Guide for Small Community
Water Suppliers and Local Health Officials on

Lead in Drinking Water

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About this Guide

This Guide for Small Community Water Suppliers and Local Health Officials is one of a series produced by the International Water Association's (IWA) Specialist Group on Metals and Related Substances in Drinking Water. It is an abbreviated compilation of the wide range of scientific, engineering, health and operational issues concerned with the control of lead in drinking water in small water supply systems.

The IWA Specialist Group is supported by members from 26 European countries, Canada and the United States. It is an active research network and has regularly convened international conferences and seminars. It has close working links with the World Health Organization, the European Commission's Joint Research Centre, Health Canada and the US Environmental Protection Agency. The IWA Specialist Group developed out of COST Action 637 (www.cost.esf.org), a European research network.

The Guide is supported by a two-day technical training course and a more comprehensive Best Practice Guide on the Control of Lead in Drinking Water (IWA, 2010). Information about training, the Best Practice Guide and the research network in general is available from www.meteau.org

This Guide for Small Community Water Suppliers and Local Health Officials explains why lead in drinking water may still be a threat to public health in small communities. It is aimed at Local Health Officials and the operators of drinking water supply systems that serve small communities. Its objectives are to raise awareness, to provide a basis for assessing the extent of problems, and to identify control options.

Disclaimer

Whilst every reasonable attempt has been made to present the information in this Guide in a fair and balanced manner, the reader should none-the-less satisfy themselves of its relevance to their specific circumstances. It must also be appreciated that some aspects of the topic of plumbosolvency control do not enjoy total consensus of opinion and that practices have varied around the world. The designations employed and the presentation of the material in this publication do not imply the expression of any opinion whatsoever on the part of any organization mentioned in this publication concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries.

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Foreword

by Roger Aertgeerts, World Health Organization

Lead has been a challenge and a bane for water suppliers since historical times. The statement that the extended use of lead in aqueducts was one of the contributing factors to the fall of the Roman Empire has entered collective memory. The numerous articles printed in leading scientific journals, in the United Kingdom and United States, in the late nineteenth century, documenting thousands of cases of lead poisoning caused by lead water pipes, have largely faded in the mist of history. These cases often resulted in death, paralysis, blindness, insanity, convulsions, miscarriages and stillbirths.

One historical example in particular gives pause for thought. In the summer of 1887, the town of Bacup, in England, experienced a severe drought. The town's water reservoir went dry for several weeks and without water regularly running through the distribution systems the interior of the lead service pipes were exposed to air. This caused the encrustation of organic and inorganic compounds that had built up over the years to break away from the pipes. Once the protective barrier was gone and water was returned to the pipes, water began to dissolve the lead. Shortly after, 404 cases of water-related lead poisoning were documented by Bacup's health office. With climate change induced droughts making uninterrupted water supply an increasingly difficult challenge in many countries, the story of Bacup looms as an early warning whose lesson should be learned earlier rather than later.

The World Health Organization has progressively tightened its guideline value for lead from a maximum allowable concentration of 0.1 mg/l to the current 0.01 mg/l. The WHO Guidelines recognize that lead is exceptional, and that most lead in drinking-water arises from plumbing, and the remedy consists principally of removing plumbing and fittings containing lead. As this requires much time and money, it is recognized that not all water will meet the guidelines immediately. Meanwhile, all other practical measures to reduce total exposure to lead, including corrosion control should be implemented. Treatment to reduce plumbosolvency usually involves pH adjustment and, additionally, dosing with ortho-phosphate may be necessary.

Small community water supply systems are very numerous throughout the world and problems caused by lead pipes may be exacerbated by the lack of reliable treatment. Particular problems can be associated with low alkalinity sources that are prone to acidic pH conditions. This Guide provides a simplified approach for assessing problems from lead pipes and gives guidance on corrective options. It is hoped that this Guide will enable those responsibly for water supplies to small communities to make important progress in reducing the potential health risks from lead in drinking water.

Introduction

The problem of lead in drinking water is most-publicized for the larger water supply systems of Cities and Towns, particularly the older districts, where lead piping was often used to connect houses to a municipal water supply system and for internal plumbing, up to the early 1980s (generally). The problem is more closely associated with the longer established industrialised and urbanised countries.

The same risk to individuals is present in smaller towns, villages and more wide-spread rural areas. Individual houses or small groups of houses with their own independent water supply can also have a problem if lead pipes are in use. Because small systems have less funding for monitoring or necessary corrective action, in many instances problems can be more severe, and have a bearing on the economic balance of corrective actions and the way in which problems are assessed.

For more detailed technical information, the reader can refer to the IWA's Best Practice Guide on the Control of Lead in Drinking Water (www.iwapublishing.com) and related training scheme (www.meteau.org). Whilst these are particularly relevant to larger water supply systems, many of the issues and principles are also relevant to small community water supply systems.

Public health concerns

The effects of lead are well documented and identify a wide range of possible clinical conditions (Troesken, 2006; Hayes and Skubala, 2009), often making medical diagnosis difficult. Published literature draws attention to adverse health effects from prolonged exposure to high amounts of lead from occupational and environmental exposure, including: interference with haemoglobin biosynthesis; interference with calcium and vitamin D metabolism; gastrointestinal irritation; dullness; restlessness; irritability; poor attention span; headaches; muscle tremor; abdominal cramps; kidney damage; hallucination; loss of memory; encephalopathy; hearing impairment, gonad dysfunction, and violent behaviour. Lead can accumulate in bone and fatty tissue, with subsequent release, particularly during the latter stages of pregnancy. Most attention has been directed towards the retardation of child development, especially reductions in IQ.

Numerous case studies have correlated exposure to lead with the concentration of lead in blood, and blood lead concentrations to clinical effects. Such quantification is difficult due to the wide range of exposures and human tolerances that complicate such studies, but general effects can be clearly demonstrated. Less well established is the potential for pre-natal mortalities, bearing in mind that lead compounds were used historically (Troesken, 2006) to induce abortion, at lead dosages equivalent to high concentrations (350 µg/l) of lead in drinking water that can occur in highly plumbosolvent water supply areas (Hayes and Skubala, 2009).

Historically, lead exposure was linked to food, paint, petrol and drinking water. Lead in paint and petrol were removed in the early 1980s. At this time, leaded solder for jointing copper pipes and jointing food cans was also banned. In consequence, any remaining problems are likely to be due to drinking water, primarily in the presence of lead pipes, although concerns continue to be voiced in North America about the potential for exposure from soil and dust. The main source of lead in drinking water is due to the continued use of lead pipes, although lead leaching from brass fittings and galvanic corrosion of leaded solder can be problematic in some circumstances (IWA, 2010).

The basis of the current World Health Organization (WHO) Guideline Value of 10 µg/l for lead in drinking water (WHO, 2004), as an average concentration, is that lead accumulation should be avoided and that blood lead concentrations should be kept well below the level of 10 µg/dl that is generally regarded as the threshold for concern. The WHO has established the Guideline Value on the basis of a provisional tolerable weekly intake of 25 µg/kg body weight, using the weight of an infant of 5 kg, a consumption of drinking water of 0.75 litres/day and an exposure contribution of 50% from drinking water.

Why problems occur

In the absence of treatment measures to reduce plumbosolvency, all types of drinking water can dissolve lead from lead pipes to concentrations that exceed the WHO Guideline Value. To reduce the plumbosolvency of drinking water sufficiently, it is necessary to increase pH (typically to between 8.0 to 9.0) and/or dose a corrosion inhibitor (UK experience is that ortho-phosphate is the most effective).

The amount of lead that dissolves depends on the quality and temperature of the drinking water, how much lead piping is present, the pattern of water use and other circumstances. More lead dissolves the longer the water is held in the lead pipes under zero flow conditions (stagnation), until an equilibrium concentration of lead is reached (after about 6 to 12 hours).

The following factors affect the concentration of lead in drinking water:

<u>Temperature</u>
Lead concentrations tend to increase at higher water temperatures, with an approximate doubling over the range 12 to 25^{o}C.

<u>pH and alkalinity</u>
Lead concentrations can be considerably higher at lower pH values (<7), particularly for low alkalinity waters (< 30 mg/l HCO_3), such as the very soft waters that are common in upland areas. Lower alkalinity also markedly increases lead leaching between pH 7.0 and pH 8.5.

<u>Natural organic matter</u>
The naturally occurring humic and fulvic acids that leach from bog-land areas, which give a straw-like colouration, can greatly increase lead concentrations by organic complexion, by as much as 10 times (on the basis of laboratory plumbosolvency testing) for coloured waters of around 20 to 30 ^{o}Hazen.

<u>Iron discolouration</u>
Iron rust particles, that are common when drinking water passes through old, corroded cast iron pipes, can adsorb lead if they settle in lead pipes under zero flow conditions. The particulate lead that is formed can be mobilized by flowing water and approximately double the over-all concentration of lead in the drinking water drawn from the tap.

<u>The amount of lead piping</u>
As a general rule, there is a greater problem with longer lengths of lead piping than for shorter lengths, and for any given length of lead pipe, the lead released will be greater for larger pipe diameters.

Flow conditions
The health effects from lead in drinking water are normally correlated with the average lead concentration. In practice, lead concentrations at the tap vary substantially as determined by the contact (stagnation) time between the water and the lead piping. As a guide, the average frequency of use of a domestic tap is around 30 minutes (but there is much variation from house to house) and this will determine the average lead concentration.

If the flow-rate is very high, lead can be scoured from pipes in significant concentrations. On the other hand, if the flow duration is infrequent, lead concentrations tend to be higher due to greater accumulation of lead sediment and dissolved lead.

How to assess your water supply system

Definitions and constraints

The WHO (2004) uses the following definition for a small community water supply:

"The precise definition of a small community water supply will vary. While a definition based on population size or the type of supply may be appropriate under many conditions, it is often administration and management that set community supplies apart. The increased involvement of ordinary, often untrained and sometimes unpaid, community members in the administration and operation of water-supply systems is characteristic of small communities: this provides a ready distinction between community water supplies and the supply systems of major towns and cities. However, water supplies in peri-urban areas – the communities surrounding major towns and cities – are often organizationally similar to those of rural communities; these may also be classified as "community water supplies."

It is also important to recognize that some countries use number of households, others number of connections, others volume of water, etc., in defining their systems. Further, limitations in resources may make it difficult to undertake risk assessments as recommended by this Guide. However, it is hoped that every endeavour to assess the risks from lead in drinking water will be made, recognising the potential impacts on human health.

System sizes

In Europe and North America, it can be assumed that 1000 litres, which is 1 cubic metre (m^3), distributed from the source will serve 5 people each day, if water loss in the distribution system through leakage is 25% and the consumption from all uses is 150 litres per person per day. In Europe and North America, the average residency of a house is around 2.5 persons. Therefore, each 1000 litres distributed from the source per day will serve 2 houses, as a general rule. These relationships should be determined specifically for each country and adjustments made to the paragraphs that follow.

In this Guide:

- a small community water supply is defined as one serving 1,000 to less than 5,000 people, or 400 to less than 2,000 houses
- a very small community water supply is defined as one serving less than 1,000 people or less than 400 houses

- an independent water supply is defined as serving no more than 50 people or 20 houses.

<u>Initial risk assessment</u>

For all system sizes, the risk of problems with lead in drinking water from lead pipes can be assessed in a simple manner by reference to Table 1. If it is known that lead pipes were never used, or in cases where all houses were built after lead pipes and leaded solder were banned (early 1980s), the risks from lead in drinking water should be very low. The risks determined from Table 1 only apply to houses built before the date when lead pipes and leaded solder were banned. This should be established in each country, but if unknown 1980 could be assumed.

Table 1. Assessing the risks from lead in drinking water for houses built before the early 1980s

Type of water source	Likelihood of risk
Soft, coloured, pH <7 from an upland lake or stream where treatment is minimal	Very high
Other lakes or streams, and springs where treatment is minimal (eg: only disinfection)	High
Water from lakes or streams where treatment includes chemical coagulation, settlement and filtration	Moderate
Groundwater (hard waters)	Moderate
Any water type where fully treated and dosed with an optimum amount of ortho-phosphate corrosion inhibitor under optimum pH conditions	Very low

<u>Assessing small community water supply systems for risks from lead pipes</u>

For systems serving 400 to 2000 houses, the number of houses at risk should be determined by:

- reviewing any records of the use of lead pipes and the local knowledge of the Municipality (water system operators, housing managers, etc);
- preparing a Plumbosolvency Map that shows the location of houses built before and after the year that lead pipes and leaded solder were banned;
- a pipe-work survey (by inspection) of 10% or 20 (whichever is the greatest) of the houses built before the year that lead pipes and leaded solder were banned.

Pipe-work inspections should record the length, diameter and type of pipe-work (ie: lead, copper, iron, plastic) from the connection point to the water main up to the cold water tap used for drawing drinking water (normally the kitchen). The results from the survey can then be extrapolated to the total number of houses built before the year that lead pipes and leaded solder were banned, to estimate (in conjunction with Table 1) the extent of the lead in drinking water problem.

<u>Assessing very small community water supply systems for risks from lead pipes</u>

For systems serving less than 400 (but more than 20) houses, the number of houses at risk should be determined in the same way as for small community water supply systems except that the number of pipe-work surveys can be reduced to 5% or 10 (whichever is the greatest).

Assessing independent water supply systems

For systems serving less than 20 houses, a pipe-work inspection of all houses built before 1980 should be undertaken to determine the number of houses at risk.

Confirmation of plumbosolvency

The plumbosolvency (ability to dissolve lead) of the source water, after available treatment, can be determined in a number of ways, to confirm the risk categories indicated by Table 1.

- plumbosolvency testing by a specialist laboratory (approximate cost € 500 per sample);
- water quality testing by an accredited laboratory for pH, turbidity, conductivity, alkalinity, organic colour and iron (approximate cost € 30 per sample).

Confirmation of lead in drinking water problems

Problems with lead in drinking water can be confirmed at each house at risk, or for a representative selection of houses at risk, by taking water samples from the kitchen cold water tap after over-night and/or 30 minutes stagnation.

For both conditions:

- flush the pipe-work for at least 2 minutes (not necessary for over-night standing);
- allow the water to stand in the pipes over-night or for 30 minutes (no water should be used for any purpose during the stagnation period);
- take three 1 litre samples in sequence of the first drawn water from the tap;
- water quality testing by an accredited laboratory for lead (approximate cost € 10 per sample).

To interpret the results relative to the occurrence of lead pipes, it is essential to make allowance for any water stood in non-lead pipe-work during the stagnation period (refer to pipe-work inspection). The simplest way is to identify the highest lead from the three samples as representative of the lead concentration after the stagnation period used. Alternatively, select for analysis the stagnation sample that best represents the water that has stood in lead pipe-work (to reduce analysis costs).

The over-night standing samples provide an indication of the potential severity of the problem, whereas the samples after 30 minutes stagnation provide an indication of typical lead concentrations. The severity of the lead problem can then be assessed by reference to Table 2.

Table 2. Severity of lead problems

Lead concentration after 30 minutes stagnation (µg/l)	Lead concentration after over-night standing (µg/l)	Severity of lead in drinking water
> 100	> 400	Extremely high
50 to 100	200 to 400	Very high
25 to 49	100 to 199	High
10 to 24	40 to 99	Moderate
< 10	< 40	Fairly low
< 5	< 20	Low

Control options

Flushing

Running the kitchen tap for one or two minutes (flushing), before each use of water for drinking or food preparation purposes, when the water has been standing for a period of time, should avoid the worst lead contamination that has built up in the pipes, in most cases. Just flushing before the first use of water, after over-night standing, will only reduce average lead concentrations by a small amount.

Regular flushing to avoid lead contamination could easily double water consumption in a house and conflicts with sustainability principles, although water can be used for other purposes not entailing human consumption. In water stressed areas, regular flushing before use may be impractical.

This approach relies on individual homeowners and may require an educational / behaviour change campaign. It may also be difficult to monitor compliance results if flushing is erratic. However, flushing provides a very low cost option and may be particularly helpful as a short-term health protection measure.

Bottled water

The use of bottled water for potable consumption (particularly baby feeds) and food preparation can also be considered as a short-term health protection measure, at an approximate cost of € 1 per litre (€ = Euro).

Point of use treatment

Small scale treatment in each house at risk from lead in drinking water is feasible, using either:

- pitcher (jug) style filters certified to remove lead where the filter is replaced every 3-6 months (approximate cost € 20 – available in some supermarket stores)
- a small in-line cartridge filter filled with an adsorbent material certified to remove lead (approximate cost € 100 plus adsorbent material changes); or
- a reverse osmosis (RO) purifier (approximate cost € 1,000 plus energy).

The problem with cartridge filters is knowing when to change the adsorbent material. Most house owners are not water treatment experts and could be at risk from rogue products and inadequate maintenance. The use of certified products maintained by a reputable company will minimise such problems. Pitcher style filters are used widely in the US.

Centralised treatment

Treatment of source waters abstracted from springs, lakes or streams should be matched to the water quality of the source to remove colour and particulate matter prior to disinfection.

pH adjustment to a value of 8 to 9, by dosing lime or caustic soda, or by filtration through dolomite media, can greatly reduce plumbosolvency, particularly low alkalinity (soft) waters. Increasing the pH of high alkalinity (hard) waters may require softening to enable the higher pH values to be achieved without calcite precipitation.

pH elevation alone will not be sufficient in many cases for achieving the WHO Guideline Values for lead in drinking water at houses with lead pipes. In these cases, the dosing of a corrosion inhibitor may be required, of which ortho-phosphate is often extremely effective at typical doses in the range 1.0 to 1.5 mg/l (P).

For a water supply system with 2,000 houses, the approximate costs of dosing ortho-phosphate at 1.0 mg/l (P) will be: (i) € 50,000 for the dosing plant and chemical storage; and (ii) an operating cost of € 1,825 per annum, assuming a unit cost of 0.5 € cents per cubic metre.

For a water supply system with 400 houses, the approximate costs of dosing ortho-phosphate at 1.0 mg/l (P) will be: (i) € 20,000 for the dosing plant and chemical storage; and (ii) an operating cost of € 730 per annum, assuming a unit cost of 1.0 € cents per cubic metre (higher cost of chemicals at smaller volumes).

Chemical dosing to less than 20 houses may not be a feasible option due to disproportionate costs and the likely lack of technical expertise at such small scale. With smaller supply systems it could well be more cost-effective, and more sustainable, to replace lead pipework within properties rather than installing chemical dosing. As the cost of phosphate based inhibitors continues to rise, the balance of economics will continue to shift and warrants continued review.

Lead pipe replacement

Lead pipe replacement will cost from between € 1,000 and € 4,000 per property, dependent on technique and ground conditions. Assuming lead pipe replacement at 1,000 houses (50% of the houses in a water supply system with 2,000 houses), the total cost will be between € 1M and € 4M. For the smaller system with 400 houses of which 50% have lead pipes, the total cost will be between € 0.2M and € 0.8M. However, lead pipe replacement does not solve problems with any lead leaching from solder and brass.

This approach is complicated by split ownership and responsibility in many cases between the water supplier and home owner. Policies on who pays will be needed at either national or local level. It should also be appreciated that partial lead pipe replacement may not be effective and can even make matters worse, due to the physical disturbance of deposits in the remaining lead pipe and possible galvanic corrosion between the remaining lead and new copper pipes. It is recommended that planners and utilities consider replacement holistically and also proactively replace pipes as opportunities arise, i.e. mains work, repairs, etc.

CAUTION! Sometimes, the electrical installation in a house is grounded by connecting it to the drinking water pipe-work. In such cases, lead pipe replacement can introduce an electrocution risk. The electrical installation should be connected directly to earth.

Conclusions

1. Lead in drinking water can pose a serious risk to the health of consumers, particularly in respect of child development.

2. The main problem arises from lead pipes, where used to connect to the water main or for internal household plumbing, although lead leaching from leaded solder or brass fittings can also be a problem in some cases.

3. The most reliable options are (i) water treatment, either centrally or at the point of use, involving pH control, absorbent filters or the use of a corrosion inhibitor (most commonly ortho-phosphate), or (ii) the replacement of all lead pipes.

4. Local community representatives and their water suppliers should work together to determine the best local options for tackling the problem of lead in drinking water.

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