three US utilities confirmed that alterations in CSMR can trigger serious lead contamination incidents.

Edwards, M., et al. (2009). "Elevated Blood Lead in Young Children Due to Lead-Contaminated Drinking Water: Washington, DC, 2001-2004." Environmental Science and Technology 43(5): 1618-1623.

Incidence of EBL (blood lead ≥ 10 $\mu\text{g/dL}$) for children aged ≤ 1.3 years in Washington, DC increased more than 4 times comparing 2001-2003 when lead in water was high versus 2000 when lead in water was low. The incidence of EBL was highly correlated ($R^2 = 0.81$) to 90th percentile lead in water lead levels (WLLs) from 2000 to 2007 for children aged ≤ 1.3 years. The risk of exposure to high water lead levels varied markedly in different neighborhoods of the city. For children aged ≤ 30 months there were not strong correlations between WLLs and EBL, when analyzed for the city as a whole. However, the incidence of EBL increased 2.4 times in high-risk neighborhoods, increased 1.12 times in moderate-risk neighborhoods, and decreased in low-risk neighborhoods comparing 2003 to 2000. The incidence of EBL for children aged ≤ 30 months also deviated from national trends in a manner that was highly correlated with 90th percentile lead in water levels from 2000 to 2007 ($R^2 = 0.83$) in the high-risk neighborhoods. These effects are consistent with predictions based on biokinetic models and prior research.

Edwards, M. A. (2008). "Response to Comment on "Nitrification in Premise Plumbing: Role of Phosphate, pH, and Pipe Corrosion". Study Used Conditions That Are Realistic and Representative." Environmental Science and Technology 42(21): 8171-8171.

Response to Comment on "Nitrification in Premise Plumbing: Role of Phosphate, pH, and Pipe Corrosion". Study Used Conditions That Are Realistic and Representative We disagree with Mr. Brown's statement that the experiments were a "set up" not representative of actual conditions present in some consumers' homes. First, while it is true that most utilities dose chloramine and chlorine disinfectant to water at the treatment plant,

the chlorine residual disinfectant can disappear completely by the time the water reaches many home plumbing systems. This is one reason that the National Research Council recently identified problems in premise plumbing as a high priority for future research (see Chapter 8, of the National Research Council Report (NCR) Drinking Water Distribution System: Assessing and Reducing Risks). That report also contains data illustrating that, even if free chlorine or chloramine are present in the water coming into the homes, it can disappear very rapidly via reactions with home plumbing systems as it sits in the pipe. Hence, our testing without any disinfectant present is perfectly representative of what occurs in many homes. The longer stagnation or storage times used in our tests occur routinely in plumbing when consumers do not use their water overnight or during vacations. Second, this research was funded by the United States Environmental Protection Agency and the Awwa Research Foundation (AwwaRF), in large part, because of widely recognized "real world" problems with nitrification. Rampant nitrification occurs in many water distribution systems that use even very high levels of chloramine (>3 mg/L). Even without stagnation and in the presence of this high chloramine, nitrifiers become established in water mains and distribution systems and there are dozens of peer reviewed papers on this subject (see for example, the EPA white paper currently at http://www.epa.gov/ogwdw/disinfection/tcr/pdfs/whitepaper_tcr_nitrification.pdf). Third, there are several case studies in the literature that document large pH drops occurring overnight in premise plumbing due to nitrification and other reactions. For example, we have recently published data collected from "real" consumer homes, in which the pH dropped more than was reported in our paper (see Zhang et al., ASCE Journal of Environmental Engineering, July 2008, page 521). Specifically, we recorded a drop in pH in some homes in Maui, Hawaii from 7.89 to 6.77. In Washington DC, the pH dropped from 7.9 to 6.7 in some instances. We have even seen cases where the pH in home plumbing dropped to 5.2, although we do not yet fully understand the circumstances which contribute to these very large pH decreases. These large pH drops in home plumbing have been observed in situations where up to 4 mg/L free chloramine disinfectant residual (the highest level allowed by law) was present in the water that is supplied to the building. In conclusion, our study is perfectly consistent with, and can explain, many practical published observations regarding the prevalence and occurrence of nitrification. The results are also consistent with several real world observations regarding lead and copper corrosion issues that occur in systems plumbed with and without plastic (as per the Kimbrough study). The notion that our results are "speculative" and have little to do with real-life is simply incorrect.

Elfland, C., et al. (2010). "Lead-contaminated water from brass plumbing devices in new buildings." Journal American Water Works Association 102(11): 66-76.

Lead in water is often assumed to be a problem in older buildings, not in new construction if appropriate plumbing standards have been followed. Exhaustive sampling by researchers from the University of North Carolina at Chapel Hill shows that this is not the case, even for devices that have passed the relevant NSF International 61 standard. The lead-in-water problem can be mitigated by enhanced commissioning procedures for the new brass before occupancy, but more drastic measures such as replacing inline valves may be needed. With existing plumbing materials and codes, it is not possible to put forth protocols and standards that guarantee compliance with the 15-µg/L U.S. Environmental Protection Agency (USEPA) action limit or the 20-µg/L Lead Contamination Control Act guidance level in a newly installed tap. Increased awareness of the problem of lead in water from inline devices may lead utility managers to further refine their corrosion control regimen and the USEPA to revise the Lead and Copper Rule to better protect public health by considering potential problems in new construction.

Elfland, C. W. and M. A. Edwards (2011). "Article reporting on lead contamination from brass plumbing devices in new buildings sparks discussion-Respond." Journal American Water Works Association 103(1): 10-13.

CONCLUDING COMMENTS

On the basis of our extensive experiences, we do not believe that NSF, or anyone, will be capable of devising a certification protocol that will guarantee that levels of lead in water will meet US Environmental Protection Agency requirements when leaded brass devices are used. There are too many independent variables, including the alloy, manufacturing process, plumbing system design, installation process, consumer water use patterns, source water characteristics, and utility water treatment protocols. Because we feel that independent academic research is essential to improving the NSF certification process - which has an inherent conflict of interest because manufacturers pay NSF for certification - we will continue to share our insights on these issues directly with NSF and through peer-reviewed research. Although NSF standards have significantly reduced lead-in- water hazards (especially for endpoint devices such as faucets that are subject to much more rigorous testing than section 8 devices), there has also been a paradigm shift with respect to lead. We now are focused on eliminating individual cases of childhood lead poisoning or even levels of lead in water that could increase a child's blood lead level just 1 pg/dL. For problematic fountains at UNC (that thankfully were never brought into service), the level of contamination was sufficient to have induced spontaneous abortions via consumption of a single glass of water. Use of new leaded-brass plumbing products stands in stark contrast to legacy problems from lead plumbing products (i.e., lead pipes and solder) installed in millions of buildings throughout the United States. New leaded-brass devices are not a past mistake, now recognized, that society must live with and manage. These devices are manufactured and installed every day, creating new problems for future generations. Although lax NSF 61 section 8 performance standards are only partly to blame - and we applaud recent attempts to increase the rigor of this test - we believe the new performance standards, by themselves, do not and cannot go far enough.

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Estelle, A. A. (2016). "Drinking water lead regulations: impact on the brass value chain." Materials Science and Technology 32(17): 1763-1770.

A detailed review of regulations restricting the use of lead in potable water systems is provided in several regions including the United States (U.S.), Canada, the European Union (E.U.) and Japan to assess the impact on the brass value chain. Covered topics include: chronology of regulations, governing bodies, compliance requirements, enforcement mechanisms and other aspects relevant to metal suppliers, original equipment manufacturers, designers, specifiers, end-users and recyclers of brass. The development and use of lead-free brass alloys and how these materials have impacted manufacturing and recycling processes is also addressed. This paper is part of a Themed Issue on Brass Alloys.

Fabbricino, M., et al. (2005). "Copper release in drinking water due to internal corrosion of distribution pipes." Global Nest Journal 7(2): 163-171.

The present paper deals with water quality modification during its stagnation in copper distribution pipes caused by electrochemical corrosion processes. Copper is chosen as plumbing material because of its wide use in drinking water distribution systems all around the world and because of its recognized toxicity at high dosages. Several experiments are developed, varying water composition and stagnation length, to ascertain the dependence of copper release on both parameters. The effect of different concentrations of bicarbonates, sulphates and phosphates on metal release is studied, assuming stagnation periods ranging from 15 to 90 minutes. The corrosion potential of the metal surface during stagnation episodes is also monitored to verify the existence of a direct correlation between this potential at the end of each stagnation episode, and the corresponding total dissolved copper concentration in the stagnating water. The correlation allows to quantify copper release in drinking water, measuring the corrosion potential, drastically reducing, in this way, the cost of water quality monitoring.

Fawell, J. and G. Stanfield (2001). Drinking water quality and health. Pollution: Causes, Effects, and Control: 59-81.

Lead in drinking water arises from dissolution from plumbing materials and lead pipes in particular. Lead has been used in plumbing since Roman times and the word plumber even comes from the Latin for lead ...See P68 Ch 3

Francis, R. (2011). "More on dezincification of brass plumbing devices." Materials Performance 50(8): 10-10.

I read with interest the article on dezincification by Sarver, et al. in the May 2011 issue of *MP* (p. 70) and I thought that the following comments might be helpful.

I worked at BNF Metals Technology Centre in the United Kingdom in the 1970s and 1980s, where a lot of the research on dezincification and dezincification-resistant (DZR) brass was carried out. I have also been contributing to the current revision of ISO 6509. The test in the ISO standard was only ever intended as a rapid method of determining whether a brass would suffer dezincification in an aggressive water. When DZR brass was developed at BNF we carried out an evaluation of rapid tests and compared them against longterm (up to one year) exposures in a number of U.K. waters known to cause dezincification. The results showed that the Swedish test (now in ISO 6509) was the best, but different pass/fail limits were imposed in different countries. In the United Kingdom, an alloy must show attack not exceeding 100 μm for a forging or in the transverse direction for extruded material to pass. In the longitudinal direction, this increases to 200 μm . In Sweden, these depths are 200 and 400 μm , respectively. The reason for this is that waters that cause dezincification vary in their aggressiveness, but why this is so is not known. The Turner diagram predicts aggressive waters using chloride content and total alkalinity, but it does not predict which ones will be most aggressive.

In Sweden, experience shows that their pass/fail limits mean that dezincification failures are rare. In the BNF tests in the United Kingdom, alloys that passed the Swedish criteria showed dezincification in the most aggressive U.K. water (a hard water in Essex), and so tighter pass/fail criteria were set by the U.K. National Water Council. To my knowledge there have been no failures in the United Kingdom of DZR brass fittings that pass the U.K. test criteria. The ISO 6509 test was never intended to predict metal dissolution into solution and BNF tried in the 1980s to devise a rapid test for leaded plumbing fittings that would predict the longterm lead dissolution rates in service. However, the results were erratic and different alloys responded differently to the various tests. The surface finish had a big



effect, but results were confusing because dissolution rates were relatively high in the first few days until a protective film formed. After this, dissolution rates were much lower. A rapid test to predict lead dissolution rates is still required. Unfortunately, all of the old BNF research reports on dezincification and lead dissolution (along with much else) were destroyed when the company went bankrupt in 1992. I have preserved what knowledge I still retained in my recent book, *The Corrosion of Copper and Its Alloys—A Practical Guide for Engineers*, which was published by NACE International last year.

Roger Francis, FNACE, Rolled Alloys, Blackburn, United Kingdom

Gagnon, G. A. and J. D. Doubrough (2011). "Lead release from premise plumbing: a profile of sample collection and pilot studies from a small system." Canadian Journal of Civil Engineering 38(7): 741-750.

The objective of this project was to examine the ability of a small system to meet new corrosion control operational guidelines in Canada. This study was conducted in three parallel program areas: (a) use of community volunteers, (b) sampling at controlled municipal buildings, and (c) conducting a pilot-scale program. The study site was a community with an approximate population of 7000. The water quality of the treated water had a low alkalinity (<5 mg/L as CaCO₃) and a target pH range of 7.0–7.5. The plant corrosion control program consisted of pH adjustment with sodium hydroxide (NaOH) and the addition of an orthophosphate–polyphosphate blend at a dose of 1.0 mg/L (as product). From the volunteer sample sites, it was found that all collected water samples were below the Canadian health-based guideline for lead of 10 µg/L. For the municipal building sites, 20 consecutive 1 L samples were used to identify lead occurrence. Two sites exceeded 10 µg/L for some sequential samples, however only one site (public works building) exceeded the guideline in the first 2 L. The public works building had the lowest pH (~7.0), whereas other sites had pH values closer to 7.4. Pilot-scale studies further confirmed that lead release was an issue at a pH of 7.0 and could be better managed at a pH of 7.5 or above. This study demonstrated that small systems need to ensure that water quality factors (e.g., pH stability), in addition to corrosion inhibitors, are managed and optimized to ensure successful corrosion control programs.

Gardels, M. C. and T. J. Sorg (1989). "A laboratory study of the leaching of lead from water faucets." Journal (American Water Works Association): 101-113.

Twelve faucets, representing various designs, materials of construction, and manufacturers, were studied in the laboratory to develop additional information about the leaching of lead and other metals from common kitchen faucets. It was found that new cast-brass faucets could contribute lead to drinking water in excess of the proposed no action level of 10 µg/L. Also, 60-75 percent of the lead leached from a faucet appeared in the first 125 mL of water collected from the faucet. After 200-250 mL of water had flowed, 95 percent or more of the lead had normally been flushed from the faucet. Determining the maximum lead concentration from a faucet requires that both cold and hot water sides of the faucet be sampled and that the samples be no larger than 100-125 mL.

Gonzalez, S., et al. (2013). "Presence of metals in drinking water distribution networks due to pipe material leaching: a review." Toxicological & Environmental Chemistry 95(6): 870-889.

Drinking water quality should remain constant from the drinking water treatment plant to the consumer's tap. However, water quality characteristics might be affected by interactions with pipe materials. This review describes the iron, copper, lead, zinc, aluminum,

chromium, and cadmium in drinking water leached from the pipe material present in drinking water, as well as the factors and mechanisms that affect leaching processes. Data analysis suggests that monitoring the water quality in distribution systems is important for their proper management; however, the low measured concentrations highlight the need for sensitive sensors. In addition, further research is necessary to anticipate possible future effects before the installation of new materials/infrastructure or changes in water source/treatment.

Gregory, R. (1990). "Galvanic corrosion of lead solder in copper pipework." Water and Environment Journal 4(2): 112-118.

The galvanic corrosion potentials of thirty-eight different waters were measured on site, using 'Oliphant' corrosion cells, for lead-tin solder coupled to copper. A wide range in corrosion potential was found, and the chloride-sulphate ratio had the most significant effect on corrosion potential. Tests to reduce corrosion potentials by dosing sulphate, silicate, zinc and orthophosphate were carried out. Zinc dosing, especially in combination with orthophosphate, was the most effective treatment for all waters, but posed problems.

Contamination of tapwater by galvanic corrosion of lead solder occurs early in the life of new plumbing, and risk of exposure to contamination can be reduced by flushing before drawing dietetic water. Best-of-all, lead-tin solder should not be used.

Gulson, B. L., et al. (1994). "Effect of plumbing systems on lead content of drinking-water and contribution to lead body burden." Science of the Total Environment 144: 279-284.

Stable lead isotopes and lead contents in drinking water from a number of Australian cities have been measured to determine the contribution of drinking water to body burden. Lead contents are generally $< 2 \mu\text{g/l}$ and thus contribute an insignificant amount to the lead budget in humans in Australia. First-flush and running water samples taken at intervals of up to 10 min show that equilibrium is reached within 1 min or approximately 10 l by volume. There is, however, large variability in both lead content and isotopic composition within the first minute which brings into question the reliability of the recommended sampling time of 30 s. Extremely large isotopic differences between individual dwellings within the one city and between dwellings and the storage tanks for the water supply are attributed to differences in lead residing in the plumbing within the dwellings, usually from lead solder in brass fittings. Isotopic analysis of solder and water from two dwellings confirm this relationship.

Hall, E. and E. Murphy (1993). "Determination of sources of lead in tap water by inductively coupled plasma mass spectrometry (ICP-MS)." Journal of radioanalytical and nuclear chemistry 175(2): 129-138.

We measured the concentrations of Pb and its isotope ratios in concomitantly obtained tap water and plumbing materials by inductively coupled mass spectrometry (ICP-MS). The Pb concentrations were determined by external calibration with ^{209}Bi as an internal standard. Isotope ratios were measured and mass discrimination corrected by normalization to NIST SRM-981 (common lead isotopic standard). Student's t-test was used to compare the isotopic ratios of $^{206}\text{Pb}/^{207}\text{Pb}$, $^{206}\text{Pb}/^{208}\text{Pb}$, and $^{207}\text{Pb}/^{208}\text{Pb}$ in the tap water with those in various plumbing materials. The comparisons revealed that the source of Pb in most of the tap water samples was derived from copper pipe or solder.

Harms, L. L., et al. (1994). Water chemistry of lead corrosion control, American Society of Civil Engineers, New York, NY (United States).

Requirements of the Lead and Copper Rule (US EPA) makes it necessary for regulators, consultants, and water purveyors to understand the fundamental relationships between water quality and lead leaching from lead based plumbing materials. This paper will address the basic concepts of water chemistry as they apply to the control of lead corrosion.

Harvey, P. J., et al. (2015). "Identification of the sources of metal (lead) contamination in drinking waters in north-eastern Tasmania using lead isotopic compositions." Environmental Science Pollution Research International 22(16): 12276-12288.

This study utilises a range of scientific approaches, including lead isotopic compositions, to differentiate unknown sources of ongoing lead contamination of a drinking water supply in north-eastern Tasmania, Australia. Drinking water lead concentrations are elevated above the Australian Drinking Water Guideline (10 µg/L), reaching 540 µg/L in the supply network. Water lead isotopic compositions from the town of Pioneer ((208)Pb/(207)Pb 2.406, (206)Pb/(207)Pb 1.144 to (208)Pb/(207)Pb 2.360, (206)Pb/(207)Pb 1.094) and Ringarooma ((208)Pb/(207)Pb 2.398, (206)Pb/(207)Pb 1.117) are markedly different from the local bedrock ((208)Pb/(207)Pb 2.496, (206)Pb/(207)Pb 1.237). The data show that the lead in the local waters is sourced from a combination of dilapidated drinking water infrastructure, including lead jointed pipelines, end-of-life polyvinyl chloride pipes and household plumbing. Drinking water is being inadvertently contaminated by aging infrastructure, and it is an issue that warrants investigation to limit the burden of disease from lead exposure.

Harvey, P. J., et al. (2016). "Widespread copper and lead contamination of household drinking water, New South Wales, Australia." Environmental Research 151: 275-285.

This study examines arsenic, copper, lead and manganese drinking water contamination at the domestic consumer's kitchen tap in homes of New South Wales, Australia. Analysis of 212 first draw drinking water samples shows that almost 100% and 56% of samples contain detectable concentrations of copper and lead, respectively. Of these detectable concentrations, copper exceeds Australian Drinking Water Guidelines (ADWG) in 5% of samples and lead in 8%. By contrast, no samples contained arsenic and manganese water concentrations in excess of the ADWG. Analysis of household plumbing fittings (taps and connecting pipework) show that these are a significant source of drinking water lead contamination. Water lead concentrations derived for plumbing components range from 108 µg/L to 1440 µg/L (n=28, mean - 328 µg/L, median - 225 µg/L). Analysis of kitchen tap fittings demonstrates these are a primary source of drinking water lead contamination (n=9, mean -63.4 µg/L, median - 59.0 µg/L). The results of this study demonstrate that along with other potential sources of contamination in households, plumbing products that contain detectable lead up to 2.84% are contributing to contamination of household drinking water. Given that both copper and lead are known to cause significant health detriments, products for use in contact with drinking water should be manufactured free from copper and lead.
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Hayes, C. R. and O. D. Hydes (2012). "UK experience in the monitoring and control of lead in drinking water." Journal of Water and Health 10(3): 337-348.

At the zonal scale (e.g. a city or town), random daytime (RDT) sampling succeeded in demonstrating both the need for corrective action and the benefits of optimised orthophosphate dosing for plumbosolvency control, despite initial concerns about sampling reproducibility. Stagnation sampling techniques were found to be less successful. Optimised treatment measures to minimise lead in drinking water, comprising

orthophosphate at an optimum dose and at an appropriate pH, have succeeded in raising compliance with the future European Union (EU) lead standard of 10 µg/L from 80.4% in 1989-94 to 99.0% in 2010 across England and Wales, with compliance greater than 99.5% in some regions. There may be scope to achieve 99.8% compliance with 10 µg/L by further optimisation coupled to selective lead pipe removal, without widespread lead pipe removal. It is unlikely that optimised corrosion control, that includes the dosing of orthophosphate, will be capable of achieving a standard much lower than 10 µg/L for lead in drinking water. The experience gained in the UK provides an important reference for any other country or region that is considering its options for minimising lead in their drinking water supplies.

Hayes, C. R. and N. D. Skubala (2009). "Is there still a problem with lead in drinking water in the European Union?" Journal of Water and Health 7(4): 569-580.

The presence of lead in drinking water poses a range of risks to human health, including the retardation of some aspects of child development, the inducement of abortion, and other clinical disorders. The extent of these risks has not been quantified at the European Union (EU) scale. A number of sampling methods are in use across the EU, some of which are inadequate for determining the concentrations of lead in drinking water at consumers' taps. In consequence, non-compliance with the EU standards for lead in drinking water has been under-estimated. Emerging data indicates significant non-compliance with these standards in some countries, particularly with the 10 µg l⁻¹ standard that will become a legal requirement in 2013; the current interim standard of 25 µg l⁻¹ is also exceeded in some locations. An initial estimate is that 25% of domestic dwellings in the EU have a lead pipe, either as a connection to the water main, or as part of the internal plumbing, or both, potentially putting 120 million people at risk from lead in drinking water within the EU. These issues are relevant to the implementation of the Protocol on Water and Health and to drinking water safety planning.

Hill, K. (2014). The dangers of lead solders. Heating and Plumbing Monthly.

Since the 1980s, use of lead solder for jointing copper pipes has been prohibited for plumbing systems supplying wholesome water for drinking, cooking or bathing. Under the Water Fittings Regulations, solder containing lead can be used only on non-drinking water installations where the water is not required to be wholesome, such as closed circuit central heating systems.

Despite this, UK water suppliers still find examples of recent installations where lead solders have been used illegally. In 2013, the Drinking Water Inspectorate received reports from water suppliers of 11 routine drinking water quality check samples exceeding the permitted amount of lead. In a recently-built luxury apartment block investigated by one water supplier, tap water samples contained more than 12 times the permitted amount of lead. Five or six joints on short lengths of distribution pipe entering each apartment had been made using solder containing lead. Enforcement notices under the Water Fittings Regulations required the developer to replace every suspect joint – at his own cost. Most people know lead is a dangerous metal which can cause serious poisoning if too much enters the body. It has been banned in petrol, paint and plastics and to reduce human exposure via drinking water, at the end of 2013 the permitted maximum was further reduced by 60% to ten micrograms per litre (one part in 100 million). Using lead-free solder isn't just a legal requirement, it safeguards customers' health. In another incident, a little boy and his father suffered from lead poisoning which was directly attributable to the illegal use of leaded solder.

Hodge, J. (2017) ABC News: Lead fears in Queensland homes after hot water system contractor used incorrect solder.

Almost 800 homeowners are being warned that a contractor who installed hot water systems across south-east Queensland used a potentially toxic solder product, but the contractor says the warning is a "beat up" and claims it is retaliation against him from authorities. An investigation by the Queensland Building and Construction Commission (QBCC) found plumbing-electrical contractor Brett George Hogan had been using a solder product for hot water systems with a lead content above the national standard. Mr Hogan worked in areas including the Fraser and Sunshine coasts, Caboolture, Logan, and Moreton Bay. The public warning also relates to Mr Hogan trading as Hot Water One. The solder is frequently used in electrical work but is not appropriate for plumbing work due to the potential risk of contamination of the water supply.

Holm, T. R. and M. R. Schock (1991). "Polyphosphate Debate." Journal-American Water Works Association 83(12): 10-12.

A reader writes that an article (Potential Effects of Polyphosphate Products on Lead Solubility in Plumbing Systems, Journal AWWA, July 1991) creates unwarranted concern about the increase in lead solubility from polyphosphates in potable water. The major error in the article, this letter-writer contends, is the use of stability constants. The authors reply that the criticisms consist of red herrings, smoke, and innuendo, and go on to defend their article in detail.

Holm, T. R. and M. R. Schock (1991). "Potential effects of polyphosphate products on lead solubility in plumbing systems." Journal American Water Works Association 83(7): 76-82.

Lead concentrations in drinking water can be minimized by adjusting the pH and alkalinity. Such lead solubility controls, however, may be offset by other water treatment measures that inadvertently increase lead solubility, e.g., the adding of polyphosphate-containing products. Through the use of solubility computations, the authors of this article conclude that, at best, the application of polyphosphates for the specific purpose of lead corrosion control entails considerable uncertainty and risk.

Hong, P. A. and Y.-Y. Macauley (1998). "Corrosion and leaching of copper tubing exposed to chlorinated drinking water." Water, Air, and Soil Pollution 108(3-4): 457-471.

The leaching of lead and copper from plumbing materials is a source of metals in drinking water and is a public health concern. This work investigated the influence of free chlorine (HOCl/OCl-) on the level of copper in water in contact with the solid metal, and proposed an oxidation-dissolution mechanism to explain copper leaching. Experimental results are presented for the leaching of copper metal exposed to chlorine-disinfected water under various pH, free chlorine, dissolved oxygen, total carbonate, chloride, and water volume conditions. The rate of copper leaching is found to be accelerated in waters with high free chlorine concentrations and low pHs. The leaching is explained by a proposed mechanism involving two consecutive steps: (1) direct oxidative attack on the solid metal surface by the free chlorine, followed by (2) dissolution of the partially oxidized copper surface as determined by the solubility of the copper mineral products at a particular pH.

Howell, R. B., et al. (1985). "Roundtable—Should Lead Solder Be Banned?" Journal-American Water Works Association 77(11): 12-30.

This article discusses the banning of the use of lead solder in water distribution systems and whether such a ban is justified. Steps taken by individual states to regulate the use of lead solder are described and practical problems resulting from these actions are addressed.

Hoyt, B. P., et al. (1979). "Evaluating home plumbing corrosion problems." Journal-American Water Works Association 71(12): 720-725.

Although the utility has been made responsible for water quality degradation caused by corrosion, there is presently no approved way to document compliance. The authors also believe that federal guidance in identifying and solving domestic water corrosion problems is lacking, but that the Environmental Protection Agency (EPA) could help to fill this void by preparing a manual that would define the state of the art in corrosion testing and water quality monitoring at the customer's tap.

Hu, J., et al. (2012). "Copper-Induced Metal Release from Lead Pipe into Drinking Water." Corrosion 68(11).

The effect of added cupric ions (0 mg/L to 5 mg/L Cu²⁺) on possible deposition corrosion of lead pipe was investigated in bench-scale experiments under flowing and stagnant water conditions. Under stagnation the presence of cupric ions in the water feeding lead pipes marginally increased lead release into the water, but under continuous recirculation it could increase lead release by orders of magnitude. Other bench-scale experiments investigated galvanic corrosion between lead and copper pipes under stagnation, confirming that water chemistry (particularly the chloride-to-sulfate mass ratio [CSMR]) is a controlling factor in either "strengthening" galvanic corrosion and increasing water lead contamination by orders of magnitude (high CSMR water) or "weakening" the galvanic effect with less but still significant contribution to water lead contamination (low CSMR water). Longitudinal water pH measurements along the length of the galvanic rigs revealed a significant pH drop close to the lead: copper junction at relatively short stagnation times in high CSMR water, which is consistent with the observations of higher lead leaching and higher galvanic current measured in that situation.

Hu, J., et al. (2010). "A historical review and bibliometric analysis of research on lead in drinking water field from 1991 to 2007." Science of the Total Environment 408(7): 1738-1744.

A bibliometric analysis based on Science Citation Index (SCI) published by Institute of Scientific Information (ISI) was carried out to identify the global research related to lead in drinking water field from 1991 to 2007 and to improve the understanding of research trends in the same period. The results from this analysis indicate that there have been an increasing number of annual publications mainly during two periods: from 1992 to 1997 and from 2004 to 2007. United States produced 37% of all pertinent articles followed by India with 8.0% and Canada with 4.8%. Science of the Total Environment published the most articles followed by Journal American Water Works Association and Toxicology. Summary of the most frequently used keywords are also provided. "Cadmium" was the most popular author keyword in the 17 years. Furthermore based on bibliometric results four research aspects were summarized in this paper and the historical research review was also presented.

Johansson, L. (2012). Methods for assessment of lead release from brass to drinking water. Department of Civil, Environmental and Natural resources engineering. Stockholm, Luleå University of Technology. MSc.

Brass is a material widely used in drinking water applications such as faucets, mixers and fittings. Brass contains small amounts of lead (Pb) which may, under unfavourable circumstances, be released to the drinking water. The parameters which affect this release are many and not fully understood today. Among these parameters are water chemistry,

operation time, stagnation time, material composition, product geometry, treatment and processing of the material. The aim of this study is to summarize current knowledge about Pb contamination from brass products to drinking water and to compare three methods for assessment of Pb release; a European material test, a Scandinavian product test and an American product test. This study shows that a product will perform differently depending on the test method, and that the results from a short-term product test are not related to the results in a long term material test. The two product tests proved to give very different results; while all samples passed the Scandinavian product test, no sample passed the American product test. Furthermore, the Scandinavian product test has been proved to be unreliable due to a number of reasons such as low repeatability, inconsistency with current drinking water parametric value and test water which does not represent a worst case. The conclusion is that the choice of test method influences the result and that short-term test cannot be used to predict the outcome of a long term test. The current Scandinavian product approval is not a reliable method for long term testing of products.

Kamble, S. D. and G. R. Munavalli (2016). "Water quality in premise plumbing-A Review." International Journal of Research in Engineering and Technology 5(18): 83-86.

Water quality is now a growing concern throughout the world since water happens to be lifeline for human beings. Most of the research till date has focused on drinking water quality in distribution systems. But it has been reported that chemical and bacterial changes takes place as the water moves from distribution system to the consumers tap. Biofilms have been reported to occur in plumbing system. However not much data is available about the behavior of premise plumbing system with respect to Indian context as far as water quality is considered. The purpose of this study is to understand water quality in premise plumbing system. This article attempts to review various studies undertaken by researchers in order to assess water quality in plumbing system. The methodology of these studies and outcomes are learnt, with reference to Indian context. The gaps in studies and possible directions for future studies are also discussed in this article.

Katner, A., et al. (2016). "Weaknesses in Federal Drinking Water Regulations and Public Health Policies that Impede Lead Poisoning Prevention and Environmental Justice." Environmental Justice 9(4): 109-117.

The failure of the regulatory community to protect the residents of Flint, Michigan, from prolonged exposure to hazardous levels of lead in their drinking water has drawn public attention to long-acknowledged weaknesses in the implementation and oversight of the U.S. Environmental Protection Agency's (EPA's) Lead and Copper Rule (LCR). This rule defines the roles and responsibilities of water utilities in reducing consumer exposures to lead-in-water hazards. Despite this regulation, water-related lead poisoning cases have been documented in cities determined to be in regulatory compliance. This article presents preliminary results from an ongoing study that documents gaps and weaknesses in the rule and its implementation, oversight, and enforcement. We detail how the original intent of the LCR to protect public health has been undermined by inadequate lead-in-water monitoring and public education, as well as weak regulatory oversight and enforcement. We summarize how these issues contributed to the Flint debacle and are still being perpetuated today in other municipalities. Finally, we discuss how these factors may be thwarting the prevention of childhood lead poisoning in the United States, and contributing to disproportionate environmental burdens on low-income communities. This review is timely, in that it may prompt public involvement in the U.S. EPA's ongoing review and revision of the LCR.

Kessel, I. and J. T. O'Connor (1997). Lead in Drinking Water. Getting the Lead Out, Springer: 141-152.

In most cases of lead poisoning, drinking water is not the primary cause, but only a contributing factor. Drinking water contributes about 20% of the lead exposure for an average 2-year-old, and from 5 to 50% for children generally. However, in some homes with corrosive water and lead pipes or fairly new lead solder, water could be the primary exposure route for lead. The most alarming occurrence of drinking water causing severe lead poisoning is that of an infant fed formula made with lead-contaminated tap water, in which case the water can account for 85% of the lead exposure, and can result in quite severe lead poisoning.¹

Kestin, J. and S. A. Goho (2017). Detecting lead in household tap water: sampling procedures for water utilities. Cambridge, MA Emmett Environmental Law & Policy Clinic Harvard Law School.

What is the purpose of this paper?

In this paper, we present recommendations for how water utilities should sample household tap water as part of a program to monitor the levels of lead in their customers' drinking water.

Who should read it?

This paper is directed at municipal water utilities, who can use it to inform their own sampling protocols; state environmental protection agencies, who can use it to establish statewide guidance; and individual water utility customers, who can advocate that their utility amend its sampling methods.

What kind of sampling do we address in this paper?

Different people may sample and test water from different places and for different purposes. For example, some samples are taken in private homes while others are taken in public buildings such as schools. The purpose may be for a utility to determine whether it is complying with the federal Lead and Copper Rule or it may be for the people in an individual household to identify the level of risk they face from their tap water. This paper focuses primarily on sampling carried out by utilities in private homes for purposes of Lead and Copper Rule (LCR) compliance.

What do we recommend?

The paper's main recommendations are that water utilities should:

- **Ensure that sampling sites genuinely represent at-risk homes:** Water utilities should constantly re-evaluate their sampling site selections to ensure that those homes do in fact contain lead pipes, lead solder, or a lead service line. If a water utility determines that one of its sampling sites does not have any lead plumbing, it should select another sampling site that comports with the requirements of the Lead and Copper Rule. Two ways to facilitate such substitutions are to identify as large a pool of eligible homes as possible and to ask customers to report any changes to their plumbing on sampling instruction forms.



- **Determine the best time of year for sampling:** Water utilities on a regular monitoring schedule should analyze data from their past samples to determine how the lead level in their customers' water fluctuates according to temperature. They should use these data to determine the best time of the year to collect their samples. However, if after analyzing the data from its own past samples, a water utility on a regular monitoring schedule is still unsure about which time of the year is best to conduct sampling, it should default to sampling during warmer months.
- **Collect additional samples:** The Lead and Copper Rule requires that utilities collect only a relatively small number of samples. For example, for a city of more than 100,000, the utility must collect only 100 samples per testing period if on standard monitoring and 50 if on reduced monitoring. Such a small sample size might miss serious problems, especially if the most at-risk homes are not in the sampling pool. If a water utility would like to be more confident that it is detecting any elevated levels of lead that are present in its customers' water, it should collect and test additional samples, beyond the minimum number required by the Lead and Copper Rule.
- **Institute a minimum nine-hour stagnation period:** When water sits in a lead service line for long periods of time, more lead can leach into the water. To better reflect the highest level of lead to which residents will be exposed after sleeping or a day at work, water utilities should instruct residents to not to run their water for nine hours before collecting samples.
- **Clarify that stagnation means no water use in entire house:** It has been reported that residents are sometimes unsure about whether the stagnation period applies to the entire house or only to the tap from which samples are being taken. Water utilities should ensure that their sampling instructions make it as clear as possible that, during the stagnation period, no water can be used in the entire house.
- **Instruct residents not to remove aerators:** Lead sediment can build up in aerators attached to faucets, from which it can then be released into the water. Water utilities should specifically instruct residents not to remove aerators from their taps before collecting samples.
- **Instruct residents to use a high flow rate when collecting samples:** More lead can be released into water when the water passes through the pipe at a faster rate. Water utilities should therefore instruct residents to run their water at a high rate of flow when they collect their samples.
- **Collect sequential samples:** Even though samples taken to comply with the Lead and Copper Rule must be first-draw samples, water utilities are free to collect additional samples that do not rely on first-draw procedures. Because the timing of peak lead levels can vary based on factors like the size of the home and the length of the lead service line, first-draw samples do not always reflect the highest level of lead to which a resident might be exposed.

Kim, E. J. and J. E. Herrera (2010). "Characteristics of lead corrosion scales formed during drinking water distribution and their potential influence on the release of lead and other contaminants." Environmental Science and Technology 44(16): 6054-6061.

Destabilization of the corrosion scale present in lead pipes used in drinking water distribution systems is currently considered a major problem for municipalities serviced in part by lead pipes. Although several lead corrosion strategies have been deployed with

success, a clear understanding of the chemistry of corrosion products present in the scale is needed for an effective lead control. This contribution focuses on a comprehensive characterization of the layers present in the corrosion scale formed on the inner surfaces of lead pipes used in the drinking water distribution system of the City of London, ON, Canada. Solid corrosion products were characterized using X-ray diffraction (XRD), Raman spectroscopy, Fourier transform infrared (FTIR) spectroscopy, and X-ray photoelectron spectroscopy (XPS). Toxic elements accumulated in the corrosion scale were also identified using inductively coupled plasma (ICP) spectrometry after acid digestion. Based on the XRD results, hydrocerussite was identified as the major lead crystalline corrosion phase in most of the pipes sampled, while cerussite was observed as the main crystalline component only in a few cases. Lead oxides including $\text{PbO}(2)$ and $\text{Pb}(3)\text{O}(4)$ were also observed in the inner layers of the corrosion scale. The presence of these highly oxidized lead species is rationalized in terms of the lead(II) carbonate phase transforming into lead(IV) oxide through an intermediate $\text{Pb}(3)\text{O}(4)$ ($2\text{Pb(II)O} \times \text{Pb(IV)O}(2)$) phase. In addition to lead corrosion products, an amorphous aluminosilicate phase was also identified in the corrosion scale. Its concentration is particularly high at the outer surface layers. Accumulation of toxic contaminants such as As, V, Sb, Cu, and Cr was observed in the corrosion scales, together with a strong correlation between arsenic accumulation and aluminum concentration.

Kim, E. J., et al. (2011). "Effect of pH on the concentrations of lead and trace contaminants in drinking water: A combined batch, pipe loop and sentinel home study." Water Research 45(9): 2763-2774.

High lead levels in drinking water are still a concern for households serviced by lead pipes in many parts of North America and Europe. This contribution focuses on the effect of pH on lead concentrations in drinking water delivered through lead pipes. Though this has been addressed in the past, we have conducted a combined batch, pipe loop and sentinel study aiming at filling some of the gaps present in the literature. Exhumed lead pipes and water quality data from the City of London's water distribution system were used in this study. As expected, the lead solubility of corrosion scale generally decreased as pH increased; whereas dissolution of other accumulated metals present in the corrosion scale followed a variety of trends. Moreover, dissolved arsenic and aluminum concentrations showed a strong correlation, indicating that the aluminosilicate phase present in the scale accumulates arsenic. A significant fraction of the total lead concentration in water was traced to particulate lead. Our results indicate that particulate lead is the primary contributor to total lead concentration in flowing systems, whereas particulate lead contribution to total lead concentrations for stagnated systems becomes significant only at high water pH values.

Kimbrough, D. E. (2001). "Brass corrosion and the LCR monitoring program." American Water Works Association. Journal 93(2): 81.

Testing conducted at water utilities in California in the late 1990s concluded that the Lead and Copper Rule (LCR) may have incorrectly identified the main sources of lead and copper in tap water as well as which sources are "high risk." According to the findings of this study, brass corrosion appears to be the main source of both lead and copper in current monitoring samples. This paper provides one method for identifying the source of corrosion byproducts in consumers' tap water.

Kimbrough, D. E. (2007). "Brass corrosion as a source of lead and copper in traditional and all-plastic distribution systems." Journal American Water Works Association 99(8): 70-76.

Corrosion by copper pipes has long been considered the main source of copper in samples collected under the Lead and Copper Rule (LCR). Furthermore, regulatory agencies generally have assumed that the primary source of lead is lead solder or pipes. Recent research, however, has suggested that brass corrosion may play a larger part in contributing to lead and copper at the customer's tap than initially supposed. One obstacle to accurately identifying sources of lead and copper in LCR samples is the possibility of several sources for both elements. This study focused on two populations, houses with traditional plumbing and houses with all-plastic plumbing, a factor that effectively eliminated all but one source. Analysis of first-draw samples collected from houses with all-plastic plumbing showed concentrations of lead and copper comparable to those found in traditionally plumbed houses, indicating that the lead and copper found in the plastic system resulted from brass corrosion. Given that the LCR has a limited focus on brass, these results call into question the efficacy of the LCR in reducing consumer exposure to lead and copper.

Kimbrough, D. E. (2009). "Source identification of copper, lead, nickel, and zinc loading in wastewater reclamation plant influents from corrosion of brass in plumbing fixtures." Environmental Pollution 157(4): 1310-1316.

A natural experiment indicated that a link between the presence and concentration of four elements, copper, lead, nickel, and zinc in the influent to two wastewater reclamation plants to the presence and concentrations of the same four elements in the tap water of residential properties. There were 36 populations of results that were assessed for the normality of their distribution, the difference in their median concentrations, the similarity in the ratios of their median concentrations, and the correlations of the concentrations. The results of this study suggest that brass corrosion is the major source of these four elements in the water reclamation plants influent and that there are two distinct populations of brass sources, those in the early stages of dezincification where the release of the non-copper elements is dominant and those in the later stages where the release of copper dominates and the type of brass that is corroding.

Kirmeyer, G. J. and G. S. Logsdon (1983). "Principles of internal corrosion and corrosion monitoring." Journal (American Water Works Association): 78-83.

Interaction of corrosive water with distribution pipelines and home plumbing systems can cause health-related, aesthetic, or economic problems. The authors of this overview define corrosion and describe common forms of internal corrosion, the basic corrosion reaction, and corrosion of iron pipe, galvanized pipe, copper pipe, lead pipe, and structures within the water treatment plant. Also considered are methods of monitoring corrosion including water quality indexes, customer complaints, and pipe and coupon testing programs including visual observation, micrographs, weight loss, pitting potential, scale and analysis, and corrosion probes.

Kleczyk, E. J. and D. J. Bosch (2008). "Incidence and costs of home plumbing corrosion." Journal American Water Works Association 100(12): 122-133.

Pinhole leaks and the damage associated with their repair have high financial, emotional, and time costs. The authors evaluated the factors influencing the occurrence and costs of pinhole leak corrosion in suburban Washington, D.C. A mail survey was used to elicit information about experiences and repair costs associated with pinhole leaks. Pinhole leak occurrences were found to be associated with plumbing type, property age, pipe failure history, and dwelling distance from a water treatment plant. Information on factors associated with pinhole leak incidence and costs can be useful to water utility managers in

formulating policies and programs to reduce pinhole leak occurrences and the negative financial and emotional impacts of corrosion on individual households. Faster responses to pinhole leak outbreaks by utility managers and policymakers would reduce the costs of pinhole leak repairs. Expanding state-funded property insurance to cover damage from leaks when private insurance coverage is inadequate would also be beneficial. The predictive equation will also provide utility managers with the basis for predicting such leaks in their service areas.

Knowles, A. D., et al. (2015). "Role of iron and aluminum coagulant metal residuals and lead release from drinking water pipe materials." Journal of Environmental Science and Health, Part A 50(4): 414-423.

Bench-scale experiments investigated the role of iron and aluminum residuals in lead release in a low alkalinity and high (> 0.5) chloride-to-sulfate mass ratio (CSMR) in water. Lead leaching was examined for two lead-bearing plumbing materials, including harvested lead pipe and new lead: tin solder, after exposure to water with simulated aluminum sulfate, polyaluminum chloride and ferric sulfate coagulation treatments with 1-25- μM levels of iron or aluminum residuals in the water. The release of lead from systems with harvested lead pipe was highly correlated with levels of residual aluminum or iron present in samples ($R^2 = 0.66\text{--}0.88$), consistent with sorption of lead onto the aluminum and iron hydroxides during stagnation. The results indicate that aluminum and iron coagulant residuals, at levels complying with recommended guidelines, can sometimes play a significant role in lead mobilization from premise plumbing.

Kvech, S. and M. Edwards (2001). "Role of aluminosilicate deposits in lead and copper corrosion." Journal (American Water Works Association) 93(11): 104-112.

Water treatment professionals have long battled corrosion of distribution system pipe materials. Although chemicals that inhibit corrosion are commonly used, they are not always effective. Thus, researchers are always on the lookout for practical corrosion mitigation strategies that do not require the purchase or use of chemicals. For example, aluminosilicates, which often deposit in distribution system plumbing lines, have previously been thought to inhibit corrosion, even though they cause increased head loss, reduced flow, and consumer complaints related to post-precipitation. However, the results of this study suggest that this assumption should be re-examined because aluminosilicates actually worsened some aspects of corrosion. There currently is no hard scientific evidence that such deposits are beneficial to corrosion in circumstances of relevance to water purveyors. With the proliferation of regulations that mandate lower levels of metals, such as lead and copper, in tap water and in the environment, more research into innovative strategies that can help prevent the release of metals is merited. This article takes the first steps to a better understanding of the impact of aluminosilicates on corrosion of copper and lead plumbing materials.

Lambrinidou, Y., et al. (2010). "Failing our children: lead in U.S. school drinking water." New solutions : a journal of environmental and occupational health policy : NS 20(1): 25-47.

Lead is the most prevalent toxicant in U. S. school drinking water. Yet for the vast majority of schools, federal regulation for testing taps and remediating contamination is voluntary. Using school case studies, this article discusses the regulatory vacuum that leaves children unprotected from potential exposure to very high lead doses through consumption of school water. Controlling lead hazards from water fountains, coolers, and other drinking water outlets in schools requires improved sampling protocols that can capture the inherent variability of lead release from plumbing and measure both the particulate and dissolved

lead present in water. There is a need to reevaluate the potential public health implications of lead-contaminated drinking water in schools. Accounting for this misunderstood and largely overlooked exposure source is necessary in order to better understand and address childhood lead poisoning in the U. S.

Lee, R. G., et al. (1989). "Lead at the tap: sources and control." Journal-American Water Works Association 81(7): 52-62.

A survey of 94 water companies and districts was conducted in early 1988 to determine lead levels at customer taps and to evaluate the factors that influence these levels. The results of the survey indicate that lead-based solder is the most significant source of lead at the tap. In addition, brass faucets were found to contribute substantially to the lead in the first-draw samples. Although water quality and site characteristics cannot be used to predict lead levels, certain factors are associated with higher lead concentrations. Other than the presence of corrosion inhibitors, pH was the only water quality factor that appeared to influence lead levels at the tap. Site factors that were also important, with plumbing age being the most significant.

Lees, M. E. (2017). Corrosion of brass meters in drinking water: the influence of alloy composition and water chemistry on metal release and corrosion scale, MSc, University of Cincinnati.

Brass plumbing components including meters, fittings and valves are used extensively in drinking water distribution systems. Until recently, most in-line brass components contained toxic lead, many of which are still presently in use. Corrosion of brass components leads to the release of metals to drinking water. The primary factors of brass corrosion in drinking water are temperature, alloy composition and water chemistry. In this thesis, a combination of mathematical modeling, analytical techniques and geochemical modeling were used to better understand what causes corrosion in brass components.

A comprehensive model for the release of copper, lead and zinc from brass water meters has been developed. This model provides a framework to evaluate how meter parameters, such as alloy composition and age, influence metal leaching from brass components. When considering brass composition, zinc concentration within the alloy is shown to be the primary factor in copper and zinc release. Brasses with greater than 8 – 9% zinc exhibit more rapid corrosion when compared to brasses with less than 8% zinc. Age was found to have more influence over lead release than alloy composition, with newer meters releasing significantly higher concentrations of lead versus older meters.

In addition to the oxidation of metallic surfaces, corrosion scale formation and dissolution also have a significant impact upon metal concentrations within drinking water. Optical microscopy, X-ray diffraction (XRD), Raman spectroscopy, and scanning electron microscopy (SEM) with energy dispersive X-ray spectroscopy (EDX), were used to characterize the morphology and mineralogy of corrosion scale in two sets of residential water meters. The meters, which were in service for up to 40 years, came from two locations with contrasting water chemistries; Seattle, with relatively low alkalinity, hardness and total dissolved solids (TDS), and Cincinnati, which has moderate alkalinity, hardness and TDS. Results showed the copper minerals cuprite and malachite, to be most abundant within the corrosion scale from both sources. Lead minerals were much more prevalent within the Cincinnati meters, as were carbonates (both Cu & Pb). In general, the Cincinnati meters contained more substantial and consistent scale coverage whereas coverage on the Seattle meters was patchier and more localized.

Real world use of drinking water systems cycle between flow and periods of stagnation, where water sits quiescently within the system. During stagnation, changes in water chemistry can include metal concentration, solution pH, and oxidation reduction (redox) potential. PHREEQC was utilized to calculate the saturation index (SI) of metallic species with changing water chemistry. The SI values were used to evaluate whether a given mineral will dissolve or precipitate from water during stagnation. These values were compared to the mineralogy identified in the meters to better understand the mechanism of scale development. Changes in redox potential had the most significant effect upon SI values. Minerals present within the scale were found to form under distinctly different conditions suggesting that dissolution and precipitation rates must also be considered.

Lehr, J. (1994). "Lead in brass pumps- drinking water risk." Environmental Protection 5(6): 61-62.

Studies show submersible domestic water pumps are a continuous source of lead in drinking water. EPA issued a warning in April against their use; several lawsuits have been filed against pump manufacturers.

Levin, R. (1987). Reducing lead in drinking water: A benefit analysis, Office of Policy Planning and Evaluation.

Economic analysis

Levin, R., et al. (2008). "Lead exposures in US children, 2008: Implications for prevention." Environmental Health Perspectives 116(10): 1285-1293.

OBJECTIVE:

We reviewed the sources of lead in the environments of U.S. children, contributions to children's blood lead levels, source elimination and control efforts, and existing federal authorities. Our context is the U.S. public health goal to eliminate pediatric elevated blood lead levels (EBLs) by 2010.

DATA SOURCES:

National, state, and local exposure assessments over the past half century have identified risk factors for EBLs among U.S. children, including age, race, income, age and location of housing, parental occupation, and season.

DATA EXTRACTION AND SYNTHESIS:

Recent national policies have greatly reduced lead exposure among U.S. children, but even very low exposure levels compromise children's later intellectual development and lifetime achievement. No threshold for these effects has been demonstrated. Although lead paint and dust may still account for up to 70% of EBLs in U.S. children, the U.S. Centers for Disease Control and Prevention estimates that $\geq 30\%$ of current EBLs do not have an immediate lead paint source, and numerous studies indicate that lead exposures result from multiple sources. EBLs and even deaths have been associated with inadequately controlled sources including ethnic remedies and goods, consumer products, and food-related items such as ceramics. Lead in public drinking water and in older urban centers remain exposure sources in many areas.

CONCLUSIONS:

Achieving the 2010 goal requires maintaining current efforts, especially programs addressing lead paint, while developing interventions that prevent exposure before children

are poisoned. It also requires active collaboration across all levels of government to identify and control all potential sources of lead exposure, as well as primary prevention.

Levin, R. and R. Morgenstern (1997). "Lead in Drinking Water." Economic Analyses at EPA: Assessing Regulatory Impact: 205-233.

US EPA Economic analysis of controlling lead in drinking water- \$2.1B saving in 1991.

Lin, N. H., et al. (1997). "Lead corrosion control from lead, copper-lead solder, and brass coupons in drinking water employing free and combined chlorine." Journal of Environmental Science & Health Part A 32(4): 865-884.

The U.S. Environmental Protection Agency (EPA) promulgated the Lead and Copper Rule (LCR) in 1991, establishing 0.015 mg/L as the lead action level in drinking water. Public water suppliers must optimize water characteristics to meet this requirement at the consumer's tap. In this study, bench-scale experiments were completed to evaluate the effects of employing either free and combined chlorine on two alternative corrosion control strategies: pH adjustment and inhibitor addition, using treated water from two different water supplies. In addition, the effect of fluoride on lead corrosion was investigated. Lead, copper/lead-solder, and brass coupon tests were employed. For lead and copper/lead solder, free chlorine produced higher lead levels than combined chlorine at different pH. However, for brass coupons at different pH as well as copper/lead solder and brass using several commercial corrosion inhibitors, combined chlorine released more lead than free chlorine. In all cases, higher water pH was effective at minimizing dissolved lead, as were the inhibitor additions. Furthermore, this study also showed that addition of both free chlorine as well as fluoride increase lead corrosion.

Lin, Y.-P. and R. L. Valentine (2008). "The release of lead from the reduction of lead oxide (PbO₂) by natural organic matter." Environmental Science and Technology 42(3): 760-765.

PbO₂ has been identified as an important scale in some distribution systems that historically use lead service lines and free chlorine for maintaining a disinfectant residual. The stability of this highly insoluble scale with respect to its reductive dissolution may play an important role in lead release into drinking water. In this study, we investigated the release of lead from a commercially available PbO₂ in the presence of natural organic matter (NOM) using a hydrophobic acid extracted from the Iowa River. Experiments were conducted using synthetic solutions with different NOM concentrations, solution pH, and NOM samples with different levels of pre-chlorination. It was found that release of lead from PbO₂ occurred both in solutions with and without NOM, and the extent of lead release increased with increasing NOM concentration and decreasing pH value. Furthermore, the released lead was Pb(II) and not particulate PbO₂ conclusively showing that reductive dissolution occurred. Pre-chlorination of NOM reduced the rate of lead release. Our results indicate that PbO₂ can be reduced both by water and NOM. Characterization of final solid phases by scanning electron microscopy and X-ray photoelectron spectroscopy are also presented.

Lodo, K., et al. (2018). "A novel public health threat–high lead solder in stainless steel rainwater tanks in Tasmania." Australian and New Zealand journal of public health 42(1): 77-82.

Objective: We identified two water tanks in Tasmania with water lead concentrations exceeding the Australian Drinking Water Guidelines (ADWG) limit; they had been constructed with stainless steel and high-lead solder from a single manufacturer. An

investigation was initiated to identify all tanks constructed by this manufacturer and prevent further exposure to contaminated water.

Methods: To identify water tanks we used sales accounts, blood and water lead results from laboratories, and media. We analysed blood and water lead concentration results from laboratories and conducted a nested cohort study of blood lead concentrations in children aged <18 years.

Results: We identified 144 tanks constructed from stainless steel and high lead solder. Median water lead concentrations were significantly higher in the stainless steel tanks (121µg/L) than in the galvanised tanks (1µg/L). Blood lead concentrations ranged from 1 to 26µg/dL (median 5µg/dL); of these, 77% (n=50) were below the then-recommended health-related concentration of 10µg/dL. Concentrations in the 15 people (23%) above this limit ranged from 10–26µg/dL, with a median of 14µg/dL. The median blood lead concentration in the nested cohort of children was initially 8.5µg/dL, dropping to 4.5µg/dL after follow-up.

Conclusions: Lead concentrations in the water tanks constructed from stainless steel and high-lead solder were up to 200 times above the recommended ADWG limits.

Implications for public health: This investigation highlights the public health risk posed by use of non-compliant materials in constructing water tanks.

Lytle, D. A. and M. R. Schock (1996). Stagnation time, composition, pH, and orthophosphate effects on metal leaching from brass, National Risk Management Research Laboratory, Office of Research and Development, US Environmental Protection Agency.

Plumbing products made of brass and similar alloys are the only lead containing materials still installed in drinking water systems and, by law, may contain up to 8% lead. Brass ranges in metal composition depending on its application. Brass is composed of approximately 60 to 80% copper, 4 to 32% zinc, 2 to 8% lead, 6% tin and trace amounts of iron and cadmium. The relationship between alloy composition and resulting amounts of metal leached from the alloy in drinking water has not been fully established. Better understanding of brass corrosion may provide information and guidance to the use of the safest materials for the production of plumbing fixtures, and optimisation of corrosion control treatments.

This study examined the effect of alloy composition, pH, orthophosphate, and stagnation time on the metal leached from 6 different brasses and the pure metals that make brass (lead, copper, and zinc) in Cincinnati, Ohio, tap water. Results demonstrated that the amount of various metals leached from the alloys corresponded well with the alloy's composition. Leaching of metals components from brass were generally less affected by pH than the pure metals. A pH of 7.5 and 0.5 to 3.0 mg/l orthophosphate significantly reduced the amount of lead leached from the alloys initially, but had less impact as time continued. Orthophosphate had a minimal impact on copper levels. The impact of stand time was dependent on water quality and alloy composition. This report covers a period from August 1991 to January 1996, and the work was completed as of December 1994

Lytle, D. A. and M. R. Schock (2000). "Impact of stagnation time on metal dissolution from plumbing materials in drinking water." Journal of Water Supply Research and Technology-Aqua 49(5): 243-257.

Studies were conducted to evaluate the impact of stagnation period on the metal dissolution from plumbing materials including lead, copper and brass. Experimental data showed that metal levels increased exponentially with time, with the sharpest increase

occurring over the first 20-24 h. Metal levels may continue to increase following well beyond 24 h of stagnation. Copper levels increased until dissolved oxygen fell below 1 mg/L after which copper levels fell. Results showed that stagnation behaviour is complex in nature, difficult to predict and dependent on water chemistry. Experimental data fit well to a radial diffusion model when a diffusion barrier term is considered.

Lytle, D. A. and M. R. Schock (2005). "Formation of Pb(IV) oxides a in chlorinated water." Journal American Water Works Association 97(11): 102-114.

Recent research has shown that Pb(IV) oxides play a significant geochemical role in drinking water distribution systems. However, most of the guidance for lead control in drinking water is based on the presumption that Pb(II) solids control lead solubility. Therefore, a better understanding of the chemistry of Pb(IV) in water is needed. Long-term lead precipitation experiments were conducted in chlorinated water (1-3 mg/L Cl₂) at pH 6.5, 8, and 10, with and without sulfate. Results showed that two Pb(IV) dioxide polymorphs - plattnerite (beta-PbO₂) and scrutinyite (alpha-PbO₂) - formed overtime, as long as a high suspension redox potential was maintained with free chlorine. Neither mineral formed spontaneously, and the rate of formation increased with increasing pH. Hydrocerrusite and/or cerrusite initially precipitated out and overtime either disappeared or coexisted with PbO₂. Water pH dictated mineralogical presence. High pH favored hydrocerrusite and scrutinyite; low pH favored cerrusite and plattnerite. Along with a transformation of Pb(II) to Pb(IV) came a change in particle color from white to a dark shade of red to dark grey (differing with pH) and a decrease in lead solubility. If free chlorine was permitted to dissipate, the aging processes (i.e., mineralogy, color, and solubility) were reversible.

Lytle, D. A. and M. R. Schock (2008). "Pitting corrosion of copper in waters with high pH and low alkalinity." Journal American Water Works Association 100(3): 115-129.

Localized or pitting corrosion of copper pipes used in household plumbing is a problem for some homeowners. Extreme attack can lead to pinhole leaks that may result in water damage, mold growth, and costly repairs. The objective of this research was to better define the specific water quality conditions that support pitting corrosion. Pilot-scale pipe rig testing found that pitting corrosion occurred in waters with low chlorine concentrations and dissolved inorganic carbon (DIC) concentrations of 5 and 10 mg/L C (and possibly 25 mg/L Q and pH 9 water in the presence of chloride. Orthophosphate and increased DIC concentrations prevented the initiation of localized corrosion. Water suppliers considering changes in treatment and water sources can use this information to avoid conditions that support localized corrosion of copper.-MPM.

Lytle, D. A., et al. (1998). "Using aeration for corrosion control." Journal American Water Works Association 90(3): 74-88.

Aeration is a useful drinking water treatment process. Aeration has been used to remove hydrogen sulfide, methane, radon, iron, manganese, and volatile organic contaminants from drinking water. Aeration also removes carbon dioxide, which directly affects pH and dissolved inorganic carbon (DIC), the parameters that most influence lead and copper solubility. As a result, aeration can be an effective corrosion control strategy, presuming the initial pH and DIC are appropriate. Mineral precipitation brought about by water quality changes resulting from aeration may present operational constraints under some conditions. Aeration produces very consistent water quality and may be advantageous (especially to smaller utilities) because of relatively low costs and simple operational and maintenance needs.

Lytle, D. A., et al. (1993). "Investigating the preferential dissolution of lead from solder particulates." Journal American Water Works Association 85(7): 104-110.

During a building corrosion control study, bottles containing acid-preserved water samples with high levels of lead often had particulate material on the bottom. Scanning electron microscope analysis of the particles showed the presence of tin and the absence of lead, indicating the probable source of lead to be lead-tin solder. A leaching study was done to investigate the effectiveness of the standard 0.15 percent nitric acid preservation procedure for dissolving lead corrosion by-products. Results indicate that the technique was adequate for dissolving lead from lead-tin solder particles but not for tin.

Maas, R. P., et al. (2007). "Effects of fluoridation and disinfection agent combinations on lead leaching from leaded-brass parts." Neurotoxicology 28(5): 1023-1031.

This study concerns effects on water-borne lead from combinations of chlorine (CL) or chloramines (CA) with fluosilicic acid (FSA) or sodium fluoride (NaF). CL is known to corrode brass, releasing lead from plumbing devices. It is known that CA and CL in different ratios with ammonia (NH) mobilize copper from brass, which we have found also enhances elution of lead from leaded brass alloys. Phase I involved leaded-brass 1/4 in. elbows pre-conditioned in DI water and soaked in static solutions containing various combinations of CL, CA, FSA, NaF, and ammonium fluosilicate. In Phase II 20 leaded-brass alloy water meters were installed in pipe loops. After pre-conditioning the meters with 200 flushings with 1.0 ppm CL water, seven different solutions were pumped for a period of 6 weeks. Water samples were taken for lead analysis three times per week after a 16-h stagnation period. In the static testing with brass elbows, exposure to the waters with CA + 50% excess NH₃ + FSA, with CA and ammonium fluosilicate, and with CA + FSA resulted in the highest estimated lead concentrations. In the flow-through brass meter tests, waters with CL + FSA, with CL + NaF, and with CL alone produced the highest average lead concentration for the first 3-week period. Over the last 3 weeks the highest lead concentrations were produced by CL + NaF, followed by CL alone and CA + NH₃ + FSA. Over the first test week (after CL flushing concentrations were increased from 1.0 to 2.0 ppm) lead concentrations nearly doubled (from about 100 to nearly 200 ppb), but when FSA was also included, lead concentrations spiked to over 900 ppb. Lead concentrations from the CL-based waters appeared to be decreasing over the study period, while for the CA + NH₃ + FSA combination, lead concentrations seemed to be increasing with time.

Magyar, M. I., et al. (2014). "Influence of roofing materials and lead flashing on rainwater tank contamination by metals." Australasian Journal of Water Resources 18(1): 71-83.

The quality of rainwater collected in polyvinyl chloride (PVC) tanks from six trial roofs (glazed tile, pre-painted steel and aluminium-zinc coated steel, each with and without uncoated lead flashing) was monitored for nine months. Samples of water and sediment were collected at three monthly intervals and analysed for concentrations of metals (Al, Cd, Cr, Cu, Fe, Mn, Ni, Pb and Zn), in order to determine the influence of roof materials and uncoated lead (Pb) flashing upon metal contamination within the tanks. Lead concentration in tank water exceeded Australian Drinking Water Guidelines for all roof types where there was lead flashing. Lead flashing also contributed to contamination of tank sediments. In all cases, pH was low which contributed to a large proportion of lead being in the dissolved form.

Marinas, B. J., et al. (1997). Method of treating lead-containing surfaces to passivate the surface lead, Google Patents.

A method for treating bronze or brass fixtures containing lead with a cupric acetate solution is described. The treatment results in decreased amounts of lead in subsequent use. A preferred embodiment uses about 0.01 M cupric acetate at pH4.

Masters, S. and M. Edwards (2015). "Increased lead in water associated with iron corrosion." Environmental Engineering Science 32(5): 361-369.

When attempting to reduce lead solubility by lowering the finished water pH in Providence, RI, from ~10.3 to 9.7, consumer red water complaints and overall lead levels increased, prompting bench-scale tests and intensive field sampling into possible associations between higher particulate iron and particulate lead. At pH 10.3, iron release to water was as much as 35% lower in bench-scale tests and 99% lower in field samples compared with pH 9.7. Lower levels of particulate iron released at higher pH, translated to lower levels of particulate lead release after contacting downstream plumbing in bench testing. Although a significant decrease in distribution system iron at pH 10.3 did not immediately translate to decreased lead levels at all field sampling sites, complementary laboratory and field studies demonstrate that lead corrosion control is sometimes strongly linked to iron corrosion control.

Masters, S., et al. (2015). "Distribution system water age can create premise plumbing corrosion hotspots." Environmental monitoring and assessment 187(9).

Cumulative changes in chemical and biological properties associated with higher "water age" in distribution systems may impact water corrosivity and regulatory compliance with lead and copper action levels. The purpose of this study was to examine the effects of water age and chemistry on corrosivity of various downstream premise plumbing pipe materials and configurations using a combination of controlled laboratory studies and a field survey. Examination of lead pipe, copper pipe with lead solder, and leaded brass materials in a replicated lab rig simulating premise plumbing stagnation events indicated that lead or copper release could increase as much as ~440 % or decrease as much as 98 % relative to water treatment plant effluent. In field studies at five utilities, trends in lead and copper release were highly dependent on circumstance; for example, lead release increased with water age in 13 % of cases and decreased with water age in 33 % of conditions tested. Levels of copper in the distribution system were up to 50 % lower and as much as 30 % higher relative to levels at the treatment plant. In many cases, high-risks of elevated lead and copper did not co-occur, demonstrating that these contaminants will have to be sampled separately to identify "worst case" conditions for human exposure and monitoring.

Masters, S., et al. (2016). "Inherent variability in lead and copper collected during standardized sampling." Environmental monitoring and assessment 188(3).

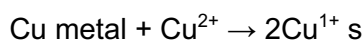
Variability in the concentration of lead and copper sampled at consumers' taps poses challenges to assessing consumer health threats and the effectiveness of corrosion control. To examine the minimum variability that is practically achievable, standardized rigs with three lead and copper containing plumbing materials (leaded brass, copper tube with lead solder, and a lead copper connection) were deployed at five utilities and sampled with regimented protocols. Variability represented by relative standard deviation (RSD) in lead release was high in all cases. The brass had the lowest variability in lead release (RSD =131 %) followed by copper-solder (RSD=149 %) and lead-copper (RSD=180 %). This high inherent variability is due to semi-random detachment of particulate lead to water, and represents a modern reality of water lead problems that should be explicitly acknowledged and considered in all aspects of exposure, public education, and monitoring.

Maynard, B., et al. (2008). "Kinetics of lead release from brass water meters and faucets." Proc. 2008 AWWA WQTC, Cincinnati.

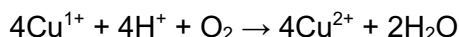
As part of AwwaRF project 3018, the release of Pb from new brass kitchen faucets and new and used brass residential-service water meters was measured. Data were obtained for brass compositions, scale compositions, and water chemistry. Pb (or Bi) is present in these brasses as small "islands" of metal, whereas Cu and Zn are mixed in a solid solution. With time, Zn in the brasses was preferentially lost relative to Cu.

Pb releases from the brass faucets in 6 hour stagnation runs increased rather than decreased with time. This behavior is inconsistent with formation of passivating scale layers, but is consistent with progressive dezincification producing a porous surface layer through which Pb can diffuse more rapidly, or from which Pb particulates can be detached more readily with time. The rate of Pb release was found to correlate inversely with the Zn/Cu ratio of the brass.

Metal release rates from meters could be effectively modeled as controlled by two processes. Initially, the release curves for Cu, Zn, and Pb follow $t^{1/2}$ kinetics, indicating that the reaction is transport limited by diffusion. At longer times, the reaction rate follows first-order kinetics consistent with consumption of oxygen as the rate limiting step. Rate constants for the first stage correlate to the age of the meters, whereas for the second correlate to the Zn/Cu ratio – higher Zn brasses corrode more slowly. This relationship is likely caused by autocatalytic oxidation of copper via



oxygen remains in the water, the cupric ions can be regenerated via



and the reaction continues. The higher Cu brasses (those with lower Zn/Cu ratios) release more Cu to solution in short stagnation cycles; therefore they corrode more quickly than lower Cu brasses. In flowing water, the build-up of the copper ions in solution is precluded, and the autocatalytic effect does not occur. In this case, the corrosion rate is controlled by the diffusion of Zn (and Pb) from the metal, which should increase with increasing Zn content.

Maynard, J. B. (2008). Lead Content of Brass Plumbing Components, University of Cincinnati.

Water distribution systems and household plumbing contain numerous brass components. Most such components in service are leaded brass and hence comprise a potential source of Pb in compliance testing under the Lead and Copper Rule. For households, the two components with the greatest potential to affect Pb content of tap samples are faucets and meters. Typical brasses used in these applications are alloys of Cu, Zn, and Pb with small amounts of other metals such as Sn. The Pb content is typically 2 to 8 %, and these can be marketed as "lead free". In true no-lead brasses, Bi and Se are used in place of Pb (<http://www.envirobrass.com>). The addition of Pb or Bi is made to improve the machinability of the brass.

McCafferty, P. (1995). "Lead contamination in Perth drinking water." Chemistry in Australia 62(8): 21-22.

A survey of cold water from kitchen taps of Perth domestic residences showed that 5% of the samples were above the National Health and Medical Research Council guideline value for lead. The contribution of drinking water to blood lead levels is discussed. Also found that 67% of hot water dispensers in Perth provided water that exceeded the drinking water standard for lead.

McCafferty, P. (2017). An assessment of lead leaching from brass following orthophosphate treatment. Perth, WA, Chem Centre.

The investigation undertaken in this report demonstrates that orthophosphate treatment provides a realistic means of passivating lead containing surfaces that can be pursued throughout the Perth Children's Hospital (PCH) building. This negates the need to replace lead-containing brass fittings throughout the building and hence offers significant financial and time savings over any other currently proposed remediation activity.

The use of a low concentration of orthophosphate in the water supply offers an economical, safe way of treating brass fittings in situ. The orthophosphate is not a one-off treatment but must be maintained to ensure that the lead does not subsequently enter the water supply.

McFadden, M., et al. (2011). "Contributions to drinking water lead from galvanized iron corrosion scales." American Water Works Association. Journal 103(4): 76.

Observations of substantial particulate lead release from galvanized iron in-home plumbing in phase 1 of the study and of lead release from galvanized pipe loops with no other source in phase 3 provide evidence that iron scales can act as a sink and source for drinking water lead.

Replacement of lead service lines can cause elevated lead levels immediately after construction, even after removal of the full lead source. Recent data collected by the District of Columbia Water and Sewer Authority in Washington, D.C., indicated that this can be partly attributed to lead release from iron corrosion scales on old, galvanized in-home plumbing. This article summarizes a three-part study investigating the phenomenon of capture and release of lead mobilized from an upstream service line by iron corrosion scales in galvanized plumbing. The study used profile sampling data from homes in the District of Columbia, corrosion scale analyses, and pipe-loop experiments to examine whether iron corrosion scales can contribute meaningfully to drinking water lead. The study concluded that iron corrosion scales can be a persistent lead source, identified factors that can trigger release, and characterized potential long-term effects.

Partial lead service line replacement (LSLR) - in which the portion of lead service line between the main and the property line is replaced - is widely practiced to remove sources of drinking water lead at household taps. However, the effectiveness of partial LSLR has been the subject of debate, given that only a portion of the primary lead source is removed, and research has found that transient elevated lead levels can be experienced after replacement (Sandvig et al, 2008; Swertfeger et al, 2006; Zietz et al, 2001; USEPA, 2000; Schock et al, 1996). Elevated lead levels following partial LSLR have been associated with several potential causes, including dislodging of particulate lead from the remaining service line during construction (Sandvig et al, 2008), galvanic corrosion (Nguyen et al, 2010; Edwards & Triantafyllidou, 2007; Britton & Richards, 1981), and mechanical disturbances such as water hammer or sudden flow changes (Hulsmann, 1990). A recent national survey of lead source characteristics found that disturbance of service lines and premise plumbing can cause short-term, high particulate lead levels even after full LSLR in which the entire

lead service has been replaced (Sandvig et al, 2008). Sandvig and colleagues hypothesized that over time, lead from upstream lead service lines "seeded" the premise plumbing, becoming incorporated into corrosion scales on the internal surfaces of downstream pipes to be mobilized later by LSLR construction disturbances. The hypothesis pointed to a largely overlooked potential source of drinking water lead, which would have important implications for the industry's understanding of issues associated with LSLR and its continuing efforts to eliminate lead sources in distribution systems. Support for this hypothesis comes from a recent study (HDR, 2009) undertaken for the Washington, D.C., distribution system managed by the District of Columbia Water and Sewer Authority, which as of 2010 became known as DC Water (DCW). That study and its findings are the focus of this article.

McFadden, M., et al. (2009). Investigation of Sorptive and Desorptive Processes Between Lead and Iron Corrosion Scales in Plumbing Materials. Proceedings 2009 AWWA Water Quality Technology Conference, Seattle, Wash.

Paper referenced by others but abstract not available.

McFarland, M. L., et al. (2015). Drinking Water Problems: Corrosion, Texas A&M Agrilife Extension Service.

One of the most common problems affecting domestic water supplies is corrosion, a chemical process that slowly dissolves metal, resulting in deterioration and failure of plumbing pipes, fixtures and water-using equipment. One type of corrosion attacks and gradually thins the entire metal surface, often causing red-colored stains in iron or steel plumbing systems or blue-green stains in copper and brass plumbing systems. Another type of corrosion attacks small areas where deep pits can develop and penetrate pipe or tank walls. This type of corrosion may not add significant amounts of iron or copper to the water, but can create small holes in a pipe or tank that destroy its usefulness, cause water leaks, and result in major water damage to a home or business. A third type of corrosion caused by the oxidation of metals involves conversion of copper or other base metal to an oxidized form in a process similar to the rusting of steel. It often results in reduced water flow through supply lines and destruction of water valves and other machined water flow control surfaces, thus resulting in internal and external leaks at valves and faucets. This type of corrosion does not necessarily occur due to the water chemistry, but is caused by exposure of the outside surface of the plumbing supply lines to soil or other corrosive environments. Especially in older installations and very new homes, two potentially toxic metals, copper and lead, may occur in tap water almost entirely because of leaching caused by corrosion. Elevated levels of copper can cause gastrointestinal problems and with long-term exposure result in liver and kidney damage. Elevated levels of lead can result in physical and mental development problems in children, and high blood pressure and kidney problems in adults. The US Environmental Protection Agency has established Primary Drinking Water Standards (<http://water.epa.gov/drink/contaminants/index.cfm>) for both copper (maximum contaminant level = 1.3 milligrams/liter) and lead (maximum contaminant level = 0.015 milligrams/ liter). In addition, two other metals (iron and zinc) usually present because of corrosion can cause water to have a metallic taste. Laboratories and publications may report concentrations using units of milligrams/liter (mg/L) or parts per million (ppm), which are the same.

Michels, H. T. (2002). "Replacing lead in brass plumbing castings." Advanced Materials & Processes 160(1): 75-77.

With the passage of the 1996 amendment to the Safe Drinking Water Act, which limits the amount of lead in public drinking water supplies, the need for a replacement for lead in brass castings for components in potable water systems emerged with a new sense of urgency. In response to this clear need, the Copper Development Association (CDA) entered into an alloy development program with the American Foundry Society, the Brass and Bronze Ingot Manufacturers (now the Brass and Bronze Ingot Industries) and the Canadian Materials Technology Laboratory (CANMET).

The goal was to find a substitute for lead in brass plumbing castings. Specifically, the objective was to develop non-leaded replacements for three traditional leaded brass casting alloys. The most common red brass, UNS Alloy C83600, is called 85 metal, or 85-5-5-5. It contains 85% copper and 5% of each of the elements tin, lead, and zinc. The next is UNS Alloy C84400, a semi-red brass known as 81 metal, or 81-3-7-9. It contains 81% copper, 3% tin, 7% lead, and 9% zinc. These two alloys are traditionally sand cast. UNS Alloy C85800 is a standard yellow brass for permanent mold casting, and it contains 31 to 41% zinc, 1.5% each of lead and tin, with the balance copper.

Following ideas that were originally developed at the ASARCO Technical Center in Salt Lake City, Utah, lead replacement choices were narrowed to bismuth and selenium. The result was a family of non-leaded bismuth- and selenium-containing brass casting alloys called the EnviroBrass alloys. This article discusses the effect of the Safe Drinking Water Act, the reasons that lead has been added to brass, and the compositions and properties of the EnviroBrass alloys.

Miranda, M. L., et al. (2007). "Changes in blood lead levels associated with use of chloramines in water treatment systems." Environmental Health Perspectives 115(2): 221.

BACKGROUND: More municipal water treatment plants are using chloramines as a disinfectant in order to reduce carcinogenic by-products. In some instances, this has coincided with an increase in lead levels in drinking water in those systems. Lead in drinking water can be a significant health risk.

OBJECTIVES: We sought to test the potential effect of switching to chloramines for disinfection in water treatment systems on childhood blood lead levels using data from Wayne County, located in the central Coastal Plain of North Carolina.

METHODS: We constructed a unified geographic information system (GIS) that links blood lead screening data with age of housing, drinking water source, and census data for 7,270 records. The data were analyzed using both exploratory methods and more formal multivariate techniques.

RESULTS: The analysis indicates that the change to chloramine disinfection may lead to an increase in blood lead levels, the impact of which is progressively mitigated in newer housing.

CONCLUSIONS: Introducing chloramines to reduce carcinogenic by-products may increase exposure to lead in drinking water. Our research provides guidance on adjustments in the local childhood lead poisoning prevention program that should accompany changes in water treatment. As similar research is conducted in other areas, and the underlying environmental chemistry is clarified, water treatment strategies can be optimized across the multiple objectives that municipalities face in providing high quality drinking water to local residents.

Moore, M. R. (1977). "Lead in drinking water in soft water areas—health hazards." Science of the Total Environment 7(2): 109-115.

Studies have been made of the uptake of lead into drinking water and the association of that with the blood lead of persons resident in houses supplied with such water. Significant regressions were found between water lead and blood lead concentrations. Very high lead concentrations were found in houses with lead plumbing. There were in addition increased lead concentrations found in houses using copper piping joined with lead soldered joints. These studies have suggested that some health hazards might be expected to be associated with the increased environmental uptake of lead in these situations.

Morwood, G. (2014, 6 April 2018). "Lead Free- An Australian perspective." Plumbing Connection. from <http://plumbingconnection.com.au/lead-free-australian-perspective/>.

On January 4 of this year, the USA quietly rolled into a new era in the plumbing industry, virtually eliminating lead from plumbing products. The change finally ended eight years of speculation and doubt which started when California introduced independent legislation to ban lead in plumbing products, during the term of Arnold Schwarzenegger as The Governor. That legislation was enacted in 2010 and for the last four years has split the USA into states with lead-free legislation and those without. This year, the legislation has gone national in the USA, but as we explore here, the effect on the Australian plumbing market is not clear-cut, nor is the benefit to consumers of plumbing products.

Murphy, E. A. (1993). "Effectiveness of flushing on reducing lead and copper levels in school drinking water." Environmental Health Perspectives 101(3): 240.

Samples from drinking water fountains in 50 schools in New Jersey were collected at specific times during a typical school day and analyzed for lead, copper, pH, alkalinity, and hardness. First-draw lead and copper levels (medians 0.010 mg/l and 0.26 mg/l, respectively) decreased significantly after 10 min of flushing in the morning (medians 0.005 mg/l lead and 0.068 mg/l copper), but levels increased significantly by lunchtime (medians 0.007 mg/l lead and 0.12 mg/l copper) after normal use of fountains in the morning by students. Corrosive water, as defined by the aggressive index, contained significantly higher levels of lead and copper (medians 0.012 mg/l and 0.605 mg/l, respectively) than noncorrosive water (medians 0.005 mg/l and 0.03 mg/l, respectively).

Murrell, N. (1986). "Summary of impact of metallic solders on water quality." Plumbing Materials and Drinking Water Quality. Noyes Publications, Park Ridge New Jersey. 1986. p 61-66, 1.

A study of the impact of lead and other metallic solders on water quality was conducted under actual field conditions at test sites in the South Huntington Water District and at private. An overview of the lead test results at three different pH's within the indicated ranges of first draw samples indicated need for lead solder ban.

Muytwyk, Q., et al. (2014). "Developing corrosion control for drinking water systems." OpFlow 40(11): 24-27.

Consider potential water corrosivity effects and possible corrosion control if source water quality changes significantly or a change is being evaluated.

Nadagouda, M. N., et al. (2009). "Effect of Phosphate Inhibitors on the Formation of Lead Phosphate/Carbonate Nanorods, Microrods, and Dendritic Structures." Crystal Growth & Design 9(4): 1798-1805.

There are several factors which influence the corrosion rate of lead, which in turn morphs into different crystal shapes and sizes. Some of the important factors are alkalinity, pH, calcium, orthophosphate, and silica. Low to moderate alkalinity decreases corrosion rates, while higher alkalinities have a tendency to increase the corrosion rates of lead. This work describes the effect of orthophosphate inhibitor and pH on the formation of different structures of lead phosphate/carbonate nanorods, nanobelts, microrods, and dendritic structures. The experiments were carried out at different pHs both with and without orthophosphate inhibitor under laboratory conditions, which were intended to represent actual drinking water distribution system (DWDS) conditions. The surface morphology and crystal structure of the different crystals were obtained using scanning electron microscopy (SEM), energy dispersive X-ray analysis (EDS), transmission electron microscopy (TEM), and selected area diffraction pattern (SAED). The phase identification was done using powder X-ray diffraction (PXRD). With the increase in pH from 6.5 to 8.5, the formation of uniform thickness coating of phosphate containing minerals was observed, which was in contrast to the different crystal growth under low pH conditions. The XRD patterns indicate that the surface solids contain a mixture of many phases.

Neff, C. H. and M. R. Schock (1987). Relationships between water quality and corrosion of plumbing materials in buildings, Illinois State Water Survey.

A 3-year corrosion study was conducted on galvanized steel and copper piping materials installed in six public water supplies in Illinois. The water supplies were selected to represent the influence of water source, treatment processes, corrosion control programs, and water quality on the corrosivity of water. A comprehensive water sampling program was implemented to quantify the total metal concentrations found in both standing and running water samples. The major inorganic constituents in the water were determined to evaluate their contributions to the corrosivity of each water supply to copper or galvanized steel plumbing materials. Corrosion rates were measured by a weight loss method using the ASTM (D2688 Method C) corrosion tester. Nineteen corrosion test sites were installed to investigate the effects of time and changes in water quality on the corrosivity. Corrosion data, metal concentrations, and water quality were incorporated into a data base from which multiple linear regression models were tested for significant data correlations. Several significant findings were observed-. Most significant was the observation that chrome-plated brass faucets were making a large contribution to the lead, zinc, and copper concentrations found in drinking water. The experiments showed conclusively that brass sampling valves can be a considerable source of readily leachable lead and zinc when lead solder, lead pipes, and galvanized pipes are not present. Metal concentrations in water were significantly reduced with increased age of the plumbing installations. Extremely high metal concentrations were observed under stagnant water conditions in new plumbing installations, whereas reduced concentrations were observed in both running and standing water from older piping and fittings. The lead, zinc, copper, iron, and manganese concentrations exceeded the MCL in 10.6 to 25.6% of the standing samples and in 2.2% to 16.0% of the running samples collected during the study. Cadmium did not exceed the MCL in any sample. The metal concentrations generally decreased to equilibrium values within 6 months at most sites, but the zinc and copper concentrations increased during the last 12 months to concentrations much above the MCL in the most aggressive water supply. The statistical association analysis was unsuccessful because of the exceedingly large number of variables encountered under the field conditions of the study. All six public water supplies experienced unanticipated upsets in water quality during the study. The simulated corrosion

test loops were effectively used to monitor the corrosivity of the water with improved control of the running and standing periods of sampling.

Ng, D. Q., et al. (2012). "Role of orthophosphate as a corrosion inhibitor in chloraminated solutions containing tetravalent lead corrosion product PbO₂." Environmental Science and Technology 46(20): 11062-11069.

Addition of orthophosphate has been commonly employed to suppress lead levels in drinking water. Its detailed mechanism and time required for it to become effective, however, have not been fully elucidated. In this study, we investigated the mechanistic role of orthophosphate as a corrosion inhibitor in controlling lead release from tetravalent lead corrosion product PbO₂ in chloraminated solutions, a system representing distribution networks experiencing disinfectant changeover from free chlorine to monochloramine. In all experiments with orthophosphate addition of at least 1 mg/L as P, peaking of soluble Pb(II) concentration within the first 24 h was observed before lead concentrations decreased and stabilized at levels lower than 15 µg/L. The variation of soluble Pb(II) concentration could be attributed to the dynamics between the rate of PbO₂ reductive dissolution, primarily induced by monochloramine decomposition, and that of chloropyromorphite (Pb₅(PO₄)₃Cl) precipitation, which did not occur until a critical supersaturation ratio of about 2.36 was reached in the solution. Our findings provide insights to how orthophosphate reduces lead levels under drinking water conditions and highlight the potential risk of short-term elevated lead concentrations. Intensive monitoring following the disinfectant changeover may be required to determine the overall lead exposure when using orthophosphate as a corrosion inhibitor.

Ng, D.-Q. and Y.-P. Lin (2016). "Effects of pH value, chloride and sulfate concentrations on galvanic corrosion between lead and copper in drinking water." Environmental Chemistry 13(4): 602-610.

This study investigates the effects of pH value, chloride and sulfate concentrations on galvanic corrosion between lead and copper in drinking water. We hypothesised that galvanic corrosion would occur immediately when a lead–copper couple is first formed and that the release of lead would be suppressed by the subsequent formation of lead corrosion products. Therefore, unlike previous long-term studies using harvested lead pipes, batch experiments employing high-purity lead and copper (99.9 %) wires under stagnant and completely mixed conditions were conducted for a 7-day period to test our hypotheses. It was found that enhanced lead release was indeed observed after the lead–copper couple was formed and the lead profiles after 48 h were strongly influenced by lead corrosion products formed in the system. Under stagnant conditions, reducing pH and increasing either chloride or sulfate concentrations promoted lead release, leading to the formation of lead corrosion products such as cerussite and hydrocerussite as experiments proceeded. The effect of chloride concentration on total lead concentration measured in the aqueous phase was similar to that of sulfate at the same molar concentration, showing that the chloride-to-sulfate mass ratio may not provide a good indication for total lead concentration in water. This study provides essential information on fundamental mechanisms and processes involved in galvanic corrosion in drinking water and may be used to explain related phenomena observed in real drinking-water distribution systems.

Ng, D.-Q. and Y.-P. Lin (2016). "Evaluation of Lead Release in a Simulated Lead-Free Premise Plumbing System Using a Sequential Sampling Approach." International Journal of Environmental Research and Public Health 13(3).



In this pilot study, a modified sampling protocol was evaluated for the detection of lead contamination and locating the source of lead release in a simulated premise plumbing system with one-, three- and seven-day stagnation for a total period of 475 days. Copper pipes, stainless steel taps and brass fittings were used to assemble the "lead-free" system. Sequential sampling using 100 mL was used to detect lead contamination while that using 50 mL was used to locate the lead source. Elevated lead levels, far exceeding the World Health Organization (WHO) guideline value of $10 \mu\text{g} \cdot \text{L}^{-1}$, persisted for as long as five months in the system. "Lead-free" brass fittings were identified as the source of lead contamination. Physical disturbances, such as renovation works, could cause short-term spikes in lead release. Orthophosphate was able to suppress total lead levels below $10 \mu\text{g} \cdot \text{L}^{-1}$, but caused "blue water" problems. When orthophosphate addition was ceased, total lead levels began to spike within one week, implying that a continuous supply of orthophosphate was required to control total lead levels. Occasional total lead spikes were observed in one-day stagnation samples throughout the course of the experiments.

Nguyen, C. K., et al. (2011). "Acceleration of galvanic lead solder corrosion due to phosphate." Corrosion Science 53(4): 1515-1521.

Although orthophosphate is often effective in reducing lead corrosion, bench-scale tests revealed cases in which even high doses of orthophosphate (1-3 mg/L P) in potable water increased lead and tin release from simulated soldered copper joints. Phosphate increased the galvanic current between tin and copper plumbing materials, especially in water with less than 10 mg/L SO_4^{2-} and when the percentage of the anodic current carried by SO_4^{2-} ion was less than 30%. Tin release was increased more than lead release from 50:50 Pb-Sn solder in these circumstances. (c) 2011 Elsevier Ltd. All rights reserved.

Nguyen, C. K., et al. (2011). "Role of Chloride, Sulfate, and Alkalinity on Galvanic Lead Corrosion." Corrosion 67(6).

Effects of chloride, sulfate, and alkalinity on galvanic corrosion were investigated using beaker tests, lead wire electrochemical tests, and lead solder galvanic cells. At relatively high concentrations of lead and low pH values that might be present at the lead anode surface, sulfate forms precipitates with lead while chloride forms soluble complexes, explaining the detriments of chloride and benefits of sulfate during galvanic corrosion in prior research. Considering these factors and transport equations for anions in water, a chloride-to-sulfate mass ratio (CSMR) above 0.77 is predicted to concentrate more chloride than sulfate at the lead anode surface, whereas the converse occurs below this level of CSMR. Bicarbonate can compete with chloride and sulfate transport and buffer pH at the anode surface, providing benefits to lead corrosion.

Nguyen, C. K., et al. (2010). "Corrosive microenvironments at lead solder surfaces arising from galvanic corrosion with copper pipe." Environmental Science and Technology 44(18): 7076-7081.

As stagnant water contacts copper pipe and lead solder (simulated soldered joints), a corrosion cell is formed between the metals in solder (Pb, Sn) and the copper. If the resulting galvanic current exceeds about $2 \mu\text{A}/\text{cm}^2$, a highly corrosive microenvironment can form at the solder surface, with $\text{pH} < 2.5$ and chloride concentrations at least 11 times higher than bulk water levels. Waters with relatively high chloride tend to sustain high galvanic currents, preventing passivation of the solder surface, and contributing to lead contamination of potable water supplies. The total mass of lead corroded was consistent with predictions based on the galvanic current, and lead leaching to water was correlated with galvanic current. If the concentration of sulfate in the water increased relative to

chloride, galvanic currents and associated lead contamination could be greatly reduced, and solder surfaces were readily passivated.

Nguyen, C. K., et al. (2011). "Chloride-to-sulfate mass ratio: Practical studies in galvanic corrosion of lead solder." Journal American Water Works Association 103(1): 81-82.

Like other utilities in the United States, the water providers participating in this study had experienced lead problems as a result of seemingly innocuous changes to their drinking water treatment. Stock cures such as increasing pH or dosing orthophosphate corrosion inhibitor were not able to reduce lead in water in some cases. Bench-scale tests conducted in this research unambiguously demonstrated that raising the chloride-to-sulfate mass ratio (CSMR) increased lead leaching from lead plumbing materials, whereas lowering the CSMR decreased lead corrosion. The CSMR can be altered by any of the following: a change from a sulfate-based coagulant to a chloride-based coagulant, a switch from a freshwater source (surface water or groundwater) to seawater (i.e., desalinated water), implementation of anion exchange, and sodium chloride brine leaks from onsite hypochlorite generators. Before making treatment changes, utilities can use the simple bench-scale test protocol described in this article to screen for potential effects on lead release from solder.

Nguyen, C. K., et al. (2011). "Nitrate accelerated corrosion of lead solder in potable water systems." Corrosion Science 53(3): 1044-1049.

Although nitrate is generally believed to have little effect on lead corrosion, bench-scale tests in this work revealed that increasing nitrate in the range of occurrence in potable water (0-10 mg/L N) can dramatically increase lead leaching from simulated soldered pipe joints. Lead in water created slightly increased galvanic currents between solder and copper pipe, but nitrate also altered the nature of the attack in a manner that caused solder particles to detach into the water. Chloramine decay and the associated conversion of ammonia to nitrate could create much higher lead contamination of potable water from solder in some cases. (C) 2010 Elsevier Ltd. All rights reserved.

NHMRC and NRMCC (2011). Australian Drinking Water Guidelines: Paper 6 National Water Quality Management Strategy: Version 3.4 Updated October 2017. Canberra, ACT, National Health and Medical Research Council (NHMRC), National Resource Management Ministerial Council (NRMCC) Commonwealth of Australia.

SCOPE OF THE ADWG

Drinking water is defined as water intended primarily for human consumption, either directly, as supplied from the tap, or indirectly, in beverages, ice or foods prepared with water. Drinking water is also used for other domestic purposes such as bathing and showering. With the exception of bottled or packaged water, the ADWG apply to any water intended for drinking irrespective of the source (municipal supplies, rainwater tanks, bores etc) or where it is consumed (the home, restaurants, camping areas, shops etc). Bottled water and packaged water are subject to the Food Standards Code¹. The ADWG do not address water used for specialised purposes such as renal dialysis and some industrial purposes where water of a higher quality than that specified in the Guidelines may be required.

PURPOSE OF THE ADWG

The ADWG provide the authoritative Australian reference for use within Australia's administrative and legislative framework to ensure the accountability of drinking water suppliers (as managers) and of state and territory health authorities (as auditors of the safety of water supplies). The ADWG are not, however, mandatory legally enforceable

standards. With appropriate consultation with the community, the ADWG may be used directly as agreed levels of service or they may form the basis for developing local levels of service. In the case of health-related water quality characteristics, there is less latitude for variation because the safety of drinking water is paramount. However, with regard to aesthetic characteristics, what is acceptable or unacceptable depends on public expectations and can therefore be determined by water authorities in consultation with consumers, taking into account the costs and benefits of further treatment of the water. The ADWG provide a starting point for that process. The ADWG may also be used by a standards body for defining quality processes suitable for third party accreditation of a quality management system.

NSF/ANSI (2016). American National Standard/NSF International Standard for Drinking Water Additives NSF/ANSI 61-2016: Drinking water system components—Health Effects. Ann Arbor, Michigan, The NSF Joint Committee on Drinking Water Additives.

NSF/ANSI 61 was developed to establish minimum requirements for the control of potential adverse human health effects from products that contact drinking water. It does not attempt to include product performance requirements that are currently addressed in other voluntary consensus standards established by such organizations as the American Water Works Association, the American Society for Testing and Materials, and the American National Standards Institute. Because this Standard complements the performance standards of these organizations, it is recommended that products also meet the appropriate performance requirements specified in the standards of such organizations. NSF/ANSI 61, and subsequent product certification against it, has replaced the USEPA Additives Advisory Program for drinking water system components. USEPA terminated its advisory role in April 1990. For more information with regard to USEPA's actions, refer to the July 7, 1988 Federal Register (53FR25586).

This Standard and the accompanying text are intended for voluntary use by certifying organizations, utilities, regulatory agencies, and/or manufacturers as a basis of providing assurances that adequate health protection exists for covered products. Product certification issues, including frequency of testing and requirements for follow-up testing, evaluation, enforcement, and other policy issues, are not addressed by this Standard. This Standard was initially approved by ANSI in 1989. NSF and all stakeholders have worked since 1988 to complete NSF/ANSI 61 by including requirements for mechanical plumbing products. Devices used within the final one L of the distribution system are covered under section 9 and include end-point devices such as faucets, glass fillers, water coolers, residential ice makers, and supply stops. Section 9 was accepted by the NSF Joint Committee on Drinking Water Additives, and the NSF Council of Public Health Consultants. It was adopted by the NSF Board of Trustees on September 9, 1994, and approved by ANSI on September 12, 1995.

O'Connor, J., et al., Eds. (2009). Where Is the Lead in Rainwater Tanks Coming From? H2009: 32nd Hydrology and Water Resources Symposium, Newcastle : Adapting to Change. Barton, A.C.T., Engineers Australia.

The water from rainwater tanks has often been found to have high lead concentrations, in some cases exceeding potable water guidelines. These high lead concentrations were previously linked to the presence of lead flashing on roofs and proximity of roofs to roads and industry. In this study, water and sediment samples were collected from 52 tanks across the Melbourne metropolitan area along with information about the tanks, roofs and the surrounding environment. The results were analysed to identify significant relationships between lead concentrations in tank water, tank sediments and a range of variables

collected. Water quality in 14 of the 52 tanks sampled exceeded Australian Drinking Water Guidelines (ADWG) for lead concentrations. It was found that lead flashing, prevailing winds, proximity to roads and commercial zones had statistically significant relationships with lead concentrations in rainwater tanks, thus implying that no single source is the sole cause of high lead concentrations.

Oliphant, R. J. (1992). Changing perceptions of the significance of potential sources of lead contamination in water-systems. Iwsa Specialized Conference on Quality Aspects of Water Supply. F. Fiessinger. 11: 399-412.

Paper referenced by others but abstract not available.

Paige, J. I. and B. S. Covino Jr. (1992). "Leachability of Lead from Selected Copper-Base Alloys." Corrosion 48(12): 140-146.

The Bureau of Mines has conducted research on the selective leaching of lead from copper-base alloys in high purity water. The alloys in this study were selected as representatives of those used in various plumbing system fixtures such as faucets and valves. Leaching tests were conducted for a total period of 14 days and at temperatures of 25, 50, and 75°C. An acetic acid pre-treatment was used in an effort to reduce the amount of lead that was leached from the alloys. The results show that, with the exception of the more complex yellow brasses, more lead is leached into water from alloys containing greater concentrations of lead and that the rate of lead leaching decreases with exposure time. Higher temperatures had relatively little effect on the leaching of lead. Lead was preferentially dissolved from all of the alloy groups. Of the small total amount of alloy dissolved, more Pb, 10 to 59 times, was dissolved than would be predicted from the proportional quantity of Pb present in the alloy (0.1 to 7.0 wt% Pb). Typically, the amount of Pb dissolved in any given test period exceeded the Environmental Protection Agency proposed action limit of 0.015 mg/L.

Payne, M. (2008). "Lead in drinking water." Canadian Medical Association Journal 179(3): 253-254.

The presence of lead in drinking water is not a new problem. Lead was historically used to produce pipes to carry water and later to solder iron and copper pipes. It is a ubiquitous heavy metal that has been used for centuries as a constituent in various products such as face powder, ceramic glazing, gasoline, plumbing, radiation shielding, children's toys and paint. Its long history of use and distribution means lead exposure and its health effects are global.

By following the risk assessment process first established by the US National Research Council, this article provides practitioners with information to respond to their patients' concerns regarding lead in drinking water.

Many countries have succeeded in reducing lead exposure through regulation of products. However, according to the World Health Organization, a number of developing countries still allow lead in gasoline. About one-fifth of the burden of disease from lead exposure occurs in Southeast Asia, and another one-fifth occurs in the western Pacific region. The burden is also felt in poorer sections of Europe: the World Health Organization estimates that nearly 157 000 days of healthy life are lost among children under 4 years old because of mild retardation from lead poisoning. In Central and South America, 33%–34% of children have blood lead levels above 10 µg/dL (0.48 µmol/L), compared with 7% in North America.

Lead exposure in Canada has decreased significantly over the past several decades, thanks to the introduction of regulations to remove lead from common sources such as paint and gasoline. However, as we control these sources, others, including drinking water, become relatively more important. Homes built before the 1950s were often built with lead plumbing, and those built as recently as 1990 may contain lead solder.³ Many communities in Canada have older sections of their drinking-water distribution systems that have lead pipes or soldering.

The risk assessment process described in this article starts with an exposure and hazard assessment, which in turn informs risk management decisions.

Pieper, K. J., et al. (2016). "Quantifying Lead-Leaching Potential From Plumbing Exposed to Aggressive Waters." Journal American Water Works Association 108(9): E458-E466.

Section 9 of NSF International/American National Standards Institute (NSF/ANSI) Standard 61 evaluates lead-leaching potential from end-point devices to protect consumer health. However, because the NSF/ANSI protocol stipulates a high pH and alkalinity characteristic of municipal waters, it is not likely generalizable to the aggressive water chemistries more consistent with water quality observed in private systems. To assess lead release from components installed in private systems, this study exposed brass and galvanized steel that meet lead-free requirements to more aggressive waters. As expected, lead leaching from C36000 brass increased with decreasing pH and alkalinity, but post-2014 lead-free brass released non-detectable concentrations when exposed to aggressive conditions. However, post-2014 lead-free galvanized steel may still release significant lead in aggressive waters as a result of the sorption of lead to plumbing. Although new lead-free brass products are more protective of communities dependent on private systems, elevated lead from both legacy materials and galvanized steel remains an issue for systems without corrosion control.

Pokomeda, K., et al. (2018). "Problems of Trace Elements in Water and Wastewater Treatment." Recent Advances in Trace Elements: 105-120.

Trace elements in small concentrations pose no threat to the environment or the human body and can be even beneficial. In larger quantities, however, they tend to be extremely toxic, causing numerous diseases and health problems, which is why it is important to use adequate methods and techniques to treat contaminated water. This chapter quotes relevant legislation on concentration limits, describes the most important sources of trace elements in drinking and wastewater, and lists water treatment methods.

Pontius, F. W. (1997). "SDWA limits lead content of plumbing materials." Journal American Water Works Association 89(7): 12-12.

The 1986 Safe Drinking Water Act (SDWA) amendments included Sec. 1417, which was intended to decrease future problems of lead contamination in water systems. The section was amended in 1996 to expand coverage to include the use of leaded plumbing fittings and fixtures (faucets).

Potter, S. (1997). Lead in Drinking Water, House of Commons Library.

Lead is a metal which is toxic to humans, and of which there is no safe level. Scientific studies have concluded that exposure to even low levels of lead can cause a small but significant reduction in the IQ of children.

Lead has been widely used in pipes to distribute drinking water since Roman times. Lead levels in drinking water when it is put into the distribution system are generally very low. However, in properties whose drinking water is still supplied through lead pipework, it can dissolve into the water at concentrations above current legal standards for drinking water quality as well as health guidelines. Although new lead pipes are no longer installed, some 8.9 million homes in England and Wales are estimated to have lead water supply pipes.

The European Union is currently in the process of revising its drinking water directive, originally adopted in 1980. One of the most significant changes in the new directive will be a substantial reduction in the permitted concentration of lead in drinking water, to only 20% of its current level. Member States will have to meet the new standard within 15 years. This may require the replacement of lead pipes throughout the UK, the costs of which have been estimated at between £7-10 billion. This paper examines current scientific evidence of the health risks from lead and the relative contribution of drinking water to these. It reviews current levels of lead in drinking water and prevalence of lead pipework in the UK, and identifies the actions which are currently being undertaken in various sectors to reduce levels of lead in drinking water and remove lead pipes. It also addresses the steps which consumers can take to inform themselves of these issues. The paper further examines the ways in which compliance with the proposed new standard for lead can be achieved and the likely costs and benefits to be derived from meeting the new standard.

Purkiss, D. (2011). "Article reporting on lead contamination from brass plumbing devices in new buildings sparks discussion." Journal American Water Works Association 103(1): 8-8.

The University of North Carolina at Chapel Hill (UNC) campus experienced an unfortunate and significant lead problem as described in the November 2010 article by Elfland and co-authors, "Lead contaminated Water From Brass Plumbing Devices in New Buildings." Although the article walks the reader through the process of their investigation, their assertion that NSF/American National Standards Institute (ANSI) Standard 61 is a root cause of this problem is unwarranted and misleading. Many manufacturers claim products are "NSF-approved" or "Proposition 65-certified." However, unless the product's specific model number appears in an official listing on the website of an ANSI-accredited certifier such as CSA, NSF, UL, or the Water Quality Association (WQA) and the product packaging and/or device has a certification mark, the product is very likely not certified. Based on the information we have, we do not believe the high-lead ball valves cited in this study (which had 6.6% lead content in the body and 18% lead on the water contact surface) were ever certified to - nor comply with- NSF/ANSI Standard 61. In our experience, products reported as having 18% lead on the surface would not comply with NSF 61, let alone the new NSF 61 -Annex F requirements that reduce the allowable amount of lead in leachate by two thirds beginning July 1, 2012. NSF 61 also has requirements that prohibit the use of lead as an intentional ingredient, except for brass materials complying with the lead-free requirements of the Safe Drinking Water Act (SDWA). Such requirements would prevent a "100% lead" device from being certified to NSF 61, which has been repeatedly alleged in studies published in Journal AWWA. In fact, if current proposed amendments are made to the SDWA to reduce the definition of "lead free" from 8% to 0.25%, then NSF 61 would automatically require all products to comply with this low lead-content requirement, which is currently mandated only in California and Vermont. The authors of this article raise important issues about the potential hazards from lead in new construction. The hazards arising from the accumulation of lead-containing debris on screens and strainers hidden upstream of faucet aerators appear very significant. Even after an initial cleaning, they can again collect debris and repeatedly become a significant source of lead. The authors also point out that installations with low flows and long stagnation times can lead to high levels

of lead contamination. These are important considerations for both system designs as well as standards. The ANSI standards development process is open and transparent. The Joint Committee on Drinking Water Additives that approves Standard 61 has representation from all interested stakeholders, including state and federal drinking water regulators, AWWA, and water utilities. The Joint Committee invites the authors and other interested parties to submit suggestions for improvements to NSF 61 by e-mailing me at purkiss@nsf.org.
Dave Purkiss General Manager Water Distribution Systems NSF International

Raab, G. M., et al. (1993). "The influence of pH and household plumbing on water lead concentration." Environmental Geochemistry and Health 15(4): 191-200.

The water lead concentrations measured in the homes of children who were part of the Edinburgh Lead study are related to the characteristics of the water supply and the household plumbing. At the time of the study one of the City of Edinburgh's two water supplies was lime treated to reduce plumbosolvency but in the second supply this treatment had not yet become effective. This allows us to estimate the extent to which this type of water treatment reduces water lead concentrations, in houses with lead plumbing, to comply with existing and proposed limits for lead in water. The kitchen cold water was supplied from a lead storage tank in 69 (15%) of the houses. These houses had the highest lead concentrations and water treatment alone is unlikely to bring them down to comply even with current statutory limits.

Rabin, R. (2008). "The lead industry and lead water pipes "A Modest Campaign". " American journal of public health 98(9): 1584-1592.

Lead pipes for carrying drinking water were well recognized as a cause of lead poisoning by the late 1800s in the United States. By the 1920s, many cities and towns were prohibiting or restricting their use. To combat this trend, the lead industry carried out a prolonged and effective campaign to promote the use of lead pipes. Led by the Lead Industries Association (LIA), representatives were sent to speak with plumbers' organizations, local water authorities, architects, and federal officials. The LIA also published numerous articles and books that extolled the advantages of lead over other materials and gave practical advice on the installation and repair of lead pipes. The LIA's activities over several decades therefore contributed to the present-day public health and economic cost of lead water pipes.

Raetz, M., et al. (2013). "Flushing of Soldering Flux from Drinking Water Plumbing in New Construction." Materials Performance 52(1): 60-64.

Many factors associated with plumbing in new buildings can cause problems with drinking water quality and contribute to reduced lifetime of the plumbing system. Flux is a commonly used material that may contribute to die problems. Flux is used before soldering metal pipes to permit uniform spreading of molten solder, remove residual traces of oxides, promote wetting, and protect surfaces from oxidation during heating. Standard testing of flux is done per ASTM Standard B813,1 which evaluates the spreading factor, aggressiveness, corrosiveness, viscosity, and residue after flushing of the flux being tested. A flux is considered compliant when it passes these tests.

Rajaratnam, G., et al. (2002). "Metals in Drinking Water from New Housing Estates in the Sydney Area." Environmental Research 89(2): 165-170.

Metals in drinking water were measured in 95 new houses less than 18 months old in the Sydney metropolitan area. Three samples (first-flush, post-first-flush, and fully flushed

water) were collected from each house, and “control” samples from the five Sydney Water points that supplied the houses, a total of 326 samples. They were analyzed for Pb, Cu, Mn, Zn, Cd, and Al. At the supply points, the levels of all metals were at or below Australian Drinking Water Guidelines (ADWG). In the houses, metal levels varied. Of the first-flush samples, Pb was above ADWG in 60% and above US EPA Guidelines in 81%, Cu was above ADWG in 12%, and Cd was above ADWG in 4%. Of the post-first-flush samples, Pb was above ADWG in 24%, Cu was above ADWG in 18%, Cd was above ADWG in 1%, and Zn was above ADWG in 1%. The other metal contaminants (Mn and Al) were within ADWG. In fully flushed water, the levels of all metals were well below ADWG.

Ramsay, C. (2003). Scottish new homes lead survey. Stage 2. . Glasgow, Scotland, Scottish Centre for Infection and Environmental Health: 155.

The Scottish New Homes Lead Survey (SNHLS) was initiated to investigate the use of leaded solder on the internal drinking water plumbing of new houses in Scotland. This followed the inadvertent discovery that leaded solder had been used in contravention of existing Water Bylaws.

The overall aims of the survey were to:

- assess the extent of leaded solder use in contravention of existing Water Bylaws.
- determine the impact of leaded solder use on the lead content of drinking water supplies in affected houses.
- investigate the impact of exposure to waterborne lead, derived from leaded solder on the health of house occupants.

The survey was conducted in two phases running consecutively. Stage 1 of the survey has been reported previously.

This report details the findings of Stage 2 of the survey.

Conclusions

The Stage 2 study therefore provides evidence for the following conclusions:

- leaded solder was used (illegally) on drinking water plumbing in new houses across Scotland,
- leaded solder was the most likely source of excess lead contamination in the drinking water of the houses sampled,
- the correlation of lead levels in blood with lead levels in the drinking water of affected houses, together with the similarity in the isotope ratios between lead in blood and water, is consistent with lead derived from leaded solder being absorbed by the house occupants,
- house occupants were therefore exposed to an additional quantity of lead from a preventable source of contamination,
- the use of leaded solder represents an avoidable hazard in terms of an unnecessary additional body burden of lead and a potential cause of lead toxicity, especially for vulnerable groups including very young children and pregnant women.
- The proportion of new houses identified by Stage 1 of the survey as being affected by the use of leaded solder, could be more than twice the original estimate of 15%.

Renner, R. (2009). "Out of Plumb When Water Treatment Causes Lead Contamination." Environmental Health Perspectives 117(12): A542-A547.

A retrospective analysis of water utility data on lead in drinking water and data on child blood levels in Washington, DC, revealed that a spike in the number of infants with blood lead levels of 10 µg/dL or higher correlated strongly with a change. Deposits of lead, copper, and other minerals can form inside plumbing pipes when the pipe walls corrode through oxidation or other chemical action. Corrosion deposits and mineral scale can serve as reservoirs for the accumulation of contaminants in water.

Rizzuti, A. and L. Rogers (2010). "Using monochloramines to disinfect drinking water: the effects it has on lead content." Water Practice and Technology 5(2): 1-8.

Over the past ten years, several U.S. cities have switched from using free chlorine to chloramines to disinfect drinking water. Coincident with this shift have been reports by some water districts of lead (Pb) levels in drinking water that exceed the action limit of 15ppb set by the EPA. In this paper, a study was conducted on a water district that utilizes monochloramines to disinfect drinking water. The purpose of this research was to determine the Pb content of drinking water treated in this district. Water samples were collected both from homes with and from homes without Pb plumbing. The water samples were analyzed for Pb content using graphite furnace atomic absorption spectrophotometry. Samples obtained from homes without Pb plumbing had a Pb concentration range of 10.7 ppb – 20.3 ppb (average = 15.9 ppb), whereas samples obtained from homes with Pb plumbing had a Pb concentration range of 20.4 ppb – 73.9 ppb (average = 29.0 ppb). The average Pb concentrations for both types of homes were above the EPA action limit of 15ppb. The most plausible explanation for this is leaching of Pb from the water distribution system caused by the water treatment plants' use of monochloramines to disinfect water.

Salehi, M., et al. (2018). "Case study: Fixture water use and drinking water quality in a new residential green building." Chemosphere 195: 80-89.

Residential plumbing is critical for the health and safety of populations worldwide. A case study was conducted to understand fixture water use, drinking water quality and their possible link, in a newly plumbed residential green building. Water use and water quality were monitored at four in-building locations from September 2015 through December 2015. Once the home was fully inhabited average water stagnation periods were shortest at the 2nd floor hot fixture (90 percentile of 0.6–1.2 h). The maximum water stagnation time was 72.0 h. Bacteria and organic carbon levels increased inside the plumbing system compared to the municipal tap water entering the building. A greater amount of bacteria was detected in hot water samples (6–74,002 gene copy number/mL) compared to cold water (2–597 gene copy number/mL). This suggested that hot water plumbing promoted greater microbial growth. The basement fixture brass needle valve may have caused maximum Zn (5.9 mg/L), Fe (4.1 mg/L), and Pb (23 µg/L) levels compared to other fixture water samples (Zn 2.1 mg/L, Fe 0.5 mg/L and Pb 8 µg/L). At the basement fixture, where the least amount of water use events occurred (cold: 60–105, hot: 21–69 event/month) compared to the other fixtures in the building (cold: 145–856, hot: 326–2230 event/month), greater organic carbon, bacteria, and heavy metal levels were detected. Different fixture use patterns resulted in disparate water quality within a single-family home. The greatest drinking water quality changes were detected at the least frequently used fixture.

Salehi, M., et al. (2018). "Investigation of the factors that influence lead accumulation onto polyethylene: Implication for potable water plumbing pipes." Journal of Hazardous Materials 347: 242-251.

The influence of polymer aging, water pH, and aqueous Pb concentration on Pb deposition onto low density polyethylene (LDPE) was investigated. LDPE pellets were aged by ozonation at 85 degrees C. ATR-FTIR and X-ray photoelectron spectroscopy (XPS) analysis of aged LDPE surfaces showed that a variety of polar functional groups (>CO<, >CO, >COO) were formed during aging. These functional groups likely provided better nucleation sites for Pb(OH)₂ deposition compared to new LDPE, which did not have these oxygen-containing functional groups. The type and amount of Pb species present on these surfaces were evaluated through XPS. The influence of exposure duration on Pb deposition



onto LDPE was modeled using the pseudo-first-order equation. Distribution ratios of 251.5 for aged LDPE and 69.3 for new LDPE showed that Pb precipitates had greater affinity for the surface of aged LDPE compared to new LDPE. Aged LDPE had less Pb surface loading at pH 11 compared to loading at pH 7.8. Pb surface loading for aged LDPE changed linearly with aging duration (from 0.5-7.5h). Pb surface loading on both new and aged LDPE increased linearly with increasing Pb initial concentration. Greater Pb precipitation rates were found for aged LDPE compared to new LDPE at both tested pH values.

Salehi, M., et al. (2017). "Metal Accumulation in Representative Plastic Drinking Water Plumbing Systems." Journal American Water Works Association 109(11): E479-E493.

Metal abundance and scale morphology for cross-linked polyethylene plastic pipes and pipe oxidative condition were examined in a one-year-old residential plumbing system. Experiments were also conducted to determine whether plastic pipe surfaces can influence scale formation. Within a single plumbing system, significant differences were found for scale morphology, the amount of metals present on pipe inner walls, and pipe aging condition. Metals found on the plastic pipes (aluminum, calcium, cobalt, copper, iron, lead, magnesium, manganese, nickel, selenium, and zinc) were corrosion products from water distribution and plumbing materials and were present in the source water. Iron was the most abundant contaminant. Bench-scale experiments revealed that plastic served as a nucleation site for iron crystal growth and expedited crystal formation. Plastic plumbing pipes can adsorb metals that have health and aesthetic drinking water limits, and additional work is needed to understand the conditions that affect metal accumulation and release.

Samuels, E. and J. Meranger (1984). "Preliminary studies on the leaching of some trace metals from kitchen faucets." Water Research 18(1): 75-80.

Preliminary studies were carried out on the leaching of copper, zinc, chromium, cadmium and lead from eight kitchen faucets by samples of raw, filtered and distributed Ottawa water, a sample of well water and deionized water containing 2 mg l⁻¹ aqueous fulvic acid. Leaching was effected by allowing the test solutions to stand in the inverted faucets for two successive 24-h periods. Concentrations of the metals found in the leachates were copper: first leaching, 0.12–28.0 mg l⁻¹, second leaching, 0.08–3.54 mg l⁻¹; zinc: first leaching, 0.13–10.25 mg l⁻¹, second leaching, 0.06–2.85 mg l⁻¹; chromium: first leaching, < 1.0 × 10⁻³ – 0.395 mg l⁻¹, second leaching, < 1.0 × 10⁻³–0.032 mg l⁻¹; cadmium: first leaching, < 0.05 × 10⁻³–0.01 mg l⁻¹, second leaching, < 0.05 × 10⁻³–4 × 10⁻³ mg l⁻¹; and lead: first leaching, < 0.2–110.0 mg l⁻¹, second leaching, < 0.2–82.0 mg l⁻¹. The faucets containing lead-soldered copper joints released high concentrations of lead, particularly in the case of leaching with the aqueous fulvic acid solution. Under the conditions of the present investigations it is indicated that in some cases the concentrations of metals leached could lead to intakes in excess of the maximum permissible limits for these metals. However, further investigations will be required to determine the possible contribution of these faucets to metal intake under normal usage.

Sandvig, A., et al. (2008). Contribution of service line and plumbing fixtures to lead and copper rule compliance issues. Washington, DC, Awa Research Foundation and United States Environment Protection Authority: 523.

Implementation of the Lead and Copper Rule (LCR) has resulted in significant reductions in first liter standing lead levels measured at the tap in the United States. However, there are still utilities that have implemented optimal treatment but may still experience lead levels at or near the action levels for lead, or those that would like to go a step further in reducing

lead levels measured in their system by proactively replacing lead source materials. For these utilities, an understanding of the contributions that various lead based materials may have on lead levels measured at the tap would be useful. The stated goal of this Project was 'to research and quantify the contribution of lead service lines, utility owned in-line components, and customer owned plumbing fixtures to Lead and Copper Rule compliance issues'. The results of this Project also address the broader long-term goals of moving the industry towards a new "lead free " future and providing information that can be directly applied to future regulatory reviews of the LCR.

Sandvig, A. M., et al. (2009). "Nonleaded brass-A summary of performance and costs." Journal American Water Works Association 101(7): 83-94.

Concerns over lead release from brass into drinking water have spurred development of nonleaded brass alloys. Water meters, components, and fittings manufactured from nonleaded alloys (most containing ≤ 0.1 -0.25% lead) are increasingly being installed in water distribution systems and premise plumbing. This article reviews commercially available nonleaded-brass alloys, including their leaching behavior, performance, and costs. Laboratory and field tests have found that nonleaded brass components contribute much lower levels of lead to water than do leaded brasses under comparable conditions, and possess mechanical strength and machinability properties comparable to leaded brass components. Although concerns remain about possible failure from dezincification and stress cracking, utilities switching to nonleaded components have not reported compromised performance. Individual nonleaded components, although more expensive than their leaded counterparts, actually result in overall replacement costs of only 2-5% when factoring in labor, equipment, and other expenses.

Sarver, E. (2010). Insights into non-uniform copper and brass corrosion in potable water systems. Civil and Environmental Engineering. Blacksburg, VA Virginia Polytechnic Institute and State University. PhD: 181.

Non-uniform corrosion of copper and brass in potable water systems poses both economic and environmental problems associated with premature plumbing failures and release of metals. With respect to copper pitting corrosion, it was found that forensic testing (i.e., in pipe-loops) is the only investigative technique that can closely mimic conditions found in real water systems and produce unambiguous results; and, if used in combination with electrochemical techniques, it may also provide some mechanistic insights into the pitting process. Using pipe-loops, it was demonstrated that copper pitting in aggressive water qualities (i.e., chlorinated, high pH and low alkalinity) is deterministic and reproducible. Additionally, the effects of various chemical and physical factors on pitting were investigated. Overall, increased flow velocity and frequency, increased chlorine residual and decreased hardness were found to accelerate pitting; whereas increased phosphate and silica were found to decelerate pitting. Several mitigation strategies for copper pitting in aggressive water were further investigated, and experimental data were interpreted utilizing electrochemical theory to evaluate specific effects on the initiation and propagation phases of pitting. Surprisingly, it was found that decreased chlorine may delay pit initiation, however, even relatively low levels of chlorine may eventually initiate and propagate pits. Increased alkalinity appears to decelerate pit growth, but does not prevent pit initiation. NOM can delay pit initiation and propagation, although the potential for DBP formation in chlorinated waters makes inhibition by NOM an unfavourable alternative. At sufficient dosages, phosphate and silica corrosion inhibitors may completely stop pitting, consistent with the success of several field trials. At very low dosages, phosphate and silica may actually accelerate pinhole failures, so these inhibitors should not be under-dosed. While

brass alloys exist that can limit dezincification problems, they are not always utilized in potable water applications due to high costs, and so dezincification is a re-emerging issue in some countries, including the US. Little research has been conducted in the past several decades regarding the effects of water chemistry, and almost no work has addressed the roles of physical factors associated with real plumbing systems. Thus, a comprehensive review of these topics was conducted. To better understand the effects of some factors associated with specific plumbing installations on dezincification and other brass corrosion types, a series of pipe-loop studies was carried out. It was confirmed that increased oxidant delivery rates to cathodic surfaces, either via increased oxidant concentration or increased flow velocity, can increase corrosion rates. Several key differences were observed with respect to corrosion of brass located in copper plumbing tube systems as opposed to plastic. When copper tubes contribute copper ions to water, brass corrosion becomes more selective for zinc; but if galvanic connections are made between the copper tubes and brass, selectivity for zinc is reduced while overall corrosion rates are accelerated. As opposed to copper tubing, plastic maintains oxidant (e.g., free chlorine) levels, and may thereby increase brass corrosion and build-up of corrosion by-products. Finally, it was found that increased temperature can significantly increase lead leaching from brass. Following recent outbreaks of brass dezincification failures, NSF/ANSI Standard 14 has been revised to require that all NSF 14-listed brass is dezincification resistant, as certified by satisfactory results from an accelerated test method (ISO 6509). Various brasses were tested using this method as well as a longer-term jar method utilizing real potable water. Results of the two tests were in good agreement with respect to dezincification, specifically; but some inconsistencies were observed with respect to uniform corrosion and lead leaching.

Sarver, E. and M. Edwards (2011). "Controlling Non-uniform Copper and Brass Corrosion in Building Plumbing." Materials Performance 50(8): 60-65.

Copper piping and brass fittings are the dominant plumbing materials in the United States, with an overall replacement value nearing \$1 trillion.¹ Non-uniform corrosion of these materials can threaten the longevity of those assets and create economic consequences for consumers, including costs of repairing or replumbing, water damages, and mold mitigation. In potable water systems, copper can be specifically attacked by pitting, which leads to pinhole leaks (Figure 1). Currently, only aggressive water has been conclusively identified as a contributor to copper pitting—although evidence strongly suggests that other factors can be influential. Pitting can also occur on brass components, but dealloying phenomena such as dezincification (selective zinc leaching) can lead to mechanical failures or clogged water lines. Lead release from brass can also pose significant health concerns. Recent research has yielded numerous insights into key factors contributing to copper pinholes and brass corrosion. These insights can assist decision-making by government agencies, water utilities, materials manufacturers, plumbers, and homeowners in preventing or mitigating problems. Although consumers alone have typically borne the costs for nonuniform corrosion failures, ethical and legal responsibilities are often shared, as indicated by decisions in a few lawsuits. This article highlights the current state of scientific knowledge and will help facilitate cooperative responses when identifying and dealing with problems.

Sarver, E. and M. Edwards (2011). "Effects of flow, brass location, tube materials and temperature on corrosion of brass plumbing devices." Corrosion Science 53(5): 1813-1824.

Effects of plumbing-specific installation factors on brass corrosion were investigated in a series of pipe-loop experiments. Increased flow velocity increased corrosion rates, but did not affect corrosion type. The presence of copper tubing in the plumbing system increased

selectivity of brass corrosion for zinc, unless a galvanic connection was made between copper and brass, in which case corrosion became more uniform and was accelerated. Plastic tubing allowed oxidant (i.e., free chlorine) to persist in water, increasing brass exposure. Additionally, hot water significantly increased lead leaching from brass. These findings may inform future investigations into brass corrosion issues and plumbing designs.

Sarver, E., et al. (2011). "Revisiting Dezincification Performance Testing for Brass Plumbing Devices." Materials Performance 50(5): 70-75.

The results of comparative analysis of the ISO 6509 test with those from a longer-term test, which subjected brasses to real potable water, are presented. The susceptibility of seven different brasses was assessed based on weight loss and metal leaching in the long-term potable water exposure test, and corrosion depth and metal leaching in the ISO 6509 test. The brass rings in potable water exposure test were lightly polished, rinsed with deionized water, dried in a desiccator, and then weighed to an accuracy of ± 0.1 mg. The pH and free chlorine residual were checked and maintained at least every 72 h. The second test was conducted following the standard procedure outlined in ISO 6509. Each sample was cross-sectioned such that corrosion depth could be measured on two unique planes, using a Boreal stereomicroscope. The alpha brass exhibited limited areas of more shallow corrosion, with the maximum observable depth being $\sim 190\mu\text{m}$.

Schock, M. R. (1980). "Response of lead solubility to dissolved carbonate in drinking water." American Water Works Association Journal 72(12): 695-704.

Because of the potential toxicity of Pb and its deleterious effects on human health, increased attention has been given to the use of Pb piping materials in household plumbing. Water that is corrosive to Pb has leached considerable amounts of Pb from pipes, especially after the water has been standing in the pipes for several hours. A revised model showed the detailed response of the theoretical solubility curves for Pb to changes in dissolved inorganic carbonate concentration (C_t) and pH at 25.degree. C. The model agreed well with previously published pipe loop solubility experimental data, and with pipe coupon tests and precipitation data at high C_t .

Schock, M. R. (1989). "CORRECTION." Journal American Water Works Association 81(10): 4-4.

The article by Michael R. Schock ("Understanding Corrosion Control Strategies for Lead") in the July 1989 issue of JOURNAL AWWA contained several errors. Corrections are given for pages 88 and 89.

Schock, M. R. (1989). "Understanding corrosion control strategies for lead." Journal American Water Works Association 81(7): 88-100.

This article reviews the factors that should be considered by individual utilities in developing a lead-solubility control program based on the adjustment of pH, dissolved inorganic carbonate, and orthophosphate. Because of the lack of fundamental and applied corrosion control research and the complexity of the chemical interactions involved, the recommendations included are only best estimates--which can be updated as new data become available. A flow chart is provided to aid in the selection of the best treatment scheme; it is based on the philosophy that chemical models are a useful qualitative guide to the impact of water chemistry on lead solubility but that levels of adjustment should be determined by feedback from pilot testing.

Schock, M. R. (1990). "Causes of temporal variability of lead in domestic plumbing systems." Environmental monitoring and assessment 15(1): 59-82.

Sources of lead in drinking water are primarily lead pipe, lead/tin solder, and brass fixture materials.

Lead levels in the water depend upon many solubility factors, such as pH, concentrations of substances such as inorganic carbonate, orthophosphate, chlorine, and silicate, the temperature, the nature of the pipe surface, etc. Physical factors, time, and chemical mass transfer are significant in governing lead levels in non-equilibrium systems. The diameter and length of lead pipe is extremely important, as well as the age and chemical history of the solder and brass fixtures. Analytical variability is not particularly significant relative to between-site and within-site variability. Knowledge of temporal variability at each site is necessary to define a statistically valid monitoring program. An analysis of published data covering repetitive measurements at a given site show that the variability of lead concentration at each site tends to be characterized by the frequent occurrence of 'spikes'. Variability expressed as approximate relative standard deviations tends to be of about 50 to 75% in untreated water, regardless of the mean lead concentration. The distributions are frequently non-normal for small numbers of samples. Monitoring programs must incorporate controls for the causes of the within-site and between-site variability into their sampling design. The determination of necessary sampling frequency, sample number, and sample volume must be made with consideration of the system variability, or the results will be unrepresentative and irreproducible.

Schock, M. R., et al. (2014). "Importance of pipe deposits to Lead and Copper Rule compliance." Journal American Water Works Association 106(7): E336-E349.

When Madison, Wis., exceeded the lead action level in 1992, residential and off-line tests suggested that lead release into the water was more complex than a lead solubility mechanism. Scale analyses (color/texture and mineralogical and elemental composition) of five excavated lead service lines (LSLs) revealed that accumulation of manganese (and iron) onto pipe walls had implications for lead corrosion by providing a high capacity sink for lead. Manganese that accumulated from source well water onto pipe scales (up to 10% by weight of scale composition) served to capture and eventually transport lead to consumer taps. In addition, manganese sometimes obstructed the predominance of an insoluble (and thus potentially protective) plattnerite [Pb(IV) solid] scale layer. Full LSL replacement in Madison achieved Lead and Copper Rule compliance and a major reduction in lead contamination and exposure, supplemented by unidirectional flushing of water mains and manganese control in the source well water.

Schock, M. R. and J. Clement (1998). "Lead and copper control with non-zinc orthophosphate." Journal New England Water Works Association, 112: 20-20.

Successful application of orthophosphate formulations not containing zinc for achieving control of copper and lead corrosion requires careful consideration of the background water chemistry, particularly pH and DIC. Inhibitor performance is extremely dependent on dosage and pH.

Schock, M. R. and J. C. Fox (2001). Solving copper corrosion problems while maintaining lead control in a high alkalinity water using orthophosphate. Proc. 2001 AWWA Ann. Conf., Washington.

Lead and Copper Rule sampling in 1992 uncovered high copper levels in many homes in the Indian Hill Water Works (Ohio) water system. The 90th percentile copper and lead levels were 1.63 mg/L and 0.012 mg/L, respectively. Indian Hill Water Works (IHWW) supplies water to several suburban communities to the east of Cincinnati. Finished water hardness is approximately 150 mg/L as CaCO₃, total alkalinity approximately 250 mg/L as CaCO₃, DIC approximately 60-65 mg C/L, and pH ranges from about 7.1 to 7.5, mostly near 7.3. Final treatment consists of chlorination, fluoridation, and at different times, addition of caustic and/or corrosion inhibitor. Historically, water heater failures and high copper levels resulting in blue water were reported in the 1950's, and caustic addition was used to elevate the pH to as high as 8 at different times throughout the next 3 decades. In the late 1980's and early 1990's, zinc orthophosphate treatment was employed, which was mostly successful for lead and inconsistently successful for copper. In 1997 with the 90th percentile still at 1.54 mg/L for copper, the zinc orthophosphate treatment was withdrawn. In 1998, new pilot tests were carried out in collaboration with the Water Supply and Water Resources Division of USEPA in Cincinnati to do some new pilot testing and a more systematic analysis of copper corrosion control chemistry. Tests compared pH adjustment, partial DIC removal through anion-exchange and increasing orthophosphate dosing. The most economical alternative identified was an increased orthophosphate residual of 3 mg/L as PO₄. The recommended treatment was implemented beginning in 1999. Lead levels were below 0.005 mg/l for the 90th percentile, and the 90th percentile copper levels were reduced to 1.04 mg/L, for the fall 1999 and Spring 2000 sampling rounds. Copper levels remain consistently below the Action Level, and IHWW has now successfully met simultaneous lead and copper control requirements of the regulations and is now in "reduced monitoring" status.

Schock, M. R., et al. (2008). "Occurrence of contaminant accumulation in lead pipe scales from domestic drinking-water distribution systems." Environmental Science and Technology 42(12): 4285-4291.

Previously, contaminants, such as Al, As, and Ra, have been shown to accumulate in drinking-water distribution system solids. Accumulated contaminants could be periodically released back into the water supply causing elevated levels at consumers taps, going undetected by most current regulatory monitoring practices and consequently constituting a hidden risk. The objective of this study was to determine the occurrence of over 40 major scale constituents, regulated metals, and other potential metallic inorganic contaminants in drinking-water distribution system Pb (lead) or Pb-lined service lines. The primary method of analysis was inductively coupled plasma-atomic emission spectroscopy, following complete decomposition of scale material. Contaminants and scale constituents were categorized by their average concentrations, and many metals of potential health concern were found to occur at levels sufficient to result in elevated levels at the consumer's taps if they were to be mobilized. The data indicate distinctly nonconservative behavior for many inorganic contaminants in drinking-water distribution systems. This finding suggests an imminent need for further research into the transport and fate of contaminants throughout drinking-water distribution system pipes, as well as a re-evaluation of monitoring protocols in order to more accurately determine the scope and levels of potential consumer exposure.

Schock, M. R. and F. G. Lemieux (2010). "Challenges in addressing variability of lead in domestic plumbing." Water Science and Technology: Water Supply 10(5): 793-799.

Current data indicates that lead exposure is of concern even at low concentrations. Corrosion is an important problem in drinking water because it can affect public health due to leaching of lead or other metals into the drinking water. For this reason, a corrosion control program is an important measure to help mitigate exposure to lead in drinking

water. The biggest challenge that remains in assessing corrosion control through monitoring programs is the variability of the concentrations of metals such as lead in drinking water, and the interpretation of the results when using different approaches for monitoring. This is due to the many factors that contribute to the leaching of metals from drinking water distribution system materials. Balancing the challenges of stagnation time, sample volume and sampling frequency to assess corrosion control with their practicality and the need to ensure optimal corrosion control treatment are important considerations for regulators and decision-makers to ensure that potential exposure to lead through drinking water is minimized.

Schock, M. R. and D. A. Lytle (1995). Control of copper corrosion of household plumbing materials. Cincinnati, Ohio, Environmental Protection Agency, Cincinnati, OH (United States).

The promulgation of the “Lead and Copper Rule” by the USEPA in 1991 has forced hundreds of water utilities nationwide to become concerned with controlling the uniform corrosion of copper plumbing materials. The exact extent of the problem is hard to quantify, but in the first round of monitoring by the large water systems (about 682), approximately 6 % exceeded the 1.3 mg/L action level according to an AWWA study. The highest copper levels for these utilities appeared to be in the southeastern and western regions of the United States, in utilities covering a considerable range of water qualities. The cuprosolvency problem apparently increases with decreasing utility size. When medium-sized water systems are included, large numbers of action level exceedences for copper occurred in the central and north-central midwest, implicating areas having hard and high alkalinity ground waters of approximately neutral pH. These water qualities are not those conventionally considered “corrosive”. Unfortunately, the regulatory monitoring data are of limited use for extracting details of copper chemistry behavior and understanding potential copper passivation strategies. Nonetheless, several interesting gross-scale trends have been discerned for large water systems. One example is that there is a poor correlation between 90h-percentile lead and copper levels. Another trend is that copper exceedences tended to be highest at very low alkalinities (<25 mg CaCO₃/L) and increasingly greater over 75 mg CaCO₃/L. Finally, no action level exceedences were reported for systems having a pH above approximately 8. The data thus far suggest that cuprosolvency (copper solubility) will be a major concern across the United States, especially for smaller water suppliers that are less likely to employ corrosion control and use ground water sources. Further, the poor correlation between reported 90m-percentile lead and copper levels suggests that different control strategies for copper than those considered appropriate for lead may need to be developed or employed by affected utilities. Understanding how copper will respond to lead control measures and the results of other regulatory treatment requirements is therefore of considerable interest. Indeed, a response that effectively controls lead corrosion might exacerbate copper corrosion. Moreover, a utility must distribute aesthetically-pleasing water. A good example of the conflicts between control of corrosion of iron mains and reducing copper corrosion rates has been given for a study in Vancouver, BC.

In attempting to address some of the data gaps for cuprosolvency control by utilities, a variety of - experimental systems have been constructed and operated in USEPA laboratories. During these experiments, some perplexing data was generated that appeared to either contradict some “conventional wisdom” on copper corrosion, or showed unexpected sensitivities to important water chemistry variables and experimental system operational protocols. These observations provided the motivation to begin.

Schock, M. R., et al. (2006). "Replacing polyphosphate with silicate to solve lead, copper, and source water iron problems (vol 97, pg 84, 2005)." Journal American Water Works Association 98(4): 178-179.

Corrosion in a distribution system can lead to colored water caused by source water iron and manganese. In addition, corrosion problems may cause the system to fail to meet the Lead and Copper Rule (LCR) action levels. This study was undertaken to demonstrate that sodium silicate addition can achieve corrosion control for the LCR and simultaneous sequestration of iron and manganese at an LCR-classified medium water system that has multiple wells and entry points. At special study monitoring sites, an initial silicate dosage of 25-30 mg/L elevated the pH from 6.3 to 7.1 and resulted in a 55% reduction in lead levels and an 87% reduction in copper levels. A further increase to 45-55 mg/L silicate dosage increased the pH to 7.5 and produced even greater reductions in lead and copper. The treatment change reduced 90th percentile lead and copper levels by at least 95%, enabling compliance with the LCR. Study results showed that the aesthetic quality of the drinking water after treatment was equal or superior to the water's quality before the treatment. The higher pH and silicate combination was also found to be more compatible with protecting asbestos-cement and cement-lined pipes than polyphosphate treatment at a lower pH.

Schock, M. R., et al. (2005). "Replacing polyphosphate with silicate to solve lead, copper, and source water iron problems." Journal American Water Works Association 97(11): 84-93.

In 1990, the town of Hopkinton, Mass., instituted a polyphosphate sequestrant feed in two of its five wells to address colored water complaints caused by source water iron and manganese. Failure to meet the Lead and Copper Rule (LCR) action levels and continuing intermittent red water problems prompted the water utility to seek an alternative treatment strategy. After analyses of the water quality of the different wells, the scales on some lead service lines, the operational patterns, the location of lead service lines, and the distribution system configuration, a combination of sodium silicate (with chlorination) and sodium hydroxide addition at different wells was investigated. At study monitoring sites, an initial silicate dose of 25-30 mg/L elevated the pH from 6.3 to 7.1 and immediately resulted in a 55% reduction in lead levels and an 87% reduction in copper levels. An increase to a silicate dose of 45-55 mg/L elevated the pH to 7.5 and produced greater reductions in lead and copper. The treatment change reduced 90th percentile lead and copper levels by at least 95%, enabling compliance with the LCR. The aesthetic quality of the drinking water after treatment was equal or superior to the quality before treatment. The study showed that for many small and medium water systems with multiple wells and entry points, simultaneous overall corrosion control and sequestration of iron and manganese is possible, and it avoids the adverse drinking water/wastewater consequences associated with polyphosphate addition.

Schock, M. R. and C. H. Neff (1988). "Trace metal contamination from brass fittings." American Water Works Association Journal 80(11): 47-56.

Data were obtained during a two-year field and laboratory corrosion study that implicated brass valves and fittings as a potential source of lead, copper, and zinc in drinking water, particularly in standing water. Contamination from this source was found to be a significant cause of metal concentrations that exceeded maximum contaminant levels. These findings should be considered in the design of water sampling programs, the selection of plumbing materials for household use, and the planning of corrosion-rate measurement and plumbing material solubility experiments.

Showman, R. (1994). Experiences with lead-free brass in the manufacture of cast valves and fittings. American Water Works Association Annual Conference,. New York, USA: 673-686.

Unless some unexpected technical problems are uncovered either in the laboratory or in early production. The marketplace will pay more for products containing brass without any appreciable visual differences from products purchased several years ago. But the lead levels will be significantly reduced and thereby contribute positively to the quality of the public drinking supply.

Singh, I. and D. S. Mavinic (1991). "Significance of building and plumbing specifics on trace-metal concentrations in drinking water." Canadian Journal of Civil Engineering 18(6): 893-903.

Samples were taken from 72 high-rise apartment suites (6 suites in 12 individual high-rise towers) and 60 single-family houses located within the Greater Vancouver Regional District. The influence of the following factors on trace metal concentrations in 1-L first-flush drinking water samples and "running" hot water samples was investigated: building height, location, plumbing age, type of plumbing, and type of building. Results of this survey show that with the exception of building height, all factors had a correlation with one or more of the trace metals investigated. The trace metals examined were lead, copper, iron, and zinc. Lead was influenced primarily by building type, copper by plumbing age and type of plumbing, and iron by location. Elevated lead levels were associated with high-rise samples. New copper plumbing systems resulted in high copper levels. Highest iron levels in the drinking water were measured in the East Vancouver location. Zinc did not show a distinct correlation with any of the factors investigated. Brass faucets were the primary source of zinc in tap water. They also contributed substantially to the lead detected in the 1-L first-flush sample. Metal concentrations measured in the high-rise and house samples were compared with the U.S. Environmental Protection Agency's (USEPA) maximum contaminant levels (MCLs) and the proposed "no-action" level for lead. In high-rise samples, the 0.01 mg/L "no-action" level proposed for lead was exceeded in 43% of the samples, and 62% of the samples exceeded the current 1.0 mg/L MCL standard for copper. In single-family house samples, these values were 47% and 73%, respectively. The average lead concentrations were 0.020 mg/L for all high-rise samples and 0.013 mg/L for house samples. Regulatory levels stated above would still be exceeded in 6% of the cases for lead and 9% of the cases for copper, even after prolonged flushing of the tap in a high-rise building. In all cases associated with single-family houses, flushing the cold water tap for 5 minutes was successful in achieving compliance levels.

Smith, S. E., et al. (2017). "At risk: Our nation's water supply." Mealey's Emerging Toxic Torts 26(14).

The fragile state of the United States drinking water system is making waves (and headlines) across the country," Goldberg Segalla partners Susan E. Smith, leader of the firm's Toxic Tort Practice Group, and George H. Buermann, a member of the Environmental Practice Group, write in Mealey's Emerging Toxic Torts. Because of incidents in Flint, Michigan and elsewhere around the country, they say, "[h]ow our water authorities treat, obtain, and distribute drinking water, and what is in the water before and after treatment, is capturing national attention.

Sorg, T. J. and F. Bell Jr (1986). "Plumbing materials and drinking water quality."

A review of drinking water problems related to plumbing materials and the identification of alternative solutions for dealing with these problems are presented in this book. Federal

regulations clearly recognize that the quality of drinking water can be affected by its distribution lines and that it is the responsibility of the water surveyor to consider these problems in providing water to its customers. Traditionally, water utilities have taken control measures to prevent or correct problems associated with water distribution mains. Studies and reports during the past several years have clearly illustrated that distribution problems are not limited only to distribution mains, but are also associated with laterals and service lines as well as the interior plumbing systems in dwellings and buildings. Some of these problems, such as lead leaching from lead service lines and plumbing, have been common knowledge for years. Other problems, such as the migration of gasoline and other petroleum distillates through plastic pipe, have been more recently identified.

Sorg, T. J., et al. (1999). "Ion exchange softening: effects on metal concentrations." Journal American Water Works Association 91(8): 85-97.

A corrosion control pipe loop study was conducted to evaluate the effect of ion exchange water softening on metal leaching from had different pH values and hardness levels. Results showed that removing hardness ions with a household water softener did not lead to a pattern of higher metal leaching from various home plumbing materials containing lead, copper, and zinc. Furthermore, the water softener did not have a detrimental effect on several significant water quality parameters that influence metallic solubility and the rate of corrosion, i.e., pH, total inorganic carbon, dissolved oxygen, chlorine, temperature, and orthophosphate.

Sosnin, H. A. and N. G. Thompson (1985). "Corrosion of 50:50 tin-lead solder in household plumbing." Welding Journal 64(4): 20-24.

The Environmental Protection Agency National Primary Drinking Water Regulations limit for lead content in drinking water is 0.05 mg/L (1000 µg/L equals 1 mg/L). The rate of lead buildup in copper plumbing systems was examined in two phases: the separate effects of water chemistry and water temperature were studied in test cells made from soldered copper tubes and in mock-up plumbing assemblies. The study showed that lead buildup estimated for 12 hour exposure to the waters tested was well below the federal limit for drinking water except for an aggressive pH 6.5 water at 60 degree C (140 degree F). For waters with 8.5 pH and 7.5 pH, respectively, at room temperature and for water maintained at 60 degree C (140 degree F), the steady-state lead buildup was equal to or less than 5 µg/L.

St Clair, J., et al. (2016). "Long-Term Behavior of Simulated Partial Lead Service Line Replacements." Environmental Engineering Science 33(1): 53-64.

In this 48-month pilot study, long-term impacts of copper:lead galvanic connections on lead release to water were assessed without confounding differences in pipe exposure prehistory or disturbances arising from cutting lead pipe. Lead release was tracked from three lead service line configurations, including (1) 100% lead, (2) traditional partial replacement with 50% copper upstream of 50% lead, and (3) 50% lead upstream of 50% copper as a function of flow rate, connection types, and sampling methodologies. Elevated lead from galvanic corrosion worsened with time, with 140% more lead release from configurations representing traditional partial replacement configurations at 14 months compared to earlier data in the first 8 months. Even when sampled consistently at moderate flow rate (8 LPM) and collecting all water passing through service lines, conditions representing traditional partial service line configurations were significantly worse (approximate to 40%) when compared to 100% lead pipe. If sampled at a high flow rate (32 LPM) and collecting 2 L samples from service lines, 100% of samples collected from

traditional partial replacement configurations exceeded thresholds posing an acute health risk versus a 0% risk for samples from 100% lead pipe. Temporary removal of lead accumulations near Pb:Cu junctions and lead deposits from other downstream plastic pipes reduced risk of partial replacements relative to that observed for 100% lead. When typical brass compression couplings were used to connect pre-passivated lead pipes, lead release spiked up to 10 times higher, confirming prior concerns raised at bench and field scale regarding adverse impacts of crevices and service line disturbances on lead release. To quantify semirandom particulate lead release from service lines in future research, whole-house filters have many advantages compared to other approaches.

Standards Australia (2000). AS 2738—2000 Copper and copper alloys— Compositions and designations of refinery products, wrought products, ingots and castings. Strathfield, NSW, Standards Australia International Ltd.

This Standard was prepared by the Joint Standards Australia/Standards New Zealand Committee MT/2, Copper and Copper Alloys, to supersede AS 2738.1—1984, AS 2738.2—1984 and AS 2738.3—1984.

This Standard is the result of a consensus among Australian and New Zealand representatives on the Joint Committee to produce it as an Australian Standard. This revision contains listings of designations and chemical composition limits for copper and copper alloy refinery, wrought, ingot and cast products in general use in Australia. In this edition the alloy designations have been changed from the three-digit numbering system to the Unified Numbering System (UNS) comprising five digits preceded by the letter C. There are no equivalent International Standards (ISO) that list designations and chemical compositions of copper and copper alloy products.

The term 'informative' has been used in this Standard to define the application of the appendix to which it applies. An 'informative' appendix is for information and guidance only.

Standards Australia/Standards New Zealand (1995). AS/NZS 4020:2005 Testing of products for use in contact with drinking water. Sydney, NSW, Wellington NZ, Standards Australia/Standards New Zealand.

This Standard was prepared by the Joint Standards Australia/Standards New Zealand Committee CH-034, Materials in Contact with Drinking Water, to supersede AS/NZS 4020:2002, Testing of products for use in contact with drinking water.

In preparing this Standard, consideration has been given to comparable overseas Standards, to minimize duplication of effort and to maintain commonality, wherever reasonable, with those Standards. Particular consideration has been given to the various parts of BS 6920, Suitability of non-metallic products for use in contact with water intended for human consumption with regard to their effect on the quality of the water. Several of the test procedures and criteria given in BS 6920 have been adopted or modified for Australian and New Zealand requirements.

This Standard departs from BS 6920 as follows:

- (a) This Standard provides a method of testing for the leaching of compounds that may produce a mutagenic effect.
- (b) The requirement for products to be tested at surface area-to-volume ratios that are not less than those in the intended end-use exposure (with the exception of the test for growth of aquatic micro-organisms). Where there is a difference between test and end-use exposures, provision is made for a scaling factor to be applied to the test result.
- (c) The inclusion of testing for metals extracted from metal products that are often components of products in contact with drinking water. Significant changes from the previous edition include the following:
 - (i) Inclusion of a colorimetric method for determination of cytotoxic activity.

- (ii) Inclusion of an appendix on the structure of test reports.
- (iii) Revision of the appendix on product submission information.
- (iv) Altered requirements for testing non-metallic products for leaching of metals.

The terms 'normative' and 'informative' have been used in this Standard to define the application of the appendices to which they apply. A 'normative' appendix is an integral part of a Standard, whereas an 'informative' appendix is for information and guidance only.

Standards Australia/Standards New Zealand (2005). AS/NZS 3718:2005 (Incorporating Amendment Nos 1 and 2): Water supply—Tap ware. Sydney, NSW, Wellington NZ, Standards Australia/Standards New Zealand.

This Standard was prepared by the Joint Standards Australia/Standards New Zealand Committee WS-001, Water Fittings, to supersede AS/NZS 3718:2003.

The objective of this revision is to incorporate the testing requirements for the determination of flow rates required by the later Efficient Labelling and Standards Scheme (WELS) and to correct errors in the previous edition.

This Standard incorporates Amendment No. 1 (May 2006) and Amendment No. 2 (December 2008). The changes required by the Amendment are indicated in the text by a marginal bar and amendment number against the clause, note, table, figure or part thereof affected.

The term 'normative' has been used in this Standard to define the application of the appendix to which it applies. A 'normative' appendix is an integral part of a Standard. Statements expressed in mandatory terms in notes to figures are deemed to be requirements of this Standard.

Stets, E. G., et al. (2018). "Increasing chloride in rivers of the conterminous US and linkages to potential corrosivity and lead action level exceedances in drinking water." Science of the Total Environment 613: 1498-1509.

Corrosion in water-distribution systems is a costly problem and controlling corrosion is a primary focus of efforts to reduce lead (Pb) and copper (Cu) in tap water. High chloride concentrations can increase the tendency of water to cause corrosion in distribution systems. The effects of chloride are also expressed in several indices commonly used to describe the potential corrosivity of water, the chloride-sulfatemass ratio (CSMR) and the Larson Ratio (LR). Elevated CSMR has been linked to the galvanic corrosion of Pb whereas LR is indicative of the corrosivity of water to iron and steel. Despite the known importance of chloride, CSMR, and LR to the potential corrosivity of water, monitoring of seasonal and interannual changes in these parameters is not common among water purveyors. We analyzed long-term trends (1992-2012) and the current status (2010-2015) of chloride, CSMR, and LR in order to investigate the short and long-term temporal variability in potential corrosivity of US streams and rivers. Among all sites in the trend analyses, chloride, CSMR, and LR increased slightly, with median changes of 0.9 mg/L, 0.08, and 0.01, respectively. However, urban-dominated sites had much larger increases, 46.9 mg/L, 2.50, and 0.53, respectively. Median CSMR and LR in urban streams (4.01 and 1.34, respectively) greatly exceeded thresholds found to cause corrosion in water distribution systems (0.5 and 0.3, respectively). Urbanization was strongly correlated with elevated chloride, CSMR, and LR, especially in the most snow-affected areas in the study, which are most likely to use road salt. The probability of Pb action-level exceedances (ALEs) in drinking water facilities increased along with raw surface water CSMR, indicating a statistical connection between surface water chemistry and corrosion in drinking water facilities. Optimal corrosion control will require monitoring of critical constituents reflecting the potential corrosivity in surface waters.

Subramanian, K. S., et al. (1994). "Drinking-water quality - Impact of non-lead-based plumbing solders." Toxicological and Environmental Chemistry 44(1-2): 11-20.

Studies were done on the leaching of Ag, Cd, Cu, Pb, Sb, Sn and Zn from 95/5 Sn/Sb-, 96/4 Sn/Ag-, and 95.5/4.0/0.5 Sn/Cu/Ag-soldered copper coupons into high-purity, tap, treated and well water samples as a function of standing time in a static test on new plumbing. No significant leaching of Ag, Cd, Pb and Sb occurred from the above solders into the water samples. Tin was released into the water samples from all the solders. The amount of Cu released from soldered copper pipes was generally lower than that released from non-soldered copper pipes, especially in the case of treated and well water samples, due to galvanic corrosion. The amount of Zn leached was well below the Guidelines (5 mg/l) for Canadian drinking water quality. Examination of the coupon surfaces using electron microprobe and X-ray photoelectron spectroscopic techniques showed the presence of tin oxides due to galvanic corrosion.

Switzer, J. A., et al. (2006). "Evidence that monochloramine disinfectant could lead to elevated Pb levels in drinking water." Environmental Science and Technology 40(10): 3384-3387.

Many water districts have recently shifted from free chlorine (in the form of HOCl/OCl⁻) to monochloramine (NH₂Cl) as a disinfectant for drinking water to lower the concentration of chlorinated hydrocarbon byproducts in the water. There is concern that the use of NH₂Cl disinfectant may lead to higher Pb levels in drinking water. In this study, the electrochemical quartz crystal microbalance is used to compare the effects of these two disinfectants on the dissolution of Pb films. A 0.5 µm thick Pb film nearly completely dissolves in a NH₂Cl solution, but it is passivated in a HOCl/OCl⁻ solution. X-ray diffraction analysis shows that the NH₂Cl oxidizes Pb to Pb(II) species such as Pb₃(OH)₂(CO₃)₂, whereas the stronger oxidant, HOCl/OCl⁻ oxidizes Pb to Pb(IV) as an insoluble PbO₂ conversion coating. Although NH₂Cl may produce less halogenated organic byproducts than HOCl/OCl⁻ when used as a disinfectant, it may lead to increased Pb levels in drinking water.

Taha, M. A., et al. (2012). "Machinability characteristics of lead free-silicon brass alloys as correlated with microstructure and mechanical properties." Ain Shams Engineering Journal 3(4): 383-392.

The aim of this work is to evaluate the machinability of Pb-free brasses with Si from 1% to 4wt%, which were prepared using Cu 60/Zn 40 and Cu 80/Si 20 Pb-free master alloys. Machinability of the investigated alloys is tested based on cutting force, tool wear, surface roughness, and chip type. In the 1wt% Si alloy, which exhibits maximum strength, the maximum cutting force is measured and undesirable continuous chip type is produced, while tool wear and machined surface roughness have the lowest values. Increasing the silicon content from 1% to 4%, results in increasing the tool wear by 140%, machined surface roughness by 25%, while the chip type changed from continuous to discontinuous type, and the cutting force was reduced by 50%. Machinability results are correlated with the alloy mechanical properties and with the phases present in the microstructure.

Tam, Y. S. and P. Elefsiniotis (2009). "Corrosion control in water supply systems: Effect of pH, alkalinity, and orthophosphate on lead and copper leaching from brass plumbing." Journal of Environmental Science and Health Part a-Toxic/Hazardous Substances & Environmental Engineering 44(12): 1251-1260.

This study explored the potential of lead and copper leaching from brass plumbing in the Auckland region of New Zealand. A five-month field investigation, at six representative locations, indicated that Auckland's water can be characterized as soft and potentially corrosive, having low alkalinity and hardness levels and a moderately alkaline pH. More than 90% of the unflushed samples contained lead above the maximum acceptable value (MAV) of 10 µg/L (New Zealand Standards). In contrast, the copper level of unflushed samples remained consistently below the corresponding MAV of 2 mg/L. Flushing however reduced sharply metal concentrations, with lead values well below the MAV limit. Generally, metal leaching patterns showed a limited degree of correlation with the variations in temperature, dissolved oxygen and free chlorine residual at all sampling locations. Furthermore, a series of bench-scale experiments was conducted to evaluate the effectiveness of pH and alkalinity adjustment, as well as orthophosphate addition as corrosion control tools regarding lead and copper dissolution. Results demonstrated that lead and copper leaching was predominant during the first 24 hr of stagnation, but reached an equilibrium state afterwards. Since the soluble fraction of both metals was small (12% for lead, 29% for copper), it is apparent that the non-soluble compounds play a predominant role in the dissolution process. The degree of leaching however was largely affected by the variations in pH and alkalinity. At pH around neutrality, an increase in alkalinity promoted metal dissolution, while at pH 9.0 the effect of alkalinity on leaching was marginal. Lastly, addition of orthophosphate as a corrosion inhibitor was more effective at pH 7.5 or higher, resulting in approximately 70% reduction in both lead and copper concentrations.

Triantafyllidou, S. (2006). Addressing and assessing lead threats in drinking water: non-leaded brass, product testing, particulate lead occurrence and effects of the chloride to sulfate mass ratio on corrosion, Virginia Tech, MSc (Env Eng).

Growing concern over adverse health effects from low level lead exposure motivated reassessment of lead occurrence in drinking water, from the perspective of 1) possibly eliminating lead from new brass materials, and 2) performance testing of existing products. During the course of this thesis work, it was discovered that several cases of childhood lead poisoning in North Carolina, South Carolina and Washington D.C. occurred from contaminated potable water. That disconcerting finding prompted additional work into 3) deficiencies in existing lead testing of drinking water samples, and 4) impacts of water treatment steps on lead leaching.

Meters, components, and fittings manufactured from non-leaded brass (< 0.25 percent lead content) are increasingly specified for use in water distribution systems and premise plumbing, in response to California's Proposition 65 and the proposed Lead Free Drinking Water Act. An in-depth review of the available literature revealed that non-leaded brass releases minimal amounts of lead and other contaminants of concern to drinking water. There is legitimate concern about the corrosion resistance and longevity of these non-leaded alloys in the range of waters that will be encountered in practice. Nonetheless, when the potential impacts to manufacturers, utilities and consumers are considered, non-leaded brasses appear to be attractive albeit at slightly higher cost.

For existing leaded brass products, concerns have been raised over potential limitations of performance standards used to certify the products as "safe" in the marketplace. The ANSI/NSF 61 Section 9 test is the industry standard, and its protocol is critically evaluated from the perspective of the leaching solution chemistry. Testing indicated that the protocol water is reasonably representative of a typical water supply. However, some lower pH and lower alkalinity waters can be much more aggressive than the existing section 9 water, and for potable water with these characteristics, problems with higher than desired lead

leaching may occur. It may be desirable to tighten the standard's pass/fail lead criterion in order to account for this problem in practice.

Several cases of childhood lead poisoning from water have been recently encountered, which prompted environmental assessments. It was visually obvious that some of the lead particles ingested by these children, present in water from the tap, were not completely dissolving in the standard method with weak acid recommended by the US EPA. A laboratory investigation proved that up to 80% particulate lead in water samples could be "missed" by the standard protocol. Unfortunately, tests with simulated gastric fluid revealed that much of this particulate lead would be bioavailable in the presence of chloride, warmer temperatures and lower pH inside the human stomach. It is recommended that water utilities be alert to this possible problem and that environmental assessments of lead poisoned children use stronger digestions to detect lead in water.

Several of the lead poisoning instances occurred after the utility changed both disinfectant chemicals (from chlorine to chloramine) and coagulant types. Although authorities initially thought chloramine was the cause based on experiences in Washington D.C., bench scale studies in this work proved that a change in coagulant from aluminum sulfate to either ferric chloride or polyaluminum chloride was in fact the main reason of the lead spikes. The reduction in sulfate and increase in chloride increased the chloride to sulfate mass ratio of the water supply. A higher chloride to sulfate mass ratio triggered much higher (2.3-40 times more) lead leaching from solder connected to copper pipe. The adverse effects of the increase in the ratio could not be eliminated by adding a corrosion inhibitor.

Triantafyllidou, S. (2011). Lead (Pb) Contamination of Potable Water: Public Health Impacts, Galvanic Corrosion and Quantification Considerations, Virginia Tech. PhD.

The issue of lead exposure through drinking water was re-examined in light of modern public health goals, recent high-profile cases of elevated lead in water, and emerging concerns regarding the efficacy of legally mandated remedial strategies. A critical literature review revealed that serious lead-in-water hazards are present at many US schools and homes, and that the threat to individuals is not eliminated by existing regulations. Health studies have provided strong links between lead in water and lead in blood of exposed populations, even at relatively low levels of exposure compared to reported lead occurrence in US tap water samples. As efforts shift from addressing pervasive lead sources that once elevated the blood lead of large percentages of the population, to more isolated individual cases requiring exceptional attention, the importance of carefully considering lead in water as a potential source for elevated blood lead increases.

Consistent with decades of prior research linking elevated water lead to elevated blood lead (EBL), lead-contaminated water in the high-profile case of Washington DC markedly increased the incidence of EBL for very young children. Specifically, incidence of EBL for children aged ≤ 1.3 years increased more than 4 times during 2001-2003 when lead in water was high, compared to 2000 when lead in water was low. The incidence of EBL for children aged ≤ 1.3 years was highly correlated ($R^2 = 0.81$) to 90th percentile lead-in-water levels from 2000-2007, and the risk of exposure to high water lead levels varied markedly in different neighborhoods of the city. Analysis conducted herein focused on identifying "worst-case" neighborhoods and populations. Specifically, this was the first study of the Washington DC case to focus on infants who are most vulnerable to harm from lead in water, and to perform smaller area analysis at the neighborhood (i.e., zip code) level in order to capture pockets of high risk among local communities.

Prior biokinetic modeling efforts, examining the potential adverse impacts of lead-in-water exposure, were re-examined to explicitly consider new public health goals. This included impacts on the most sensitive population groups (e.g., young children and particularly formula-fed infants), the potential variability in blood lead levels (BLLs) amongst exposed individuals within those groups (e.g., most sensitive children at the upper tail of the BLL distribution), more conservative BLL thresholds reflecting low-level adverse effects (e.g., 5, 2 and 1 $\mu\text{g/dL}$ versus 10 $\mu\text{g/dL}$), and the possibility of acute health impacts. This re-evaluation creates a paradigm shift, in that levels of lead in water that were previously considered inconsequential are demonstrated to be of concern in specific circumstances.

The replacement of lead service lines in front of consumers' homes is a costly, federally mandated remedial action if a water utility exceeds the US EPA lead action level. Because utilities do not own the entire lead service line, they often only replace the portion of the service line up to the property line, typically with copper pipe. Experiences in Washington DC, as revealed by Freedom of Information Act requests, indicated that partial pipe replacements were not decreasing lead in water, and were actually associated with relatively high incidence of childhood lead poisoning. This prompted the first comprehensive investigation of potential long-term problems arising from galvanic corrosion between the remaining lead pipe and the newly installed copper pipe. Bench-scale experiments demonstrated that galvanic connections between lead pipe (new or aged) and copper pipe increased lead release into the water by 1.1-16 times, when compared to a full length of lead pipe alone. The small area of lead pipe adjacent to the copper joint (<0.5 ft) was gravely affected by galvanic corrosion, and accumulated a thick lead-rust layer (1 inch wide) that constituted a reservoir for semi-random particulate lead detachment into the water.

The work on simulated partial pipe replacements revealed that under worst-case scenarios of highly contaminated water samples, most of the lead was not quantified if water samples were not mixed thoroughly after standard preservation (i.e., after addition of 0.15% v/v HNO_3), or if water samples were transferred from one bottle to another prior to preservation. While there is no reason to believe that sample handling and pre-treatment dramatically skew regulatory compliance with the US EPA lead action level, slight variations from one approved protocol to another may cause lead-in-water health risks to be dramatically underestimated. This is of special concern in unusual situations of "worst-case" individual exposures to highly contaminated water, associated with childhood lead poisoning.

This work provides the water industry and health agencies with important new insights and perspectives on an old problem. Results can improve strategies to detect and mitigate lead-in-water hazards for individuals or populations, and inform future revisions to the US EPA Lead and Copper Rule.

Triantafyllidou, S. and M. Edwards (2010). Galvanic impacts of partial lead service line replacement on lead leaching into drinking water. Metals and Related Substances in Drinking Water, Kristianstad, SWEDEN, IWA Publishing.

Due to jurisdiction issues, partial lead service line replacement (and not full) is widely implemented in the United States (US), in order to alleviate lead-in-water problems. A portion of the lead service line is replaced with copper, and the dissimilar pipe materials are then connected to restore drinking water service. This practice creates an electrochemical or galvanic cell, which can accelerate corrosion of the lead pipe by galvanic action. The adverse effects of such connections in the context of lead leaching were verified in experiments of simulated lead service line replacement. Galvanic connections between lead pipe and copper pipe increased lead release, compared to lead pipe alone. The extent

of galvanic corrosion was dependent on drinking water quality, and specifically on the Chloride to Sulfate Mass Ratio (CSMR) of the water. Higher galvanic currents between lead and copper were measured when the CSMR was high, mechanistically explaining the trends in lead release. Consideration of galvanic corrosion long-term impacts after partial lead service line replacements is deemed important, on the basis of the results presented herein.

Triantafyllidou, S. and M. Edwards (2012). "Lead (Pb) in Tap Water and in Blood: Implications for Lead Exposure in the United States." Critical Reviews in Environmental Science and Technology 42(13): 1297-1352.

Lead is widely recognized as one of the most pervasive environmental health threats in the United States, and there is increased concern over adverse health impacts at levels of exposure once considered safe. Lead contamination of tap water was once a major cause of lead exposure in the United States and, as other sources have been addressed, the relative contribution of lead in water to lead in blood is expected to become increasingly important. Moreover, prior research suggests that lead in water may be more important as a source than is presently believed. The authors describe sources of lead in tap water, chemical forms of the lead, and relevant U.S. regulations/guidelines, while considering their implications for human exposure. Research that examined associations between water lead levels and blood lead levels is critically reviewed, and some of the challenges in making such associations, even if lead in water is the dominant source of lead in blood, are highlighted. Better protecting populations at risk from this and from other lead sources is necessary, if the United States is to achieve its goal of eliminating elevated blood lead levels in children by 2020.

Triantafyllidou, S., et al. (2014). "Assessing risk with increasingly stringent public health goals: the case of water lead and blood lead in children." Journal of Water and Health 12(1): 57-68.

Previous predictions of children's blood lead levels (BLLs) through biokinetic models conclude that lead in tap water is not a primary health risk for a typical child under scenarios representative of chronic exposure, when applying a 10 µg/dL BLL of concern. Use of the US Environmental Protection Agency Integrated Exposure Uptake Biokinetic (IEUBK) model and of the International Commission on Radiological Protection (ICRP) biokinetic model to simulate children's exposure to water lead at home and at school was re-examined by expanding the scope of previous modeling efforts to consider new public health goals and improved methodology. Specifically, explicit consideration of the more sensitive population groups (e. g., young children and, particularly, formula-fed infants), the variability in BLLs amongst exposed individuals within those groups (e. g., more sensitive children at the upper tail of the BLL distribution), more conservative BLL reference values (e. g., 5 and 2 µg/dL versus 10 µg/dL) and concerns of acute exposure revealed situations where relatively low water lead levels were predicted to pose a human health concern.

Triantafyllidou, S., et al. (2009). "Lead (Pb) exposure through drinking water: Lessons to be learnt from recent US experience." Global Nest Journal 11(3): 341-348.

Lead (Pb) particles that detach from the plumbing and contaminate drinking water can pose a significant health threat, which is often underestimated. Laboratory simulation of this problem revealed that standard quantification protocols in the US may miss 80% of the lead present in the water. At the same time, a significant fraction of this undetected particulate lead may be bioavailable when ingested. A critical review of the Washington DC lead-in-water crisis suggested that lead in water might constitute a greater public health risk than

generally acknowledged, in at least some circumstances. It also revealed deficiencies in the public health response as well as in alerting the public to elevated levels of lead, and the subject continues to be mired in controversy. Our independent testing at six Washington DC public schools in 2008 showed that problems with elevated lead still persist at 2-41% of taps sampled at each school, even after remedial measures were implemented.

Triantafyllidou, S., et al. (2014). "Reduced risk estimations after remediation of lead (Pb) in drinking water at two US school districts." Science of the Total Environment 466: 1011-1021.

The risk of students to develop elevated blood lead from drinking water consumption at schools was assessed, which is a different approach from predictions of geometric mean blood lead levels. Measured water lead levels (WLLs) from 63 elementary schools in Seattle and 601 elementary schools in Los Angeles were acquired before and after voluntary remediation of water lead contamination problems. Combined exposures to measured school WLL (first-draw and flushed, 50% of water consumption) and home WLL (50% of water consumption) were used as inputs to the Integrated Exposure Uptake Biokinetic (IEUBK) model for each school. In Seattle an average 11.2% of students were predicted to exceed a blood lead threshold of 5 $\mu\text{g}/\text{dL}$ across 63 schools pre-remediation, but predicted risks at individual schools varied (7% risk of exceedance at a "low exposure school", 11% risk at a "typical exposure school", and 31% risk at a "high exposure school"). Addition of water filters and removal of lead plumbing lowered school WLL inputs to the model, and reduced the predicted risk output to 4.8% on average for Seattle elementary students across all 63 schools. The remnant post-remediation risk was attributable to other assumed background lead sources in the model (air, soil, dust, diet and home WLLs), with school WLL practically eliminated as a health threat. Los Angeles schools instead instituted a flushing program which was assumed to eliminate first-draw WLL as inputs to the model. With assumed benefits of remedial flushing, the predicted average risk of students to exceed a BLL threshold of 5 $\mu\text{g}/\text{dL}$ dropped from 8.6% to 6.0% across 601 schools. In an era with increasingly stringent public health goals (e.g., reduction of blood lead safety threshold from 10 to 5 $\mu\text{g}/\text{dL}$), quantifiable health benefits to students were predicted after water lead remediation at two large US school systems.

Triantafyllidou, S., et al. (2013). "Lead (Pb) quantification in potable water samples: implications for regulatory compliance and assessment of human exposure." Environmental monitoring and assessment 185(2): 1355-1365.

Assessing the health risk from lead (Pb) in potable water requires accurate quantification of the Pb concentration. Under worst-case scenarios of highly contaminated water samples, representative of public health concerns, up to 71-98 % of the total Pb was not quantified if water samples were not mixed thoroughly after standard preservation (i.e., addition of 0.15 % (v/v) HNO_3). Thorough mixing after standard preservation improved recovery in all samples, but 35-81 % of the total Pb was still un-quantified in some samples. Transfer of samples from one bottle to another also created high errors (40-100 % of the total Pb was un-quantified in transferred samples). Although the United States Environmental Protection Agency's standard protocol avoids most of these errors, certain methods considered EPA-equivalent allow these errors for regulatory compliance sampling. Moreover, routine monitoring for assessment of human Pb exposure in the USA has no standardized protocols for water sample handling and pre-treatment. Overall, while there is no reason to believe that sample handling and pre-treatment dramatically skew regulatory compliance with the US Pb action level, slight variations from one approved protocol to another may cause Pb-in-water health risks to be significantly underestimated, especially for unusual situations of "worst case" individual exposure to highly contaminated water.

Triantafyllidou, S., et al. (2007). "Lead particles in potable water." Journal American Water Works Association 99(6): 107-117.

The occurrence of particulate lead in drinking water deserves increased scrutiny. This is especially true because models of human exposure to lead, sampling protocols, analytical methods, and environmental assessments are often based on the presumed dominance of soluble lead in drinking water. Recent cases of childhood lead poisoning were tied to solder particles that detached from the plumbing and contaminated the potable water supply. In cases such as these, common sample-handling procedures can "miss" particulate lead present in water samples. In some instances, the actual amount of lead present in drinking water samples may be five times higher than that obtained using approved protocols. The presence of chloride, warmer temperature, and lower pH in the human stomach may render a significant fraction of this "missed" particulate lead as bioavailable when ingested.

The presence of lead particles in tap water is an under-appreciated cause of lead poisoning in the United States. Routine water sampling procedures can "miss" lead particles present in drinking water. Consequently, the true extent of human exposure through this type of lead contamination can be underestimated. The authors describe recent cases of lead poisoning in Washington, D.C., Greenville, North Carolina, and Durham, North Carolina, when approved water sampling procedures did not show cause for alarm. Also, the authors compare the bioavailability of lead particles when ingested to their detection in drinking water samples and, in turn, compare human exposure to what utilities detect in water samples. Their findings reveal the potential limitations in current lead detection methods. This information can be used to improve current water sampling and preservation procedures.

Triantafyllidou, S., et al. (2012). "Understanding how brass ball valves passing certification testing can cause elevated lead in water when installed." Water Research 46(10): 3240-3250.

The lead leaching potential of new brass plumbing devices has come under scrutiny as a significant source of lead in drinking water ($>300 \mu\text{g/L}$) of new buildings around the world. Experiments were conducted using ball valves that were sold as certified and known to have caused problems in practice, in order to better understand how installed products could create such problems, even if they passed "leaching tests" such as National Sanitation Foundation (NSF) Standard 61 Section 8. Diffusion of lead from within the device into water when installed can increase lead leaching by orders of magnitude relative to results of NSF testing, which once only required exposure of very small volumes of water within the device. "Normalization" of the lead-in-water result tended to produce estimates of lead concentration that were much lower than actual lead measured at the tap. Finally, the presence of flux could also dramatically increase lead leaching, whereas high water velocity had relatively little effect.

Triantafyllidou, S., et al. (2015). "Low contribution of PbO_2 -coated lead service lines to water lead contamination at the tap." Environmental Science and Technology 49(6): 3746-3754.

To determine if residential water sampling corroborates the expectation that formation of stable PbO_2 coatings on lead service lines (LSLs) provides an effective lead release control strategy, lead profile sampling was evaluated for eight home kitchen taps in three U.S. cities with observed PbO_2 -coated LSLs (Newport, Rhode Island; Cincinnati and Oakwood, Ohio). After various water standing times, these LSLs typically released similar or lower peak lead levels (1 to $18 \mu\text{g/L}$) than the lead levels from the respective kitchen faucets (1 to

130 µg/L), and frequently 50–80% lower than the lead levels typically reported from Pb(II)-coated LSLs in comparable published sampling studies. Prolonged stagnation (10–101 h) at the Cincinnati sites produced varying results. One site showed minimal (0–4 µg/L /L) increase in lead release from the PbO₂-coated LSL, and persistence of free chlorine residual. However, the other site showed up to a 3-fold increase proportional to standing time, with essentially full depletion of the chlorine residual. Overall, lead release was consistently much lower than that reported in studies of Pb(II)-coated LSL scales, suggesting that natural formation of PbO₂ in LSLs is an effective lead “corrosion” control strategy.

Trueman, B. F. and G. A. Gagnon (2016). "Understanding the role of particulate iron in lead release to drinking water." Environmental Science and Technology 50(17): 9053-9060.

Lead service lines (LSLs) are a major source of drinking water lead, and high iron levels are frequently observed along with elevated lead release. A model distribution system, dosed with orthophosphate, was used to evaluate the effect of corroded iron distribution mains on lead release from recovered LSLs. Lead release was higher by 96 µg L⁻¹, on average, from LSLs supplied by corroded iron compared to the inert reference material (PVC). This effect may be explained by deposition of semiconducting iron oxide particles within LSLs. When galvanic cells with lead and magnetite (Fe₃O₄) electrodes were short-circuited, lead release increased 8-fold and a current averaging 26 µA was observed. In effluent from LSLs with an upstream iron main, colloidal lead and iron occurred in the same size fraction—possibly due to release of colloidal particles from LSL corrosion scale enriched with iron. Under these circumstances, high molecular weight (>669 kDa) 208Pb and 56Fe elution profiles, observed via size-exclusion chromatography, were highly correlated (average R² = 0.97). Increasing orthophosphate from 0.5 to 1.0 mg /L (as PO₄³⁻) accompanied an average reduction in lead release of 6 µg L⁻¹ month⁻¹ but did not significantly reduce the effect of an upstream iron main.

Trueman, B. F., et al. (2017). "Galvanic Corrosion of Lead by Iron (Oxyhydr)Oxides: Potential Impacts on Drinking Water Quality." Environmental Science and Technology 51(12): 6812-6820.

Lead exposure via drinking water remains a significant public health risk; this study explored the potential effects of upstream iron corrosion on lead mobility in water distribution systems. Specifically, galvanic corrosion of lead by iron (oxyhydr)oxides was investigated. Coupling an iron mineral cathode with metallic lead in a galvanic cell increased lead release by 531 µg/L on average—a 9-fold increase over uniform corrosion in the absence of iron. Cathodes were composed of spark plasma sintered Fe₃O₄ or alpha-Fe₂O₃ or field-extracted Fe₃O₄ and alpha-FeOOH. Orthophosphate immobilized oxidized lead as insoluble hydroxypyromorphite, while humic acid enhanced lead mobility. Addition of a humic isolate increased lead release due to uniform corrosion by 81 µg/L and—upon coupling lead to a mineral cathode—release due to galvanic corrosion by 990 µg/L. Elevated lead in the presence of humic acid appeared to be driven by complexation, with (208)Pb and UV254 size-exclusion chromatograms exhibiting strong correlation under these conditions (R² average = 0.87). A significant iron corrosion effect was consistent with field data: lead levels after lead service line replacement were greater by factors of 2.3–4.7 at sites supplied by unlined cast iron distribution mains compared with the alternative, lined ductile iron.

Turek, N. F., et al. (2011). "Impact of plumbing age on copper levels in drinking water." Journal of Water Supply Research and Technology-Aqua 60(1): 1-15.

Theory and practical experiences suggest that higher copper levels in drinking water tap samples are typically associated with newer plumbing systems, and levels decrease with increasing plumbing age. Past researchers have developed a conceptual model to explain the 'aging effect' founded in the proposed evolution of copper(II) corrosion by-products on the pipe surface, based on theoretical considerations, anecdotal evidence and some data. In this study, the impact of plumbing age on copper levels in tap water samples and the internal surface corrosion of copper plumbing were systematically evaluated in 16 buildings with plumbing ages ranging from less than one to 44 years, using solids analysis approaches including XPS and XRD. Copper levels decreased with plumbing age and supported theory. A mix of stable and relatively unstable scales appeared on pipes, including cupric hydroxide, cuprite and malachite, although no obvious trend in scale composition with age was noted.

Urbansky, E. T. and M. R. Schock (1999). "Issues in managing the risks associated with perchlorate in drinking water." Journal of Environmental Management 56(2): 79-95.

Perchlorate (ClO_4^-) contamination of ground and surface waters has placed drinking water supplies at risk in communities throughout the US, especially in the West. Several major assessment studies of that risk in terms of health and environmental impact are expected to be released by the US Environmental Protection Agency in early 1999, and preparations for how best to manage and minimize that risk are underway. Perchlorate salts are used in rocket and missile propulsion; therefore, it is believed that the pollution is derived primarily from defence and supporting industry. Due to the perchlorate anion's fundamental physical and chemical nature, the contamination is difficult to treat or remediate. The current work describes the evolution of the unique team-based governmental response to the problem and the rapidity of its development. Technologies under consideration that may prove feasible for treating contaminated water supplies are discussed and evaluated. The impact of these treatment technologies on other regulatory compliance matters and limitations of space, cost, and other resources are considered. Practical guidelines for approaching the problem are outlined, and current research needs are identified.

USEPA (2001). Report on the corrosion of certain alloys, EPA 260-R-01-002. Washington, DC, United States Environmental Protection Agency, Office of Prevention, Pesticides, and Toxic Substances; and Office of Information Analysis and Access, (Office of Environmental Information): 71.

Lead is added to copper in amounts up to 40 wt%. Lead is insoluble in copper-based alloys and because of its low melting point is found distributed in the grain boundaries of the casting. Because lead imparts a certain degree of brittleness to the structure, it enhances machining operations by causing the alloy to break into chips as cutting tools are thrust into the matrix. Additions of lead up to 1.5 wt% significantly improve machinability without a serious decrease in tensile strength. Lead concentrations of 5-25 wt% greatly increase machinability of the alloy but with a resulting decrease in tensile strength.

Vale, P. (1996). "A brief history and forward look into the materials used in plumbing." Health estate journal : journal of the Institute of Hospital Engineering 50(3): 2-6.

Paper referenced by others but abstract not available.

Vargas, I. T., et al. (2017). "Copper Corrosion and Biocorrosion Events in Premise Plumbing." Materials 10(9).

Corrosion of copper pipes may release high amounts of copper into the water, exceeding the maximum concentration of copper for drinking water standards. Typically, the events with the highest release of copper into drinking water are related to the presence of biofilms. This article reviews this phenomenon, focusing on copper ingestion and its health impacts, the physicochemical mechanisms and the microbial involvement on copper release, the techniques used to describe and understand this phenomenon, and the hydrodynamic effects. A conceptual model is proposed and the mathematical models are reviewed.

Vasquez, F. A., et al. (2005). "The Effect of free chlorine and chloramines on lead release in a distribution system." Journal - American Water Works Association 98(2)(2): 144-154.

To comply with disinfection byproduct regulations, many utilities have chosen to use chloramines rather than chlorine for residual maintenance in drinking water distribution systems. However, the switch to chloramines may expose these systems to another health risk, increased concentrations of lead. This study investigated total lead release in the presence of free chlorine and chloramine residuals in drinking waters produced from ground, surface, desalinated, and blended water sources. For both desalinated and blended finished waters, more total lead was released in the presence of chloramines than in the presence of free chlorine. Little research has focused on the effect of oxidation-reduction potentials on metal release. This work verified theoretical predictions from extensive field data that showed the chloramine redox potential was lower than the free chlorine redox potential under equivalent pipe and distribution system environments; however, the released lead in the lower redox potential chloramine environment was higher than in the lower redox potential chlorine environment. The article relates redox potential to pH and the controlling solid lead phase for lead release and demonstrates that theoretical thermodynamic diagrams are practical tools for predicting release of lead (and perhaps other metals) in distribution systems. Utility managers who select chloramines for residual maintenance can use this information to help avoid potential problems of violating the lead action level.

Viraraghavan, T., et al. (1999). "Impact of household plumbing fixtures on drinking water quality—a review." International Journal of Environmental Studies 56(5): 717-743.

This paper reviews the pertinent literature published since 1970 on the impact of household plumbing systems on drinking water quality through the leaching of metals such as cadmium, copper, iron, lead, tin and zinc into potable water. Copper is found to be more easily and extensively leached than lead. Copper is leached almost exclusively from copper tubing. Lead can be leached from lead pipes, lead-tin solders and faucets in residences. Zinc and tin require to be monitored as well.

Viraraghavan, T., et al. (1996). "Drinking water at the tap: Impact of plumbing materials on water quality." Journal of Environmental Science and Health Part a-Environmental Science and Engineering & Toxic and Hazardous Substance Control 31(8): 2005-2016.

Copper and galvanized steel plumbing systems in houses contribute to trace metal concentrations in drinking water. Levels of lead, zinc, copper, iron and manganese in tap water at various locations in Regina, Canada were monitored and the effect of various factors such as building height, type of building, plumbing age and type of plumbing and water chemistry on trace metal levels was examined. It was found that there was no significant effect of plumbing age or type on the extent of metal leaching in South Regina. In North Regina, plumbing type had a marked effect on the lead and iron levels in drinking water. Lead levels in some individual residences were high; these were probably local

effects. It was found that corrosion of solders did not contribute significantly to metal levels. Metal leaching into standing water was found to be mostly from kitchen faucets.

Walker, R. and R. J. Oliphant (1989). Contamination of potable water by corrosion of tin-lead solder joints. Watershed 89 : The Future for Water Quality in Europe, Vols 1 and 2, Guildford, England.

A survey of houses in Great Britain in 1977 found that 9% of homes had a lead content in domestic water in excess of 0.1 mg/L and 20% over 0.05 mg/L in the first draw sample i.e. the water which is run off after remaining in pipes overnight. This compares unfavourably with the report of The Commission of European Communities which in 1980 gave a level of lead of 0.05 mg/L for a sample of running water as the maximum admissible concentration with the rider that where samples "either frequently or to an appreciable extent exceed 0.1 mg/L, suitable measures must be taken to reduce the exposure to lead on the part of the consumer". This concentration of lead in water can arise from the corrosion of tin-lead solders in copper water pipes. Hence a galvanic corrosion cell has been designed and used to quantitatively assess the effects of various water quality parameters on corrosion rates of the solder.

Wasserstrom, L. W. (2014). Uptake of Lead by Iron Corrosion Scales: Effects of Iron Mineralogy and Orthophosphate. Cincinnati, Ohio, University of Cincinnati. MS.

Owing to its toxic nature, lead (Pb) in tap water (released from pipes, solder, and brass fittings) poses an important risk to human health. High concentrations of lead have recently been found to accumulate in iron corrosion scales formed in galvanized iron pipes in household plumbing, but the interaction between iron and lead in this situation is not well understood. Therefore, a model system of simulated iron-bearing corrosion scales in household plumbing was devised to isolate the variables that influence lead uptake. Continuous flow experiments were performed to test the interaction of lead with the iron minerals in corrosion scales in household plumbing, and to assess the influence of changing orthophosphate concentration on lead previously accumulated in the analog iron corrosion scales. Serving as laboratory analogs for the capture of lead by iron corrosion products, sediment filters impregnated with various iron oxy-hydroxides that represent actual iron corrosion scale solids were synthesized and tested in a laboratory apparatus. Water quality was monitored and the analog iron corrosion scales were analyzed. A mass balance was performed on lead to evaluate the effectiveness of the iron filter.

Results showed that the presence of iron greatly enhances lead uptake by the sediment filter compared to the control containing no iron. Filter efficiency was evaluated using normalized ratios of lead, phosphorous, and copper uptake to the mass of iron (Fe) in the sediment filter. This revealed very different behaviors for the iron minerals. Lead uptake by the filter was highest with ferrihydrite (0.02 mg of Pb per mg of Fe), followed closely by lepidocrocite (0.01), and then by goethite (0.003), magnetite (0.002), and ferrihydrite (0.002). Variable uptake of phosphorous and copper was also observed. Phosphorous was most strongly associated with lepidocrocite, followed by ferrihydrite, ferrihydrite, and magnetite, but did not bind to goethite. Copper was taken up more by ferrihydrite and lepidocrocite with some uptake by goethite and magnetite, but did not bind to ferrihydrite.

Ferrihydrite and lepidocrocite appear to be the most effective scavengers for lead and copper, whereas phosphorous uptake is highest with lepidocrocite. Although lead uptake was highest for ferrihydrite it has not been reported in drinking water corrosion scales. Based on these findings, lepidocrocite was chosen as the most appropriate model corrosion scale.

Lepidocrocite-impregnated filters were used in the final stage of the study to evaluate the impact of varying orthophosphate concentrations on lead previously accumulated in the iron-bearing filter. Increasing the orthophosphate levels suppressed the release of lead. However, the effect was only noticeable at 3.5 mg/L as PO_4 or higher. These findings confirm the suggestion that galvanized pipes in household plumbing have the ability to trap lead from upstream sources, and emphasize the need to consider galvanized pipes as a significant source of lead in tap water. Furthermore, typical orthophosphate dosing used in the U.S. (< 3.0 mg/L as PO_4) will not be sufficient to prevent lead release from galvanized pipes.

Wasserstrom, L. W., et al. (2017). "Scale Formation Under Blended Phosphate Treatment for a Utility With Lead Pipes." Journal American Water Works Association 109(11): E464-E478.

US corrosion control practice often assumes that the orthophosphate component of blended phosphate corrosion inhibitors causes the formation of low-solubility lead-orthophosphate solids that control lead release into drinking water. This study identified the solids that formed on the interior surface of a lead service line and a galvanized steel pipe excavated from a system using a proprietary blended phosphate chemical. The scale was analyzed by X-ray diffraction, X-ray fluorescence, and scanning electron microscopy/energy dispersive spectroscopy. Instead of crystalline lead-orthophosphate solids, a porous amorphous layer rich in aluminum, calcium, phosphorus, and lead was observed at the lead pipe scale-water interface. Thus, the mechanism inhibiting lead release into the water was not a thermodynamically predictable passivating lead-orthophosphate scale, but rather an amorphous barrier deposit that was possibly vulnerable to disturbances. Galvanized pipe scales showed relatively crystalline iron and zinc compounds, with additional surface deposition of aluminum, phosphorus, calcium, and lead.

WHO (2003). pH in Drinking-Water: Background document for development of WHO Guidelines for Drinking-water Quality. Geneva, World Health Organisation (WHO)

Although pH usually has no direct impact on water consumers, it is one of the most important operational water-quality parameters. Careful attention to pH control is necessary at all stages of water treatment to ensure satisfactory water clarification and disinfection. For effective disinfection with chlorine, the pH should preferably be less than 8. The pH of the water entering the distribution system must be controlled to minimize the corrosion of water mains and pipes in household water systems. Failure to do so can result in the contamination of drinking-water and in adverse effects on its taste, odour, and appearance.

The optimum pH will vary in different supplies according to the composition of the water and the nature of the construction materials used in the distribution system, but is often in the range 6.5–9.5. Extreme pH values can result from accidental spills, treatment breakdowns, and insufficiently cured cement mortar pipe linings. No health-based guideline value is proposed for pH

WHO (2004). Monochloramine in Drinking-water: Background document for development of WHO Guidelines for Drinking-water Quality. Geneva, World Health Organisation (WHO)

It has been shown that the use of chloramines for disinfection instead of chlorine reduces the formation of THMs in drinking-water supplies, often by as much as 40–80%. Compared with chlorine, use of monochloramine resulted in lower levels of total chlorinated by-products, as measured by such parameters as total organic halides, non-purgeable organic halides and non-purgeable organic chlorine.

Another study indicated that while chloramination significantly reduces the formation of purgeable organic halides, significant amounts of non-purgeable organic halides are still formed. Although chloramination significantly reduces THM levels, formation of other byproducts, such as haloketones, chloropicrin, cyanogen chloride, haloacetic acids, haloacetonitriles, aldehydes and chlorophenols, has been reported.

Wollmann, M., et al. (1998). "Corrosion of copper in cold-water plumbing systems." Chemical Engineering & Technology 21(3): 264-267

After replacing the cold water piping in a public building in 1985, copper content increased after one year and pipe perforations occurred in 1989. The corrosion was different from previously known types; copper resistant microorganisms caused the microbiologically induced corrosion. The experimental results are presented.

Woszczynski, M., et al. (2013). "Comparison of chlorine and chloramines on lead release from copper pipe rigs." Journal of Environmental Engineering 139(8): 1099-1107.

The objective of this study was to assess lead release in a pipe rig system that was disinfected with either chloramines or free chlorine. The study was carried out using pipe loops and copper pipe rigs that had lead solder, which provided the only source of lead. The water quality of the treated water had a low alkalinity (<5 mg/L as CaCO₃), neutral pH, and low hardness (<5 mg/L as CaCO₃). However, the study used a corrosion control program that consisted of dosing with 0.8-mg PO₄/L of zinc orthophosphate and controlling the pH to 7.3, that was consistent with the corrosion-control program operated in the host water treatment plant. Key findings from the study confirmed that chloramines would result in lead release under the current corrosion-control program, whereas free chlorine was not as compromising. Lead concentrations were approximately an order of magnitude lower in the free chlorine system than the chloramine systems. In this study, chloramines with a target residual concentration of 5 mg/L released 382 µg/L and 49 µg/L following stagnation times of 24 h and 30 min, respectively. Furthermore, chloramines with a target residual concentration of 1 mg/L resulted in a lead release of 73 µg/L and 14 µg/L following a stagnation time of 24 h and 30 min, respectively. By comparison, the pipe rigs that were dosed with a free chlorine target residual concentration of 1 mg/L had lead concentrations of 12 µg/L and 2 µg/L for the 24-h and 30-min stagnation times. This project demonstrates that care needs to be taken when evaluating secondary disinfectants, particularly for those water systems having a low dissolved inorganic carbon concentration.

Xie, Y. and D. E. Giammar (2011). "Effects of flow and water chemistry on lead release rates from pipe scales." Water Research 45(19): 6525-6534.

Lead release from pipe scales was investigated under different water compositions, stagnation times, and flow regimes. Pipe scales containing PbO₂ and hydrocerussite (Pb₃)(OH)₂(CO₃)₂ were developed on lead pipes by conditioning the pipes with water containing free chlorine for eight months. Water chemistry and the composition of the pipe scales are two key factors affecting lead release from pipe scales. The water rarely reached equilibrium with pipe scales within one day, which makes solid-water contact time and corrosion product dissolution rates the controlling factors of lead concentrations for the conditions tested. Among five water compositions studied, a solution with orthophosphate had the lowest dissolved lead release rate and highest particulate lead release rate. Free chlorine also decreased the dissolved lead release rate at stagnant conditions. Water flow increased rates of release of both dissolved and particulate lead by accelerating the mass

transfer of lead out of the porous pipe scales and by physically destabilizing pipe scales. Dissolved lead comprised the majority of the lead released at both stagnant and laminar flow conditions.

Zhang, Y. (2009). Dezincification and brass lead leaching in premise plumbing systems: Effects of alloy, physical conditions and water chemistry. Blacksburg, Virginia, Virginia Polytechnic Institute and State University. MSc (Environmental Engineering): 139.

Brass components are widely used in drinking water distribution systems as valves, faucets and other fixtures. They can be corroded by "dezincification," which is the selective leaching of zinc from the alloy. Dezincification in potable water systems has important practical consequences that include clogged water lines, premature system failure and leaks, and release of contaminants such as lead. Brass failures attributed to dezincification are known to occur at least occasionally all over the world, and have emerged as a significant problem in the U.S. recently due to the use of inexpensive high zinc brass fittings in cross-linked polyethylene (PEX) plumbing systems. As PEX systems gain popularity and leaded brass is recognized as an important source of lead in potable water systems, it is important to examine dezincification corrosion in more detail. An in-depth literature review revealed that conventional wisdom about dezincification was no longer adequate in explaining failures observed in modern water systems. Little research has been conducted since the landmark work of Turner et al. nearly half a century ago. The potential role of chloramines, phosphate inhibitors, and modern understanding of water chemistry need evaluation. The role of physical factors including stirring, heating and galvanic connections are also potentially influential. A mechanistic study of zinc solubility and corrosion of copper: zinc couples provided insight to factors that might mitigate and exacerbate zinc leaching from brass. Zinc solubility and corrosion was reduced by higher pH and bicarbonate, but was enhanced by higher chloride. Hardness ions including Mg^{+2} and Ca^{+2} had little effect. Alloys with higher zinc content had a greater propensity for dezincification corrosion. Stirring and galvanic connections caused brass to leach more metals and have higher weight loss. Heating may contribute to corrosion scale accumulation. A comprehensive examination of dezincification as a function of water chemistry used numerous techniques that include measurement of galvanic currents, metal leaching, and weight loss. In general, as would be predicted based on results of the study of solubility and corrosion of pure zinc, chloride emerged as an aggressive ion whereas bicarbonate was beneficial to brass corrosion. Hardness had little impact, and phosphates, silicates and Zn^{+2} inhibitors had a significant short-term benefit but little long-term benefit. The relationship between dezincification corrosion, lead leaching from brass, and water chemistry was investigated in Chapter 5. Surprisingly, lead and zinc leaching from a range of brasses were found to be negatively correlated. Hence, use of brasses that minimize dezincification problems might increase lead leaching. This thesis represents a comprehensive analysis of factors that are influential for dezincification and lead leaching from brass in premise water distribution systems through literature reviews, mechanistic investigations, bench-scale experiments, and case studies. Results can be used by water utilities, plumbing engineers, manufacturers and home owners to better prevent, recognize, and mitigate brass and dezincification corrosion problems.

Zhang, Y. and M. Edwards (2011). "Effects of pH, chloride, bicarbonate, and phosphate on brass dezincification." American Water Works Association. Journal 103(4): 90.

Knowledge about the long-term effects of water constituents on brass dezincification is fairly limited, and important quantitative data such as weight loss and levels of zinc leaching were rarely collected in earlier research. The effects of hardness and alkalinity in dezincification are unclear because of various interpretations of the classic Turner diagram. In this research, experiments were conducted to elucidate the interplay between water

chemistry and dezincification. The authors identified a critical pH range of 8 to 9 at which "meringue" dezincification is problematic and refined the interpretation of the Turner diagram by attributing beneficial effects to higher alkalinity rather than hardness (or temporary hardness). Chloride was found to increase dezincification propensity by increasing zinc solubility and galvanic current, whereas hardness had little to no effect on brass dezincification. That inhibitive effects of orthophosphate dissipated after about 100 days raises questions about the long-term efficacy of phosphate inhibitors in mitigating brass dezincification.

Zhang, Y. and M. Edwards (2011). "Zinc content in brass and its influence on lead leaching." American Water Works Association. Journal 103(7): 76.

It has been speculated that lead leaching is related to dezincification, which is characterized by the preferential leaching of zinc from the alloy, leaving behind a porous residue of copper and corrosion products. This increasingly porous layer allows lead to detach and diffuse more rapidly from the brass surface into solution. High-zinc brasses are usually more susceptible to dezincification attack; therefore, the high-zinc brasses might be expected to experience more severe lead leaching. This article found that using dezincification- reduction (DZR) brasses that minimize dezincification might create increased problems with lead leaching. Therefore, to limit lead leaching, it is important to limit the amount of lead in all brasses or limit the use of leaded brasses. Given recent concerns about failures from dezincification, a forthcoming requirement to mandate DZR brass in some potable water applications (i.e., lower zinc content or DZR resistance from arsenic or other substances) is on the horizon. From the perspectives of public health protection and regulatory compliance, it may be important to limit the lead content of brasses.

Zhang, Y., et al. (2008). "Nitrification in Premise Plumbing: Role of Phosphate, pH and Pipe Corrosion." Environmental Science and Technology 42(12): 4280-4284.

Nitrification in PVC premise plumbing is a weak function of pH over the range 6.5–8.5 and is insensitive to phosphate concentrations 5–1000 ppb. Lead pipe enhanced nitrification relative to PVC, consistent with expectations that nitrifiers could benefit from ammonia recycled from nitrate via lead corrosion. Relatively new copper pipe (<1.5 years old) did not allow nitrifiers to establish, but nitrifiers gradually colonized over a period of months in brass pipes when copper concentrations were reduced by pH adjustment or orthophosphate. Nitrifiers were inhibited by trace copper, but not by lead levels up to 8000 ppb. In some systems using chloramines, brass in plastic plumbing systems might be more susceptible to lead/copper leaching, and accelerated dezincification, due to lower pH values resulting from nitrification.

Zhang, Y., et al. (2008). "Effect of nitrification and GAC filtration on copper and lead leaching in home plumbing systems." Journal of Environmental Engineering-Asce 134(7): 521-530.

Nitrification and granular activated carbon (GAC) filtration impact leaching of lead/copper to potable water under typical home plumbing configurations. GAC filters removed the disinfectant and caused rapid establishment of nitrification in chloraminated systems. The potential adverse consequences of whole house GAC filters deserve increased scrutiny in chloraminated systems. The lower pH values from nitrification and other microbes during overnight stagnation in pipes can markedly increase (up to 800%) lead and copper contamination of water.



Zietz, B. P., et al. (2015). "Release of metals from different sections of domestic drinking water installations." Water Quality, Exposure and Health 7(2): 193-204.

Different metals can leach from piping materials into the tap water, which can be of health concern. This study investigated in which amount abundant metals were released from different parts of domestic installations into the cold tap water. For the approximate spatial allocation of the metal releasing sources, a sequential water sampling protocol was used after three hours of stagnation time representing the first five litre of the water column. After stagnation ten sample volumes were collected in series. Existing facilities of domestic installations constructed with different plumbing materials were examined predominantly from residential buildings. The elements Al, As, Cd, Cr, Cu, Fe, Mg, Mn, Ni, Pb, Sb, Se, U and Zn were detected by means of ICP-MS. In total 16 water pipe strands of 11 domestic installation systems were examined. They comprised 401 single water samples and 5,614 single parameters. Depending upon the type of plumbing, different courses and concentration ranges of the elements could be measured in the tap water samples. Terminal taps or installation parts were in all investigated systems responsible for a release of nickel and in several cases of low concentrations of cadmium. The concentration courses of the element zinc proved as a good indicator for the allocation of the metal source to a brass containing section of the installation (zinc as an alloy component of brass). One can conclude that sequential water sampling protocol in combination with multi-element detection can be a valuable non-destructive method for drinking water-hygienic investigations of domestic installations.

Appendix C – PPI Group submission to the Review

Lead in Drinking Water – PPI Group Position Paper

PPI Group Policy position

PPI Group supports properly developed measures to address the emerging policy challenge of lead leaching into the water supply and its potential health risks for the community. It is of the view that there are no simple or cost-free pathways forward.

Central to the mitigation of risk from lead in drinking water is the urgent need to introduce Point of Sale Legislation for plumbing products in Australia supported by clearly defined materials specifications, product and testing standards and robust policing and surveillance at a commonwealth and state level.

PPI Group seeks to work closely with government to achieve national consistency, true consumer empowerment and scheme transparency and deliver:

- reduced risk for the community from the effects of lead leaching into the water supply;
- a positive investment climate to encourage new process and product technologies via an orderly transition to a 0.25% maximum lead content in copper alloys through the National Construction Code (NCC)cycle of 2018-2022;
- the timely changeover to a more robust risk-mitigation regulatory environment no earlier than 2022 through better aligned materials standards, product testing and water sampling standards as well as the introduction of Commonwealth Watermark Point of Sale Legislation; and
- greater public awareness of, and transparency about, plumbing products performance and their contribution to positive health outcomes.

STRATEGY

Aim for a minimum timeframe for change to Lead-Free materials no earlier than 2022 (assuming the current 3 year amendment cycles for the NCC are adhered to and that any decision occurs before the end of calendar year 2018).

Review the US model process for implementation and subsequent performance as a guide to how Australia should implement Lead-Free regulation.

Ensure robust assessments of any changes to materials composition or plumbing regulations are carried out with full industry stakeholder engagement and with public health and safety as a primary concern.

Encourage ABCB to draw on the expertise of PPI Group members who have vast experience or contacts in global market places to assess the real cost impact of implementing Lead-Free material requirements.

Recognise that without proper enforcement and without Point of Sale Legislation for WaterMark a change in lead content will do nothing to eradicate the proliferation of non-compliant building products within the plumbing sector of Australia.

MEASURES

Enhance the WaterMark Scheme operating as Point of Sale Legislation.

Align product testing and compliance requirements (in particular AS/NZS 4020:2005) with in-field, water sampling testing and guidelines to remove interpretation and comparison error.

Revise Australian Standards, AS1565 maximum allowable lead content 4.5%, AS1567 at 3.5%, AS1568 at 3.5% and AS1572 at 5%, that are referenced in various product standards to identify Lead-Free alloys.

A maximum of 0.25% lead content as the preferred Lead-Free definition.

On-going coordination between:

- Pre-certification activities
- Auditing and enforcement across the supply chain
- In market policing (post sale)
- Laboratory testing regimes, accreditation, protocols and techniques
- In- field testing regimes, protocols and techniques
- Alignment with above to Australian Standards
- Alignment of the above to Point of Sale Legislation for plumbing products

TECHNICAL

Maintain or enhance lead leachate and the full suite of requirements contained in AS/NZS 4020:2005 (and any revisions) be maintained or enhanced.

Lead-Free proposals must also consider:

- Maintaining the Australian requirements contained in AS 2345 for the Dezincification Resistance (DR) of copper alloy materials in contact with drinking as a co-requisite performance characteristic; and
- Microbial growth or bacterial growth scenarios associated with alternative materials.

Lead in Drinking Water, PPI Group

A number of recent events and actions within the plumbing and building sector¹ have given the lead in drinking water debate considerable momentum. The Australian Building Codes Board (ABCB) has commissioned Professor Mark Taylor of Macquarie University to examine the *"potential for plumbing products and materials to contribute to the presence of lead levels in drinking water in excess of those permitted by the Australia Drinking Water Quality Guidelines."* Members of the Plumbing Products Industry Group (PPI Group) have been invited to submit answers to Prof. Taylor's short list of questions as part of the consultation process being administered by the ABCB. The aim of the ABCB in this case is to inform ongoing development of Volume Three of the National Construction Code (NCC), the Plumbing Code of Australia (PCA).

PPI Group supports properly developed measures that further reduce risks from the effects of lead leaching into the communities' water supply. We believe PPI Group has an important role to play in assisting Industry and Government adopt changes that achieve this goal and we fully support a move to Lead-Free Materials² in the PCA. Our intention is to ensure that the most robust assessment of any change to materials composition or plumbing regulations is carried out with full industry stakeholder engagement and that public health and safety is carried as a primary concern throughout.

Based on overseas experience, PPI Group supports the review, decision and implementation of new regulations to be carried out over the next NCC amendment cycle and for introduction no earlier than 2022. PPI Group also holds the position that any changes under the NCC and/or PCA with respect to materials and plumbing products would be suitably complemented by the enhancement of the WaterMark Scheme operating as Point of Sale Legislation. This provides both the opportunity for a hard cut over date to new materials and in turn will support the implementation of changes throughout the entire supply chain; from raw materials supply through to end user.

¹ The various responses to Lead in Drinking Water at the Perth Children's Hospital and the new Perth Stadium precinct, and the Sydney Kitchen Sink Mixer report by Macquarie University.

² The PPIG defines Lead-Free Materials as any materials that contain less lead than currently found in the Australian plumbing supply chain under the current regulatory environment.

PPI Group has formed a Lead in Drinking Water Working Group to focus on this issue on behalf of members. The working group has identified a number of areas of concern with respect to changes in material specifications and performance requirements within the PCA. Based on these areas of concern we have established a series of questions and our subsequent position on that area. We believe consideration of both the areas of concern and our position will assist the ABCB to ensure a full and robust assessment is carried out before final decisions are made.

Areas of Concern

1. Lead-Free Materials

There are multiple approaches to reducing the risk of Lead in Drinking Water worldwide. The primary markets that have adopted Lead-Free materials are Europe and the USA. Both markets focus on different copper alloys compositions and plumbing materials specifications. Through industry knowledge and research, it is noted by PPI Group that:

- a) There is currently NO readily available copper alloys material containing 0% lead in use anywhere in the world, including the Lead-Free jurisdictions of Europe and the USA.
- b) It is noted that to step from lead levels as low as 0.25% to 0% significantly impacts raw material prices, supply chain availability and manufacturability.
- c) A number of Australian Standards exist, namely AS1565, AS1567 & AS1568 that are referenced in various product standards which do not identify Lead-Free alloys and must be revised to do so.
- d) Any Lead-Free proposal must consider Australian requirements for the Dezincification Resistance (DR) of copper alloys materials in contact with drinking water³.
- e) Microbial growth or bacterial growth scenarios with alternative materials must be considered. Some risks could be equal to or create a higher risk situation to that experienced under the current requirement of maximum lead leachate in water under AS4020:2005 (or its pending revised version).

2. The Regulatory Stakeholders

Australia currently has a regulatory framework (NCC-PCA/WaterMark/WELS)⁴ that is designed to reduce the risk of failure of the drinking water supply in Australia. This

³ DR material is called up under Australian Standard, Dezincification of Copper Alloys, AS 2345-2006

⁴ The WaterMark Certification Scheme (Scheme) is a mandatory certification scheme for plumbing and drainage products to ensure they are fit for purpose and appropriately authorised for use in plumbing and drainage installations. The Water Efficiency Labelling and Standards (WELS) scheme is Australia's urban water saving scheme

framework protects the safety, health and amenity and sustainability of plumbing infrastructure across Australia. The Australian plumbing market place has evolved and built businesses around this framework such that:

- a. All legitimate suppliers in the chain currently adhere to, have invested in and have built processes and procedures around these regulations to ensure ongoing compliance for the benefit and wellbeing of the community
- b. The technical capability of laboratory, Conformity Assessment Body (CAB) and other stakeholders within the plumbing industry is designed and accredited around these schemes and regulations

It is the position of PPI Group that the minimum timeframe for change to Lead-Free materials shall be no earlier than 2022 (assuming the current 3 year amendment cycles for the NCC are adhered to and that any decision occurs before the end of calendar year 2018). Further, any change will require full coordination between the following elements:

- i. Pre-certification activities
- ii. Auditing and enforcement across the supply chain
- iii. In market policing (post sale)
- iv. Laboratory testing regimes, accreditation, protocols and techniques
- v. In- field testing regimes, protocols and techniques
- vi. Alignment with above to Australian Standards
- vii. Alignment of the above to Point of Sale Legislation for plumbing products

3. The Supply Chain

Copper alloys currently in circulation have been manufactured unchanged in composition since 1980. Changes to the supply chain in order to deliver a material specification change are significant and complex covering many areas. Impacts are expected on:

- a. Cost of materials - new Lead-Free alloys are expected to be considerably more expensive than alloys currently in use in Australia
- b. Manufacturing costs – manufacturing techniques (including development of new skills and knowledge) will drive up costs – it is globally recognised that machining, forging and casting costs increase when Lead-Free alloys are utilised (refer Commercial Impact point 5 below)
- c. Availability of materials and components - the ability to produce and supply Lead-Free materials and components is restricted through current local technical capability and experience.
- d. Audit and policing of supply chain – delivering compliance to a new set of rules and material specifications

- e. The long chain of plumbing products utilised in the Australian market - Material change will drive consolidation and/or out of step cost increases for small volume, unique products.
- f. The regulations and legislation that support the schemes through different points of the supply chain – alignment of which is imperative for any change to both make sense to the participants and be transparent and workable for the general public
- g. Recycling of materials currently containing lead – separation of old/new materials to protect future manufacturing material purity and a possibility that recycling of materials becomes unviable.

4. Community expectations

The current WaterMark scheme is the primary, legislated benchmark under which the plumbing industry works. Honest and legitimate members of the supply chain currently comply with all of the requirements of the WaterMark scheme including the AS/NZS 4020:2005 testing requirements for materials in contact with drinking water.

Public testing (of water samples) from installed product in several jurisdictions has recently provided conflicting results to those received during product certification testing under AS/NZS 4020:2005. The negative press subsequent to these test results being made public has been considerable. PPI Group strongly recommends the alignment of materials standards, product testing and water sampling standards referenced in the PCA along with the introduction of Point of Sale Legislation for plumbing products in Australia.

5. Commercial Impact

The commercial impacts of introducing Lead-Free alloys will relate to manufacturing costs and subsequently to international competitiveness.

Increasing Manufacturing Costs

The introduction of new Lead-Free alloy requirements for plumbing products in Australia will have a significant impact on current manufacturing processes and costs.

Understanding of the role of lead in manufacturing is a key point to understanding the cost implications. Lead is not soluble in copper alloys, it forms primarily as flakes/globules/particles along grain boundaries which act as a kind of internal lubricant during the machining process. This lubricating effect helps to decrease heat generation, improve tool life, and break up swarf into finer chips which are far less likely to block up machines.

By removing lead, the machining process becomes far more difficult, machines are required to run slower to prevent excessive heat generation and the likelihood of cracking/rejects is

increased. Using copper alloys containing alternative ingredients to lead⁵ increases overheads substantially (including energy costs and consumables utilised in the manufacturing process), reduces production capacity and drives up raw material costs. It is understood by PPI Group that the value of cost changes can range from 15%-40% depending on the processes and product configurations.

While not discounting the obvious benefits of reducing the chance of lead leaching into the drinking water supply, PPI Group believes a change to Lead-Free will result in increased product costs for industry and consumers.

Global Competitiveness

Robust codes, regulations and product certification are required to keep the Australian public safe and our drinking water supply healthy. Australian industry who are committed with their products to be WaterMark compliant will be further unfairly disadvantaged in the market if approved, yet non-compliant plumbing products with higher lead levels can still be sold. In the interests of consumers and to resolve industry concerns there is an urgent need to introduce Point of Sale Legislation for plumbing products in Australia supported by clearly defined materials specifications, product and testing standards and robust policing and surveillance at a commonwealth and state level.

⁵ The three major alternative solutions for Lead-Free Copper alloys are:

- Bismuth: Similar mechanism to Pb, also insoluble in Copper alloys, more brittle, less effective.
- Silicon: Acts to form a different crystal structure/s in the Copper alloys matrix, aids machinability in terms of swarf morphology and drill torque, however overall the material is stronger so tool wear is still an issue.
- Naval Copper alloys: Essentially removing the Lead and replacing with a combination of Copper, Zinc, and Tin. Machinability drops off significantly, but at least the alloy is simple to predict.

Questions arising from areas of concern

1. To what extent will assessment of current schemes around the world be used as a guide to the best approach for Australia and how will these assessments be undertaken?

The PPI Group position is that the US model is an effective and suitable model to be implemented in Australia. We advocate for a maximum 0.25% lead content as the preferred Lead-Free definition. There are members of PPI Group who work extensively with the US who may be called upon to provide technical advice to the ABCB on this point. PPI Group recommends a review of the US model process for implementation and subsequent performance as a guide to how Australia should implement a Lead-Free regulation.

The increased incidence of lead in USA potable water supplies has moved that country, through the Environmental Protection Agency (EPA) to set a goal of “zero” parts per million of lead in drinking water. “Lead is a neurotoxin that can cause long-term health effects, even at very low exposure levels. No amount of lead in children's blood is considered safe by any health authority.

The US EPA has set a goal of “zero” parts per million of lead in drinking water because no safe level of exposure is known. And, as of 2014, it became illegal to install new pipes, pipe fittings, other plumbing fixtures and solders that are not “Lead-Free” (i.e., containing more than 0.25% lead).” This has led to an amendment to the Safe Drinking Water Act to reduce lead in drinking water

2. What is the position of the ABCB with respect to current materials specifications in Australia that ensures Dezincification Resistant Copper alloys be used?

PPI Group submits that any Lead-Free proposal must consider Australian requirements for the Dezincification Resistance (DR) of copper alloys materials in contact with drinking water as a co-requisite performance characteristic.

3. To what extent will alternate water chemistry results be assessed beyond Lead in Drinking Water when determining the best approach for the long term health and safety of our plumbing systems?

PPI Group propose that along with lead leachate the full suite of requirements contained within AS/NZS 4020:2005 (and any ensuing revisions) be maintained or enhanced.

4. To what extent will the ABCB work with Standards Australia, JASANZ and the registered CAB's to coordinate and then align changes across these existing areas of control?

It is the position of PPI Group that without proper enforcement and without Point of Sale Legislation for WaterMark a change in lead content will do nothing to eradicate the proliferation of non-compliant building products within the plumbing sector of Australia. The coordination and clarity of responsibility, particularly with respect to policing will need to be addressed by the ABCB.

5. How does the ABCB intend to assess the cost impact of materials changes across the supply chain?

PPI Group members have vast experience or contacts within global market places which should be called upon by the ABCB to assess the real cost impact of implementing Lead-Free material requirements.

6. How will the alignment of testing regimes, accreditation, regulations and standards be coordinated with the change program so as to minimise potentially inaccurate in field results and unnecessary negative publicity for those who have been supporting and adhering to the existing suite of requirements under the PCA?

PPI Group believes coordination between product testing and compliance requirements (in particular AS/NZS 4020:2005) be aligned with in field, water sampling testing and guidelines to remove interpretation and comparison error.

7. What time frame does the ABCB intends to work towards for any changes and what cut-off date will industry be expected to work towards?

It is the belief of PPI Group members that at this point in time a 2022 transition date is a reasonable cut over date if the decision can be made before the end of calendar year 2018 and is suitably detailed in its expectations and requirements.

8. To what extent will the ABCB work with State Governments and State Regulators to coordinate and then align changes across their existing areas of control?

PPI Group believes national consistency can be delivered through Commonwealth Point of Sale Legislation with accompanying state-based legislation for WaterMark certification of plumbing products.

9. Does the ABCB intend to amend The WaterMark Scheme to facilitate change and empower consumer choice with respect to Lead-Free products?

PPI Group believes true consumer empowerment, scheme transparency and thus scheme performance can be delivered through Commonwealth Point of Sale Legislation with accompanying state-based legislation for WaterMark certification of plumbing products.

Plumbing Products Industry Group (PPI Group) and the Australian Plumbing Industry

PPI Group is the premier voice of manufacturers and importers of plumbing products used in the Australian plumbing industry. The Association is well represented on all relevant plumbing industry Australian Standards Committees and other national committees and groups. PPI Group members are committed to the development of the plumbing industry in Australia and work together to deliver quality, safe products, fit for purpose for use by industry and consumers for their benefit and the safety of the wider community. A number of plumbing product manufacturer members of PPI Group are also exporters of product manufactured in Australia creating additional employment opportunities and earning export dollars. The objectives of PPI Group are to:

- Promote, encourage, foster and develop the Plumbing Products Industry Group in the interests of its members in Australia and New Zealand.
- Promote the establishment and maintenance of high standards of quality, service and ethics throughout the industry.
- Place before Industry, Government, Statutory Authorities and others in Australia, New Zealand and elsewhere, the policies and views of the Association.
- Take a pro-active and interactive role in matters connected with regulators, Standards Australia/Standards New Zealand, Water Authorities and like national or state bodies and authorities in Australia, New Zealand and elsewhere.
- Foster a cooperative and mutually supportive effort in improving the export potential of its members.
- Uphold the ideals and principals that the plumbing industry is responsible for and concerned for Public health and safety as a priority

PPI Group members work very closely with a large number of small-scale contracting firms employing over 50,000 Australians. The plumbing industry makes a significant

contribution to economic activity in the building and construction industry and to the health and wellbeing of Australians. It has annual total revenue of \$5 billion and the industry includes importers and manufacturers of pipe, fittings, fixtures, valve products, drainage, sanitary ware and water heaters.

The Australian plumbing industry, including PPI Group, has been a strong supporter of the efforts made in recent years to take a high level national approach to the regulation of plumbing i.e. the improved watermark Scheme. By operating within a comprehensive national regulatory regime in the public interest, the plumbing industry ensures the community is well served because it delivers safe and effective plumbing, drinking water, hot water systems, effective sanitation and efficient waste water removal.

Appendix D – Galvin Engineering submission to the Review

25/03/2018

SUBJECT: Response to ABCB's Research Project - Lead in Plumbing Products and Materials

Dear Mark Taylor

Thank you for inviting Galvin Engineering to contribute to this important Research Project. The Australian plumbing industry is extremely important to us and we are proud to remain as one of the few local manufacturers of commercial plumbing products serving our community. We believe our commitment to the public is captured in our purpose statement - *Water solutions for a Healthier Environment*.

Please find below responses to the questions posed in your letter dated 19 March 2018:

1. Does your organisation or have you commissioned another authority to routinely test for lead in plumbing products and materials?

As part of our QA/QC program, we routinely test materials and components used to manufacture our Watermarked products using both our inhouse laboratory and external NATA approved laboratories. We do this to ensure they comply with our specifications and those set out in the relevant Australian Standards.

Whilst some of the testing we perform will identify levels of lead, they are not solely for this purpose, rather to identify the entire chemical composition of the material, as well as other material properties such as susceptibility to dezincification.

2. If there is no routine testing, has your organisation undertaken or have you commissioned another authority to undertake any testing of lead in plumbing products and materials at any point in time?

Refer to response for Question #1.

3. How are your plumbing products and materials screened to determine whether they meet the current relevant Australian Standards?
Relevant standards could include the AS/NZS 4020 - Testing of products for use in contact with drinking water; the WaterMark Certification Scheme and the Plumbing Code of Australia.

Firstly, we have documented Supply and Manufacturing Specifications that all products and materials must comply with and meet our performance requirements, and the minimum requirements of relevant Australian Standards. Their conformance is routinely verified using several methods, including common ones such as:

- Spectrometer Analysis - to determine conformance to our written specifications and specific material standards such as AS1565, AS1567, AS1568, etc.

- Dezincification Resistance Testing – to determine conformance to AS2345.
- Detailed Testing for Materials and Products in Contact with Drinking Water – to determine conformance to AS/NZS 4020.

Secondly, we ensure conformance to current relevant standards through internal and external audits of our quality system (ISO 9001:2015), independent annual product certification audits (Watermark Level 1 requirement), monitoring of Australian Standard changes through our R&D and Compliance Departments, and subscription to online standards databases.

Furthermore, new products undergo a full set of tests as prescribed by Watermark Conformity Assessment Bodies (WMCABs) for materials and performance, which is also conducted at independent NATA approved laboratories.

Whilst it may not be part of your scope, I believe it is critical that the regulation of the WaterMark scheme is improved across all states and territories. Media and government reports in WA over the last year, tend to point to the fact that a lot of the issues with lead in water may be coming from taps / fittings that are not compliant to the current scheme.

Without ensuring the WaterMark scheme is adequately regulated, and the regulators are adequately resourced to do so, making changes to the legislation / standards covering materials, may not ultimately improve the outcome for the public. Having a very robust Point of Sale legislation (like that used for WELS), would be a huge advance in this regard, and would hopefully cut out the suppliers / manufacturers that are skirting around WaterMark. Currently only the plumber doing the installation is subject to any disciplinary actions if non-WaterMarked product is used, whereas we believe responsibility needs to be shared across the whole supply chain. At the same time, I think auditing of WaterMark holders should be increased to ensure people claiming they have WaterMark are doing the right thing.

4. Does your organisation have alternative fittings that have no or low lead or have knowledge of their availability?

Yes, we offer several product lines in low lead or lead-free alternatives. We select product lines where it is practical to produce in alternative materials without compromising compliance to current Australian Standards and Watermark requirements, and where we believe there is a willingness from consumers to pay the increased cost of these alternative material products. I have listed two examples below:

- 4.1 The Ezy-Drink GalvinClear range of stainless steel drinking bubbler taps, was designed to offer consumers a choice of a lead-free drinking tap. These are made in our factory in Perth and are ideal for schools, universities and other public areas. It was featured on Channel Seven News late last year on:

<https://www.galvinclear.com.au>

One of the models can be found on:

<https://www.galvinengineering.com.au/ezy-drink-galvinclear-316-stainless-steel-piezo-el>

- 4.2 The Conti range of electronic tapware is made for us by a partner in Switzerland. Conti offers a selection of products that not only pass the Australian Standard testing for potable water (AS/NZS 4020), they also comply with s1417 of the Safe Drinking Water Act in the USA (and USA standards NSF61 / NSF372). Therefore, in the USA these taps can be labelled as 'lead free'. In addition, all metallic materials used in these taps are listed on the European Standard (4MS Common Approach), which ensures they meet the strict German Drinking Water Guidelines. One of the models can be found on:

<https://www.galvinengineering.com.au/conti-electronic-iq-a10-ir-hob-basin-tap-w-temp-mi>

As a side note, I read in section 4.3.3 of your 2016 published article, *ScienceDirect - Environmental Research - Widespread copper and lead contamination of household drinking water, New South Wales - Harvey et al*, that lead-free taps are often far more expensive (~ 3 times the price). With this in mind, our experience to date has been with manufacturing taps / valves in 316 stainless steel and in some of the low lead DZR brass alloys used in Europe like CW511L. With regards to material costs, we tend to find the material is typically more expensive depending on the actual material, and it can be harder to get in the desired sizes due to the reduced number of suppliers and stock holdings. However, it is with the machining costs where the biggest cost increase tends to lie. Due to the hardness of the metal, we find with 316 stainless steel for example, the machining time can be up to 2 or 3 times as long. In addition, we end up using many more machining tools which means there needs to be more supervision of the CNCs by machinists. Overall, we find stainless steel taps cost at least twice as much to produce, and some of the taps made from lower lead alloys are upwards of 30% to produce. Obviously, this would reduce over time as you gain competency in the manufacturing process, negotiate better rates for volume buys of materials, adjust designs, etc.

- 5. Has your organisation or have you commissioned another authority to undertake any testing of dissolution of lead from plumbing products and materials in:**
- a. Real systems**
 - b. Laboratory simulation of plumbing systems?**

From time to time we have used independent NATA labs to conduct water composition analysis on products of ours that are installed in the field. We have done this to get a better understanding of how our products perform in different locations and under different operating conditions. This has included testing for recently installed products and for products installed for a longer period. We have also performed inhouse testing using our own test rigs.

As a side note, the Department of Health in WA does not itself provide a documented procedure for in-field water testing. Instead they publish a list of recommended test labs to use for the analysis of water. After contacting most of these test labs, we were surprised that they could not provide us with a consistent documented procedure for the way water samples should be collected and tested.

Through our own experiments, we found five key variables exist when collecting and testing water samples from the field, and that these factors impact the results of the water tests. Therefore, it is reasonable to assume these variables could impact on testing being done by other people in the field, and this could lead to questions as to whether there is compliance to Australian Drinking Water Guidelines. These variables are:

- Volume of sample used in the test
- Duration of stagnation in the plumbing system being tested (time in which the actual water outlet and other close proximity outlets are not operated)
- Flush duration and amount used in the test
- Complexity of the plumbing system being tested
- Composition (chemical, physical, etc) of the water in the plumbing system being tested

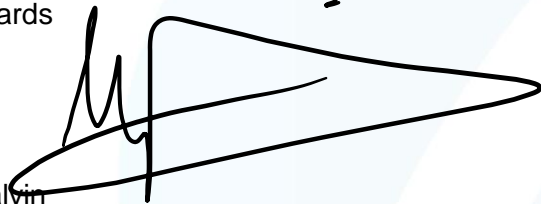
We researched this further to identify correct collection methods and found that whilst AS/NZS 4020 was quite prescriptive in water collection methodology and seems suitable for controlled laboratory conditions, there was little guidance for in-field testing.

The most relevant Australian standard we could identify for in-field collection, AS/NZS 5667.5, is ambiguous and lacks a lot of detail regarding the variables outlined above. This is likely due to the fact AS/NZS 5667.5 is meant for analysis of the water supply, where AS/NZS 4020 is for the analysis of the effect materials have on water supply.

As the discussion around testing of water in the field probably falls outside of your current scope, I will send through a white paper we have done on this issue separately just for your reference. Note, this report has been done by a lay-man who is interested in this issue due to its relevance to the health and safety of the community. The main aim of the paper was to promote discussion amongst industry groups and government. Further, I have attached a proposal for review of in-field water testing procedures in Appendix A.

If you would like any further information on the response above, or on other related matters, please feel free to call me on +61 413 620 794.

Best regards

A handwritten signature in black ink, appearing to be 'Chris Galvin', with a long, sweeping horizontal stroke extending to the right.

Chris Galvin
Managing Director

Appendix A – Draft proposal for review of in-field water testing procedures

Aim

To develop and draft an Australian standard that incorporates; *Water quality – In field sampling and testing of drinking water – Extraction of metals (typically lead)*. This may be a new standard or an update to an existing standard such as AS/NZS 5667.5:1998 *Water Quality Sampling*.

Issue/s Identified

Currently a situation exists in Australia where water testing being done in the field, is being used to make decisions on the continuation of water supply systems in facilities and public areas. These reported results and their interpretation are also creating public concern about elevated levels of lead in drinking water and compromising confidence in water supply systems.

The methods used for this in-field water testing vary dramatically across states and individual projects, and it is possible that some of these testing techniques may/or may not be adequate in generating accurate data on metal levels such as lead in water. Available International and Australian Standards are not prescriptive in nature to provide a consistent approach to the current localised issues the Australian water supply is faced with.

The results of recent reports are being interpreted by a range of different interest groups generating much debate. This has the potential to impact judgement and subsequent decisions regarding the possible effects on public health, and/or the suitability and safety standards of plumbing products.

The issue affects the confidence that the public has in the water supply systems currently in place. This lack of confidence is then transferred to government departments (such as health, education & building), the health community, the plumbing industry at large, the media, and approved testing facilities. Not only is the issue a sensitive one that leads to sensationalised media reporting, political jockeying and the resulting public outcry, it is extremely costly for the public purse.

AS/NZS 5667 provides useful information with regards to water testing, however, it leaves a lot of variables up to the individual testing facility, which leaves room for different results to be generated from the same site.

It is believed that a standardised method of water sampling and testing with regards to extraction of lead (and other metals) in the field, should be developed and for use across all states and territories in Australia. The objective of these sampling protocols would be to monitor for typical exposure to lead to determine if there are concerns related to effects on human health. The testing method should be appropriate for the type of building and should reflect typical usage patterns of the inhabitants.

Many factors contribute to the variability of lead concentration results from drinking water testing. These factors include the type of materials used in the plumbing system, the age & complexity of the plumbing system itself, usage patterns, flow rates, stagnation areas, chemicals introduced into the water supply, and fluctuations in water quality (pH and alkalinity). The new standard should consider these variables and suggest water testing protocols that take them into consideration.

It is important that the selected testing protocol should be appropriate to meet the desired objectives. If the objective of the water testing revolves around public health, then the sampling and testing protocols should represent the average or typical exposure to lead in drinking water for a population in the water supply zone.

In addition, any prescribed flushing regimes, stagnation periods and volume of water extracts, should consider the complexity, water quality, flow rates, chemical composition and age of the plumbing system being tested, and the typical usage of the water by the inhabitants/consumers.

Recent Examples

You only need to look at one recent example being the Perth Children's Hospital to get an idea of the impact of an inconsistent approach to water testing. This \$1.2 billion hospital was due to open in November 2015, but now looks likely to open in May 2018. One of the main reasons for the delays and rectification works, has been concerns about lead levels in the hospitals plumbing system and /or water supply, and whether these levels breach the Australian Drinking Water Guidelines (AWDG). The guideline states that based on health considerations, the concentration of lead in drinking water should not exceed 0.01mg/L.

The State's December midyear budget review revealed \$22.4 million would be spent this financial year alone to meet the costs associated with the delays. This doesn't take into account the massive financial burden placed on the taxpayer over this 2 ½ year delay, and the loss of much needed health care for the public. The issues surrounding the hospital have led to constant media stories across all TV channels, newspapers such The Australia and The West Australian, and radio stations. There is much debate about the suitability of the testing regimes being used between different government departments, independent experts, and industry groups. There is also debate as to whether the actual results are being interpreted correctly, and whether or not, there is a real cause for the health concern being raised.

The issue in WA has spread into public parks and schools with different political parties and media creating concern with the community, parents and teachers around lead levels in water at schools and public areas. This concern has been raised on the back of unspecified testing regimes, and inconsistent interpretation of results by different parties.

Perth's new Optus Stadium is the most recent high-profile case in Western Australia. The Sunday Times has conducted independent water testing of its own, with results that identify excessive levels of lead in the water of fountains surrounding the stadium. These results contradict with the results of tests conducted by the stadium operator, Venue West, and have led to a protracted debate in the media. The Health Department is currently suggesting there is no health risk to the public.

Another high-profile case in Queensland involving Aldi versus the Queensland Building and Construction Commission (QBCC), has been in play since Jul 2017. The stir has revolved around differences in water composition results from Aldi's AS/NZS 4020 test reports and independent test reports commissioned by the QBCC. This has led to Aldi and the QBCC waging a war against each other in the media (ABC, Sydney Morning Herald, and TV stations), as to who's results are correct and whether there is a real cause for health concerns for the public. Whilst this issue is yet to be resolved, Aldi continues to face backlash from the media and the public, which has led to damage to its reputation and sales, and significant costs in having extra testing done and dealing with the negative PR.

Research Review

An example of where another jurisdiction has applied a tailored water testing protocol approach, is in Canada. In their paper *'Lead in Drinking Water – Document for Public Consultation; Consultation Period Ends March 15, 2017'*, they compare three main water sampling protocols:

- RDT Protocol (Random Day Time) – collection of a random 1L sample from a drinking water tap without any prior flushing and no specified stagnation time.
- FF Protocol (Fully Flushed) – flushing for 5 minutes then collecting a 1L sample.
- 30MS Protocol (30 minutes) – tap is flushed for 5 minutes; water is allowed to stand for a 30-minute stagnation period; Two x 1L samples are taken; Results are averaged.

The European studies referenced in the report indicate that RDT sampling is representative of usage patterns, enabled the detection of a substantial proportion of sites with lead issues, is relatively inexpensive, is practical to implement and is acceptable to consumers. It was also determined RDT had a stagnation time close to or higher than the actual average inter-use stagnation time, and therefore RDT may over estimate lead exposure.

The studies also show 30MS to be representative of usage and enables lead detection nearly as well as RDT, but that 30MS is more reproducible than RDT. However, 30MS is relatively expensive, less practical to implement and less convenient to consumers. FF sampling was not found to be representative and did not enable detection at sufficient problem sites.

Based on this, the report suggests both RDT and 30MS can be appropriate for compliance monitoring, and that the selected protocol should be appropriate to meet the desired objective. If the objective is public health, p12 states the sampling protocol should represent the *'average of typical exposure to lead drinking water in the population. It is important to note that a sampling protocol that assesses the average intake of lead will not capture the highest concentrations of lead or the full contribution of lead from the service line'*. That is, sampling protocols using long stagnation times to capture the highest levels of lead are best used for treatment purposes (eg. investigating the efficacy of corrosion control treatments).

With regards to sampling protocols, the report recommends different protocols as follows:

Monitoring in residential buildings:

- Recommends testing once per year at 20 residences in a water supply zone
- Typically, sampling is done on the cold water tap in the kitchen or another suitable location used for drinking or food preparation
- Can use either protocol:
 - o RDT Sampling – to better reflect consumer use there is no prior flushing and no prescribed stagnation period; A 1L sample is collected.
 - o 30MS Sampling – the tap is flushed for 5 minutes and allowed to stand for a 30-minute stagnation period; Two x 1L samples are collected; Results are averaged.

Monitoring for schools, multi-dwelling residences and large buildings:

- Recommends testing once per year
- Typically, sampling at each drinking water fountain and at a proportion of taps used for drinking or food preparation
- Suggest use only RDT protocol as it captures typical exposures:
 - o RDT Sampling – without a stagnation period and without prior flushing; Two x 125mL samples are collected (total of 250mL); Results are averaged.

In the USA, the Environmental Protection Authority prescribes a sampling procedure for home owners in 'WSG197 – Clarification of Recommended Tap Sampling Procedures for the Purposes of the Lead and Copper Rule – Signed February 29, 2016'. Homeowners are required to collect samples from a tap that has not been used for 6 hours, and to collect the samples in a 1L sample bottle.

Moving back to Australia, a similar procedure was used in 2016 by the Macquarie University in their study titled '*Widespread copper and lead contamination of household drinking water, New South Wales – August 2016*'. In Phase 1 of the study they used two methods:

- Sample size of 212 - First draw samples were taken after a stagnation period of 9 hours in 1L bottles (to simulate filling a kettle first thing in the morning),
- Sample size of 10 – Samples taken after a 2-minute flush period in 1L bottles.

Also, whilst '*AS/NZS 4020:2005 – Testing of products for use in contact with drinking water*' (AS/NZS 4020) which is a pre-requisite of gaining certification to the WaterMark, has been written with the testing of specific plumbing products in mind, it's comprehensive and prescriptive testing protocols could also provide a lot of useful information when writing a standard on infield water testing.

For end-of-line fittings, Appendix I states that 'in-the-product exposure is used wherever possible for test extractions'. In brief I6.3 details that:

- testing is performed using duplicate product samples which undergo a cleaning and flushing protocol
- using test water, the first water extract of 250mL is taken after 16 hours of contact time, then the product sample is flushed.
- The second water extract of 250mL is taken after 30 minutes contact time, the product sample is flushed, and this is repeated another six times.
- In total, eight water extracts of 250mL are taken.
- The eight water extracts of 250mL are mixed together to create the composite water extract of 2L.
- Blank tests are also performed to determine the level of metals from other sources such as the container or external sources.
- If the composite extracts do not exceed specified limits, no further testing is required.
- If either composite extract does exceed the specified limits, the test extractions are repeated using a further three fresh samples.

This method would seem to approximate how much lead an adult who drinks 2L of water a day would consume via eight separate intakes of 250mL (ie. a glass of water) - one long stagnation period and seven shorter stagnation periods.

Scope

To develop and draft an Australia standard that incorporates; *Water quality – In field sampling and testing of drinking water – Extraction of metals* (typically lead).

To develop testing protocols that are appropriate to meet the desired objectives. If the objective of the water testing is to monitor for typical community exposure to total metal (typically lead) in water, to determine whether there are concerns related to effects on human health, then the sampling and testing protocols should represent the average or typical exposure to lead in drinking water for a population in the water supply zone.

To develop standardised sampling protocols and water monitoring for typical water supply exposure to metals (typically lead).

To design testing methodology that is appropriate for the type of building and is reflective of typical usage patterns of the inhabitants. These test methodologies will align with in-line and end of line fittings.

In development of a water quality sampling standard conduct a review of the following existing Australian standard: 'AS/NZS 5667.5:1998 – Water quality—Sampling – Guidance on sampling of drinking water and water used for food and beverage processing' (AS/NZS 5667). Namely:

1. Flushing / Stagnation – the standard is vague on flushing regimes and stagnation periods. In the standard, when looking at testing of a distribution system, clause 4.1.4 recommends that samples should be collected at distinct locations in the system, and from the ends of distribution systems. It states that samples should be collected after a flushing time of 2 to 3 minutes, but sometimes as long as 30 minutes. When looking specifically at consumer's taps, clause 4.1.5 states that *'the flushing time depends on the sampling purpose; if the effects of material on water quality are being investigated then the initial draw-off should be sampled. For most other purposes, a flushing time of 2 min to 3 min is sufficient to establish equilibrium conditions'*. Whilst this is useful, it does not specify how long the stagnation period should be before an initial draw-off sample is taken. It is proposed that the new standard should prescribe the actual stagnation periods and flushing regimes to be used for the different test objectives.
2. Extract Volumes - the actual volume of water to be collected is not specified in the standard. Clause 7.1 just states that *'The volume of the sample to be collected depends on the number and types of analyses to be performed'*. As concentrations of metals in water will vary depending on contact time of the water with other materials, and as the measured levels may be more concentrated or diluted depending on the water sample extract volume, results on the same source may vary significantly depending on who is performing the testing. It is proposed that the new standard should prescribe the actual water extract volumes that would be needed to be collected for the different test objectives.
3. Site Specific Issues – In addition, it is proposed, that when referring to the flushing regime, stagnation period and volume of water extracts, the new standard should consider the complexity, water quality, flow rates, chemical composition and age of the plumbing system being tested, and the typical usage of the water by the inhabitants/consumers.

To review and adopt where appropriate International Standards as referenced in AS/NZS 5667.5:

ISO 5667-1:2006 Water quality - Sampling Part 1: Guidance on the design of sampling programmes and sampling techniques

ISO 5667-3:2012 Water quality - Sampling Part 3: Preservation and handling of water samples

ISO 5667-5:2006 Water quality - Sampling Part 5: Guidance on sampling of drinking water from treatment works and piped distribution systems



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