



Review of Harvey et al (2015) Project 1094-15

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JUNE 2015



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Expert Panel Report – Review of Harvey et al (2015)

Report Title: Review of Harvey et al (2015)

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WaterRA Project No. 1094-15 – Review of Harvey et al (2015)

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- Understanding trophic interactions, tracking nutrient sources, elucidating food webs; and
- Application of stable isotope analysis aquatic environments to determine pollution and energy sources.

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Associated with this activity has been the production of a series of Guides to the Operation of key Control Points in WTPs for the Water Industry Operators Association (WIOA). A similar series is also being produced for wastewater treatment.

Most recently in 2013 and 2014, a project has been initiated with the Queensland Water Directorate to provide specialist technical assistance, training and mentoring to a large number of WTPs in rural and remote Queensland.

Peter was project manager for the Water Treatment Alliance in Australia and has been a member of the NHMRC WQAC. He also edits and produces WaterWorks magazine for WIOA.

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1 EXECUTIVE SUMMARY

A report entitled “Identification of the sources of metal (lead) contamination in drinking waters in north-eastern Tasmania using lead isotopic compositions” by Harvey P.J., Handley, H.K. and Taylor, M.P, was published in Environmental Science Pollution Research in April, 2015. The paper concluded that the lead contamination of the drinking water in the town of Pioneer could be attributed to three sources.

1. The water race infrastructure including the large leaded joint pipelines of the Frome Dam, the Moorina Power Station and the Pioneer holding dams;
2. The PVC pipes that connect the Pioneer holding dams to the residential service lines; and
3. Lead contaminated fittings and fixtures within individual properties.

The authors used an isotopic “fingerprinting” technique to differentiate between the different possible sources of this lead contamination. They also analysed water, soil and sediment samples as well as scrapings from various pipelines within the water supply scheme.

TasWater, as operators of the Pioneer water supply scheme, engaged Water Research Australia (WaterRA) to undertake a review of this paper with the intent of assessing the following aspects.

- Review of the science around the application of source identification markers – in particular the use of isotope “fingerprinting”;
- Application of the science to the drinking water supply system of Pioneer;
- The study methodology employed by Harvey et al (2015);
- The amount and strength of data gathered;
- The types of data collected and the links between the analysis and the conclusions;
- The conclusions as they relate to the water supply system; and
- Other possible explanations that have not been canvassed but that may be supported by the data.

An expert panel was formed to undertake this work. The work included a close analysis of the paper and its supporting data, an inspection of the water supply system for the town of Pioneer, discussions with TasWater staff with knowledge of the Pioneer system and an analysis of additional data supplied by TasWater.

A visit to the town of Pioneer and an inspection of its water supply system was undertaken by two members of the expert panel on May 18, 2015. This visit also provided the opportunity for extended discussions with TasWater staff. From these discussions it became clear that the Frome Dam and the Moorina Power Station had not been directly connected with the Pioneer water supply scheme since at least 2009. As a consequence, the panel concluded that the data taken by Harvey et al (2015) from the Frome Dam and Moorina Power Station were not relevant to the outcomes of the study. However, the data they took from within the town distribution system and at individual households remained relevant.

A review of the use of isotopic “fingerprinting” techniques to assess the source of lead within the Pioneer water supply system found that, while the technique has the potential for identifying the sources of lead in drinking water, the data contained in the Harvey et al (2015) paper were insufficient to draw any conclusions. One reason for this outcome was the use of a sample from the Moorina Power Station as one potential source of the isotopic composition. Another reason was lack of multiple samples and a consequent inability to estimate the variability of the results obtained.

Another major concern of the review panel was the lack of duplicate analyses and repeat samples from within the town itself. This, combined with an unclear sampling protocol, was seen as a major

weakness of the study. However, when data from both TasWater and Harvey et al (2015) were considered together, there was little doubt that the levels of lead and copper measured at the various locations in the town were intermittently elevated. The source of these metals was the key point in question.

The potential sources of contamination identified by the panel were:

- Water in the Pioneer Dam;
- Sediment in the Pioneer Dam;
- Pipes in the town distribution system; and
- Local plumbing in individual houses.

An analysis of the data available for each of these potential sources found that:

- Based on limited data, there appears to be very low levels of lead and no copper in the raw water sourced from Pioneer Dam. However because of low pH and alkalinity, raw water from the Pioneer Dam would be considered aggressive and likely to leach metals from sediment and pipe materials;
- While the data is limited, it appears that the levels of lead in sediments within the Pioneer dam are low, although there may be some spatial variability;
- It is possible that wind and flood events could raise the turbidity in Pioneer Dam and contribute to lead bearing sediments in the town distribution system; and
- While the aggressive nature of the water could result in the leaching of lead from the PVC pipes, a report from CSIRO, Burn et al (2005) and subsequent discussion with Burn indicate that in well flushed systems this should not result in lead reaching levels dangerous to public health. However, it is possible that in stagnant and dead-end zones within the Pioneer system elevated lead levels could arise. Considering that the PVC pipes in this system are about 35 years old, only further testing could answer this question.

The panel concluded that, while the data contained in the paper by Harvey et al (2015) are sparse and their reproducibility can be questioned, the general conclusions reached in the paper are plausible.

The use of first flush samples in the paper would help explain the strong correlation found between lead and copper levels in their analyses. Consequently, these samples would not necessarily reflect the quality of water in the distribution mains which were well flushed. Calculation of daily flow rates and system volumes indicate that the main east-west distribution pipe in Pioneer should be well flushed. However, the system also contains significant dead-end zones

One option for TasWater to consider is the stabilisation of the raw water by passing it through a bed of limestone particles. This method is being used in various water supplies in both Australia (Bundaberg) and overseas (Scotland). The review panel has also suggested further investigations which would be needed to more accurately identify the source of contaminant metals in the Pioneer water supply.

2 INTRODUCTION

This report is a review of the paper “Identification of the sources of metal (lead) contamination in drinking waters in north-eastern Tasmania using lead isotopic compositions” published in Environmental Science Pollution Research” by Harvey, P.J., Handley, H.K. and Taylor, M.P. in April, 2015. The review was commissioned by TasWater with the intent of covering the following aspects:

- Review of the science around the application of source identification markers – in particular the use of isotope “fingerprinting”;
- Application of the science to the drinking water supply system of Pioneer;
- The study methodology employed by Harvey et al (2015);
- The amount and strength of data gathered;
- The types of data collected and the links between the analysis and the conclusions;
- The conclusions as they relate to the water supply system; and
- Other possible explanations that have not been canvassed but that may be supported by the data.

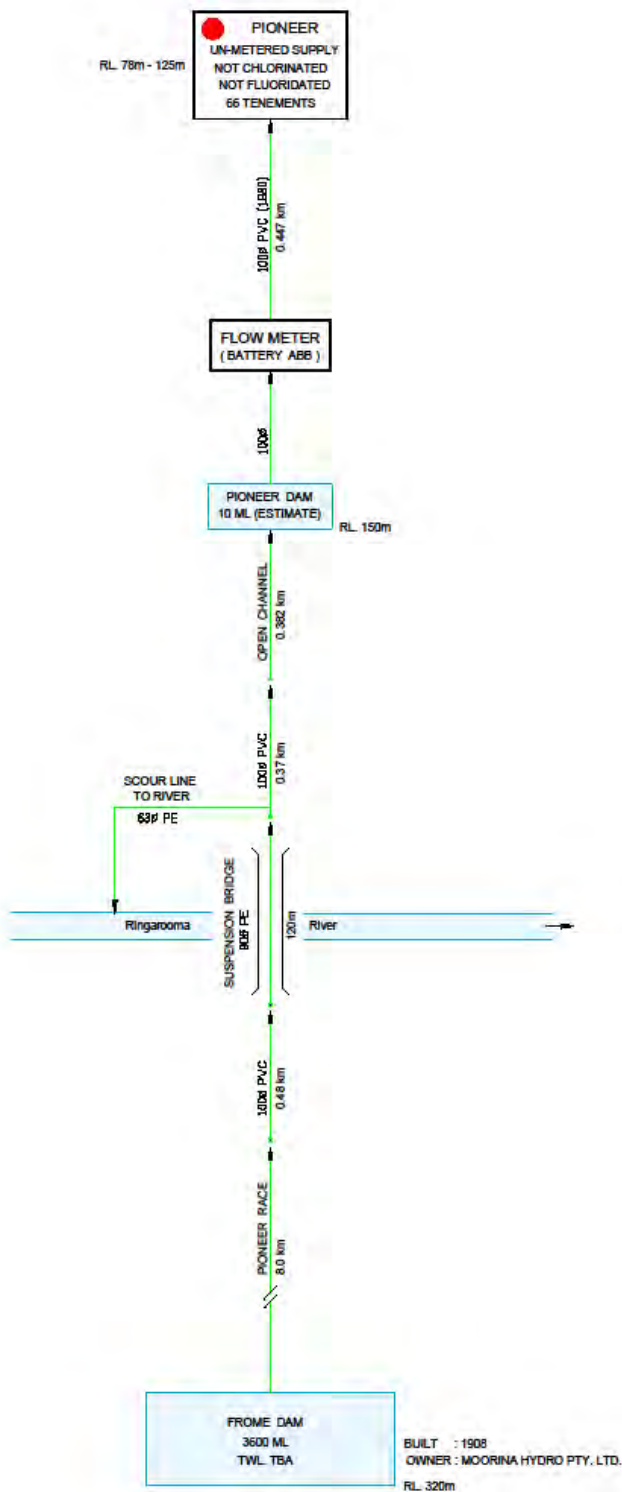
The work included a close analysis of the paper and its supporting data, an inspection of the water supply system for the town of Pioneer, discussions with TasWater staff with knowledge of the Pioneer system and an analysis of additional data supplied by TasWater.

This report:

- 1) Outlines the current water supply system for the town of Pioneer, including both the supply to Pioneer Dam and reticulation of this water to households in the town;
- 2) Reviews the science of “isotopic fingerprinting” and its application to identify sources of lead in the Pioneer system; and
- 3) Discusses the methodology of the paper and, in particular, the quality and quantity of data used to justify the paper’s conclusions.

The potential sources of lead contamination are then discussed in light of the data provided, as well as the strength of the links between the data and the conclusions reached.

2.1 The Pioneer Town Water Supply System



SCHEMATIC DIAGRAM

NOTES:

1. Levels are approximate only - derived from contours.

A schematic diagram of the Pioneer Water Scheme dated 2010, provided by TasWater, is given in Figure 1. The diagram shows that at that time water was supplied to the Pioneer Dam from the Frome Dam via an open raceway and a series of 100mm diameter polyvinyl chloride (PVC) pipes. Water was then transported from the Pioneer Dam via another length of 100mm diameter PVC pipe into a mixture of PVC and polyethylene (PE) pipes, which form the basis of the town's distribution system. Detailed plans of the distribution system within the township indicate that it consists largely of 50mm diameter PVC pipes laid in about 1980, plus further additions of 40mm diameter PE pipes.

Information from TasWater states that, since around 2009, the water supply to Pioneer is no longer sourced from Frome Dam or the raceway infrastructure immediately below it. About 900 metres of the old water race downstream of the dam are no longer used and, since the construction of an irrigation project, it has not been possible to transfer water from the Frome River along that part of the water race. This change also applies to the infrastructure associated with the old Moorina Power Station. Since this change, water for the Pioneer Dam is sourced from the open Pioneer water raceway immediately above the dam, which collects surface water runoff and water from a small water course intercepted by the raceway somewhere between the site of the old Moorina Power Station and the town of Pioneer (a distance of 5 kilometres).

While some of the water samples described in the report were taken within the town's distribution system and in some local houses, a number of samples were also taken from the Frome Dam and the infrastructure associated with the old Moorina Power Station. As these two pieces of infrastructure have not been directly associated with the town's water supply since at least 2009, the data associated with these samples are not applicable to the considerations of the paper.

Figure 1 Pioneer Water Scheme in 2010

2.2 Review of the application of isotope “fingerprinting” to the identification of the sources of lead in drinking water

Lead (Pb) has four stable isotopes: ^{204}Pb (1.4%), ^{206}Pb (24%), ^{207}Pb (23%) and ^{208}Pb (52%) (Larsen et al (2012)). The difference in ratios between the lead isotopes from different locations is a function of the starting composition and decays of the original ore content. Hence the isotope ratios can be attributed to the geological formation time of lead in different mines (Larsen et al (2012)). Although maximum information is obtained from the measurements of all four stable isotopes, generally most tracer work has been done using just the ^{206}Pb : ^{207}Pb ratio because this can be measured most accurately (Maring et al (1987)).

The isotopic compositions of lead ores are retained during natural and man-made processes that contribute to environmental lead. They are also conserved during manufacture of consumer products which subsequently may become sources of human lead exposure (Delves and Campbell (1993)). Fortunately, tracing lead contamination in Australia is often rather simple because almost all of its industrial lead came from a few large, geologically old (w1700 million years) ore deposits that have relatively unique isotopic fingerprints (Gulson (2003)). The principal Australian lead ore deposits are in Broken Hill (New South Wales) and Mount Isa (Queensland), which are among the largest in the world and have distinctive lead isotopic compositions (e.g. Gulson (1985), Gulson and Mizon (1979)).

Measurements of lead isotope ratios have been applied to a number of fields in recent years, covering environmental, geological and forensic applications. Lead isotope ratios have been successfully used to document the contribution of anthropogenic lead from leaded gasoline and mining in the environment and freshwater systems (Larsen et al 2012). It is also possible to use measurements of stable lead isotope ratios to distinguish different sources of lead in drinking water systems.

The major source of lead in drinking water has been identified to be plumbing materials (Lasheen et al (2008)). Lead pipes, lead-based solder, brass fittings and plumbing fixtures such as pipe’s jointing faucets are known to be dominant lead sources in public water supply systems (Gulson et al (1994)). Lead pipes have been replaced with other types of pipes such as polymer materials like polyvinyl chloride (PVC), polyethylene (PE) and polypropylene (PP). PVC polymer is mixed with a number of additives including stabilisers in order to provide the range of properties needed in the final products. Stabilisers are often composed of salts of metals like lead and cadmium (Kim (2001)). PVC as a potential source of lead in water is discussed in a later section.

Fingerprinting based on stable lead isotope ratios of environmental samples can help to identify lead exposure pathways (Gwiazda and Smith (2000)). In general, natural sources of lead have Pb isotopic ratios different than those of anthropogenic sources (Komarek et al (2008)). As a result, when environmental lead sources are isotopically distinct from one another, lead exposure pathways may be identified. For example, Cao et al (2014), Gulson et al (1995) and Delves and Campbell (1993) have successfully identified drinking water as a source of lead in children.

However, there have also been studies that failed to identify lead sources using stable isotopes. One reason is the overlap of isotopic compositions of different environmental samples with one another. For example, Soto-Jiménez and Flegal (2011) found that the lead isotope ratios of dust, soil, and aerosols from a smelting area of Mexico were indistinguishable from each other making it impossible to apportion the dominant source of lead. Therefore, investigations require that the different sources of lead be isotopically distinct and that uptake of a given lead source produces a measurable change in the isotopic composition of the receiving water/organism.

In recent years, stable isotopes have increasingly been used as environmental tracers (Lathja and Michener (1994)). One common application uses isotope mixing models to quantify source contributions to a mixture (Phillips et al (2005)). Examples include pollution inputs to air, soil, or water bodies; food sources in animal diets and plant water use from different soil depths. Linear mixing models based on isotopic mass balance have long been used for this purpose (Phillips et al (2005)) as have two-dimensional vector-based source apportionment calculations (Larsen et al (2012)). The benefit of these models is to provide a relative contribution (%) of each source to the final mixture identifying the major pollutant source.

2.3 Application of stable isotopes to the Pioneer drinking water system

There is evidence of elevated lead concentrations in the Pioneer drinking water system. Harvey et al (2015) have used lead isotopic compositions to attempt to differentiate unknown sources of lead contamination of the drinking water supply in north-eastern Tasmania, Australia. The application of the lead stable isotope method is feasible if all potential sources of lead are identified and the isotopic composition of those potential sources are distinct. The potential sources of lead in the local waters were identified as dilapidated drinking water infrastructure, including lead jointed pipelines, end-of-life polyvinyl chloride pipes and household plumbing (Harvey et al (2015)). However, only the lead isotopic ratio of the Moorina Power Station pipe surface and at one joint were determined in this study – a fundamental flaw, as water no longer flows through these pipes. This is considered in more detail below. The study would have benefited from determination of the lead stable isotope composition of PVC pipe and pipes within dwellings of Pioneer.

There is large variability in lead isotopic composition within the first minute of tap flushing which brings into question the reliability of the recommended sampling time of 30 seconds (Gulson et al (1994)). Harvey et al have not described in enough detail how water samples for stable isotope analysis were collected to allow a detailed review of this component of the paper.

Furthermore, only single samples were collected of the potential sources (infrastructure) and mixture (three (3) water samples from three (3) individual locations). This does not provide an estimate of the range or variability of isotope ratios. There can be extremely large lead isotopic differences between dwellings within the one city and between dwellings and the storage tanks for a water supply (Gulson et al (1994)), which can lead to over or under estimation of the correct source apportionment of lead sources. Also, the authors only provide an indicative relative standard deviation for lead isotope values. Collection of replicate samples from the sources and mixture (tap water) would alleviate this uncertainty.

To determine the relative contribution of lead from potential sources, the authors have used a two-dimensional vector-based source apportionment calculation, as described by Larsen et al (2012). This model was used to determine the source of lead to: (1) the Moorina Power Station pipes and (2) water from the Pioneer House and Pioneer public toilets. Using the isotopic composition of the potential sources of local bedrock (included from other sources - see references in Harvey et al 2015) and that of lead ore from Mt Isa/Broken Hill, the joints in the Moorina Power Station pipes have 43% of their lead attributed to Broken Hill/Mt Isa type ores. Whilst this is interesting, it is irrelevant to the study, given that water no longer flows through the Moorina Power Station infrastructure and into Pioneer. It also appears that the authors use the isotopic composition of Broken Hill/Mt Isa lead ore and Moorina Power Station joints as potential sources for the apportionment of lead to the water samples collected. The authors fail to justify the use of different potential sources for each calculation.

Key points

1. The use of the Moorina Power Station joint (as a sampling location pivotal to the isotopic results) is problematic as it is not connected to the Pioneer drinking water system
2. The sampling protocol was poorly described and insufficient for confidence in repeatability
3. Accuracy and reliability of the source apportionment would have been more credible with more appropriate potential sources or “end members” and inclusion of error estimates which would provide a range of values for each lead source. Appropriate “end-members” should include the stable isotope composition of PVC pipes and pipes within dwellings of Pioneer.

3 PAPER METHODOLOGY AND THE AMOUNT AND STRENGTH OF THE DATA

The paper's major aim was to identify sources of metal contamination in drinking water in the town of Pioneer. The approach was to take a series of samples of water, soil/sediment and bedrock in areas closely associated with the water supply infrastructure e.g. transfer channels and pipes, dams and the town reticulation network. Samples were analysed for arsenic (As), copper (Cu), lead (Pb) and tin (Sn), as well as isotopic lead breakdowns for 5 samples. The general conclusions of the paper pointed to lead contamination arising from the local town infrastructure e.g. transfer pipes, PVC reticulation mains and household plumbing.

General comments on the paper's methodology and the amount and strength of the data it contains are outlined below, followed by another section containing more detailed comments on various aspects of the paper.

General Comments

It appears that the paper's authors did not fully understand or appreciate the exact scope of the current water supply system. As described earlier, the Frome Dam and the Moorina Power Station have not been directly connected to the Pioneer town water supply since around 2009. This situation appears to discount data collected by the authors on Frome Dam and the Moorina Power Station infrastructure. Having said this, it is possible that contamination from the Power Station infrastructure may have been transferred to the Pioneer Dam before the disconnection around 2009 and may have accumulated within the sediments contained in Pioneer Dam.

The second general comment relates to the quantity of data collected to support the conclusions of the paper and, in particular, the sampling protocols used to collect that data. An examination of the supplementary data sheets provided with the paper does not provide evidence of significant numbers of duplicate analyses and/or repeat samples. Particularly when it comes to some key results within the town of Pioneer itself, there appear to be no repeat samples or duplicate analyses. Given the importance of these particular results in drawing the paper's conclusions, this is a major weakness and a cause for some uncertainty.

Particular concerns regarding the methodology and the amount and quality of data collected arise from the following observations. This section goes into the details of the working group's thoughts on the Pioneer water supply system and provides the basis for the subsequent discussion.

Specific Comments

3.1 Sampling Sites

The working group was most concerned about the inclusion of samples from Frome Dam, Moorina Power Station and the old lead-jointed pipes associated with the Power Station – none of which have been connected to the Pioneer system since some time in 2009 (Wright 2015).

This major flaw raises significant uncertainty about any conclusions relating to these sites as sources of contamination.

The remaining sample sites are legitimate, although the nomenclature and actual nature of the sample point is at times confusing (see below).

3.2 Samples

Water samples were collected into appropriately prepared sample bottles.

There were two sampling events in October 2013 and March 2014 which the authors state "*encapsulated seasonal variability in the water race of Pioneer*" but they provide no meteorological data to support this statement. There is also no record of the water temperature at the sample sites even though it was stated in the methods that temperature was measured. Examination of the

temperatures may have made it possible to have made some assessment of the “seasonal variability”. It is also not clear why the authors make the point about seasonal variability.

Further, the authors state that “*water samples were collected as a dissolved (<0.45 µm) and total (unfiltered) fraction. There was limited difference between the two fractions for lead so only total (unfiltered) samples were collected on the second visit. Water pH and temperature were measured at each site*”. In fact, the differences between filtered and unfiltered samples were quite significant for those samples with elevated lead levels. This difference is significant because it relates to the possible mechanisms for lead dispersal into the water. It would also have been useful to include turbidity data to allow the reader to make some independent interpretation of this statement; however there is no turbidity data.

3.3 First Flush and Time Series Sampling

While the authors have recognised the value of obtaining first flush samples, the information relating to the sampling does not make it clear whether the water was sampled from hot or cold water taps.

(Volunteers for kitchen water sampling were sought from the local population. Volunteers were instructed how and when to collect samples. First draw samples were collected after 8 h stagnation time on the first sampling trip.) (Harvey et al (2015))

This is important since levels of metal contaminants are likely to be higher in first draw hot water samples. It is also not clearly stated that the household samples were collected in the pre-prepared sample bottles. It seems reasonable to assume this was the case but it is not stated. There is also a very real risk in taking unsupervised samples. For the integrity of the data it would have been far better if the researchers had collected the samples themselves. There is absolutely no guarantee that all the first draw samples are in fact genuine first draw samples.

3.4 Sample Numbers and Replication

The paper is based on a very small number of samples with essentially no replication. For example, the data in Figure 4 appears to be based on single samples. With only single samples there can be no statement as to the variability of the data and the variability can be significant. Inspection of any NATA inter-laboratory testing report readily reveals significant variation in values returned from identical samples. In support of this statement, in one set of data reported by Harvey et al (2015) where there was replication (see Table 2 in Harvey et al), lead content in Pioneer Cesspit #1 Lower Dam Pipe Joint 2 varied with 94, 484, 274 mg/kg. Clearly this refers to a sediment sample however it emphasises that variations occur. While there do appear to be significant differences between houses in Pioneer the combination of the sampling issues and data variability make interpretation of such differences very difficult.

3.5 Lead and Copper Levels at the Customer Tap

There is little doubt that the levels of lead and copper in drinking water sampled at customer’s taps in Pioneer are elevated in some samples. Lead regularly exceeds the ADWG health limit of 0.01 mg/L while copper occasionally exceeds the ADWG aesthetic limit of 1 mg/L and rarely the health limit of 2 mg/L.

The question is what are the sources? While the Harvey et al (2015) paper is entitled “Identification of the sources of metal (lead) contamination in drinking waters in north-eastern Tasmania using lead isotopic compositions” the paper does not provide enough evidence to conclusively identify the exact sources of the contamination.

3.6 Pioneer Demand and Distribution System Turnover

TasWater report that typical monthly usage for the township of Pioneer is in the region of 0.3 ML or around 10 kL/d.

Based on the system drawings provided by TasWater, and only including pipes in the direct line from the primary 100 mm feed main, the calculated volume for the western part of the town (including the 100 mm feed main) is approximately 5.2 kL and for the eastern part of town (including the 100 mm

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feed main) is approximately 3.8 kL. Therefore it seems likely that the water in the mains is fairly well turned over on a daily basis.

There are however a number of quite long dead end mains in the supply system and these may not get turned over. These different parts of the distribution system may also have contributed to some of the variability in the data shown in Figure 4 of Harvey et al (2015).

Key points

1. Data from Frome Dam and Moorina Power Station are not applicable as these sources have not been directly connected to the Pioneer Dam since 2009.
2. A lack of duplicate samples and repeat analyses, combined with an unclear sampling protocol, is a major weakness of the paper.
3. There is little doubt that lead and copper in drinking water sampled at customer's taps in Pioneer are elevated in some samples.

4 POTENTIAL SOURCES OF CONTAMINATION

There are a number of possible sources for contamination of the Pioneer town water supply. These include:

- Water in the Pioneer Dam
- Sediment in the Pioneer Dam
- Pipes in the town distribution system
- Local plumbing in individual buildings

Each of these potential sources will be considered below.

4.1 Water in Pioneer Dam

A description of the water source to the Pioneer Dam as outlined earlier is provided by Wright (2015).

The Pioneer Dam is fed by the open Pioneer water race which originally extended from Frome Dam to Pioneer and supplied water to the Moorina Power Station on the way. Water from the Frome Dam has not now supplied Pioneer for several years. Water that is transferred from the race to the Pioneer Dam is water trapped by the open race from surface water runoff and small watercourse intercepted by the race between the site of the old Moorina PS and Pioneer.

While TasWater refers to the water body supplying the township of Pioneer as Pioneer Dam, Harvey et al (2015) refer to a number of samples as Cesspit #1. By entering the provided latitude and longitude into Google Earth, the sites seem to map to different sites around Pioneer Dam. The use of the term Cesspit to describe part of a water supply system lacks a professional and objective approach to the study. The identification of the sites is made more difficult since in their text they refer to the Cesspit when considering water sample data but then refer to Pioneer Dam when discussing sediment and solid samples. Only the authors know the full details of these sites.

Based on this information, the data for the various Cesspit #1 samples have been interpreted as pertaining to Pioneer Dam. Hopefully this is correct.

There is only limited water quality data available for raw water sampled directly from the Pioneer Dam. The data provided to the panel by TasWater covers the period of 29/8/2012 to 27/6/2013. Sample sites include Dam Inlet, Dam Surface, Dam Bottom and Dam Outlet. Table 1 summarises the lead results for the dam outlet.

TasWater advises that “*historically this system has only been sampled from the standard compliance location within the town distribution system. Due to the fact this system receives no form of treatment other than settlement within Pioneer Dam this was taken to reflect the raw water quality*”. While this statement is true for some parameters it is not true for all parameters.

The data from the June 2013 sampling period shows the following.

- pH is between 5.7 and 6.0;
- True colour ranges between 5 and 77 CU;
- Turbidity varies between 0.4 and 7.3 NTU; and
- Alkalinity (mg/L CaCO₃) is consistently 2 or less.

Based on the pH and alkalinity, the water would be considered aggressive and would likely leach metals from sediments and pipe materials. However, there is insufficient data to carry out any statistical analysis to demonstrate this point.

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Data from the Harvey et al (2015) paper includes three results from a site called Cesspit #1 and Cesspit Lower Dam which, as outlined above, are assumed to have been taken from the Pioneer Dam. Two separate samples were taken in October 2013 and March 2014. These samples show very low levels of copper and lead, although one sample had unfiltered lead levels of 7 µg/l. The one pH measurement provided of 5.33 indicates that the water is acidic.

While the TasWater data is limited, it appears that all the water sampled from the Pioneer Dam Outlet, with one exception, has very low levels of lead (Table 1). One sample on 21/11/2012 has a value of 1690 ug/L. This is an extremely high value, particularly with respect to all the other measurements. Unless this sample had been retested and the result verified, preferably with a second sample, this value should be considered doubtful.

Table 1. Lead levels in water sampled from the outlet to Pioneer Dam. (Data from TasWater)

Sample Site	Date	Parameter	Value	Units
Pioneer Outlet	29/08/2012	Lead	<0.5	ug/L
Pioneer Outlet	10/09/2012	Lead	<0.5	ug/L
Pioneer Outlet	10/09/2012	Lead	<0.5	ug/L
Pioneer Outlet	18/09/2012	Lead	0.7	ug/L
Pioneer Outlet	25/09/2012	Lead	<0.5	ug/L
Pioneer Outlet	2/10/2012	Lead	<0.5	ug/L
Pioneer Outlet	21/11/2012	Lead	1690	ug/L
Pioneer Outlet	27/11/2012	Lead	<0.5	ug/L
Pioneer Outlet	29/11/2012	Lead	<0.5	ug/L
Pioneer Outlet	3/12/2012	Lead	<0.5	ug/L
Pioneer Outlet	13/12/2012	Lead	1	ug/L
Pioneer Outlet	20/12/2012	Lead	<0.5	ug/L
Pioneer Outlet	6/06/2013	Lead	<0.5	ug/L
Pioneer Outlet	27/06/2013	Lead	1.1	ug/L

There is no data provided by TasWater on copper levels in the raw water. This is consistent with the fact that copper is not normally sampled in raw water. Most copper in water comes from domestic plumbing.

Harvey et al (2015) provide data in their paper and in a supplementary data sheet. The data provided are difficult to interpret partly due to the use of the names of the sample sites, for example W1 to W20 is particularly uninformative. They appear to be from the Ringarooma River. Either way, with the exception of W20, the levels of arsenic, copper, lead and tin are all below detection limits except for one very low positive value. W20, which appears to map somewhere near Frome Dam, had moderate levels of copper and low levels of lead. The source of copper at this point is puzzling. However, this result is not relevant to the considerations of this report since Frome Dam no longer feeds Pioneer Dam.

The issue of copper in the raw water is also raised by the results for one of the Cesspit #1 samples. This sample had low levels of both copper and lead. Once again the presence of copper at this point is puzzling. However the authors do not adequately describe the characteristics of the different sample points. Was it a grab sample or was it sampled through some sort of tap and pipe?

Based on the limited data available, it appears that there are very low lead levels and no copper (with the exception of the sample described above) in the raw water sourced from Pioneer Dam.

Key points

1. Based on the limited data available, it appears that there are very low lead levels and no copper in the raw water sourced from Pioneer Dam.
2. Based on the pH and alkalinity, the water would be considered aggressive and would likely leach metals from sediments and pipe materials.

4.2 Sediments

Pioneer Dam Sediments

As with the raw water, there is only limited data available on the lead content of Pioneer Dam sediments. In the data provided to the panel by TasWater, there appear to be only two sediment samples. One sample (6/6/2013) returned a value of 416 ug/L and the other (20/6/2013) a value of <7 ug/L. A March, 2013 memorandum to Ben Lomond Water authored by GHD provides a single figure of 117 mg/kg of lead for a soil sample from the dam. The use of ug/L as a concentration unit for a sediment sample in the TasWater data is puzzling. In addressing this question, TasWater state

Attached are the two analytical reports covering these sampling events. Previously unless otherwise specified as a sediment investigation, the laboratory's normal process for "sediment" samples with very low solids was that they were tested as water and hence reported with "water" units. (AST#59735)

Unfortunately this only adds to the problem of interpreting the data. If the samples only had "very low solids" then it is difficult to see how they are in fact sediment samples.

So can any conclusions be reached based on this data? At best they suggest variable amounts of lead in the sediments in Pioneer Dam but this would need to be verified with more and careful sampling and testing.

Harvey et al (2015) report some sediment results from Cesspit #1. The values for lead for this site range between 12 and 27 mg/kg. The authors conclude "*analysis of soil and sediment in and around Pioneer Dam show low lead*".

While the data is limited, it appears that the levels of lead in Pioneer Dam sediments are low. There may however be some spatial variability.

The presence of some lead in the sediments is not surprising given the fact that Pioneer Dam was originally supplied from Frome Dam via the Moorina Power Station and old pipes. Harvey et al (2015) have clearly demonstrated a possible lead contamination along that route.

Potential Impact of Pioneer Dam Sediments on Drinking Water Supplied to Pioneer

There is some lead in the sediments in Pioneer Dam, albeit quite low. However it could be a source of lead under conditions where sediment is carried into the system. Again while the data is very limited, the turbidity of the Dam Outlet during the June 2013 sampling period varies between 0.4 NTU and 1.7 NTU. The slightly higher turbidity could contribute to slightly higher total lead concentrations during the periods of elevated turbidity. It is also possible that the turbidity could be quite a bit higher during flood or wind events which could contribute to variable levels of lead bearing sediment in the mains.

There does appear to be a definite reduction in colour between the Dam Inlet and the Dam Outlet in the June 2013 samples (Figure 1). The difference is significant ($P < 0.05$).

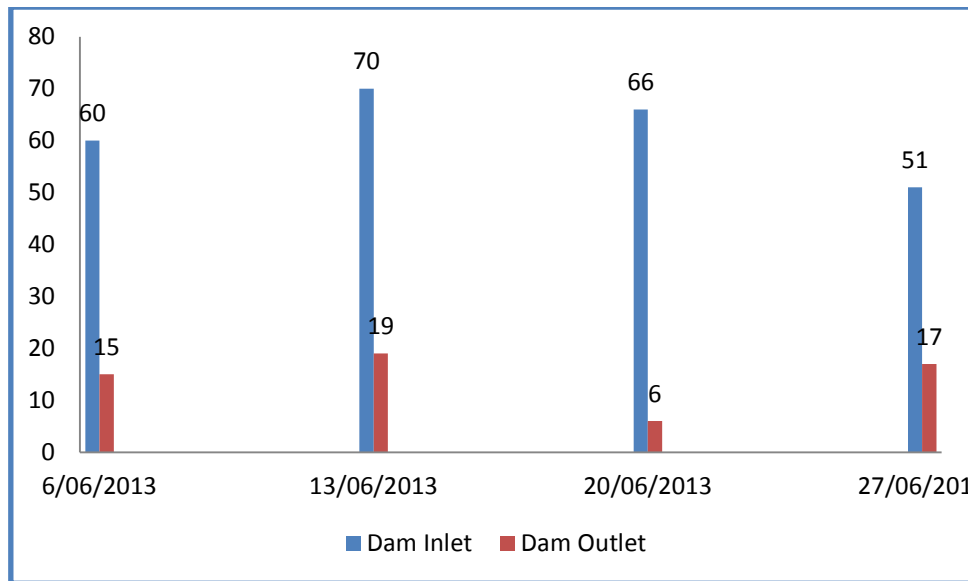


Figure 1. True colour at the Pioneer Dam Inlet and Outlet in June 2013.

This suggests that the sediments may have a significant organic component which in turn might support a range of microorganisms. It is further likely that the redox status of these sediments may change.

In the June 2013 sampling event, Dissolved Oxygen (DO) was also measured in some of the samples. On the 6th June, the DO is recorded as <1 mg/L while on the 13th June the DO is recorded as between 7.8 mg/L and 8.1 mg/L. This is a huge difference, and if correct, suggests the nature of the water can change dramatically. This data needs to be checked carefully. Further, given the apparent variability, it seems unfortunate that TasWater did not continue to collect DO data for the remaining test days.

If the DO results are correct, it is possible that during any anoxic events, metals could be released from the sediment. However, the lead data from the two samples in June 2013 do not support this hypothesis. The DO levels need to be checked carefully and ideally more testing done on the redox status of the water.

Key points

1. While the data are limited, it appears that the levels of lead in Pioneer Dam sediments are low. There may however be some spatial variability.
2. It is possible that the turbidity could be higher during flood or wind events which could contribute to variable levels of lead bearing sediment in the mains.

4.3 Pipes

As a Source of Lead

The pipes that constitute the distribution system in Pioneer are of two types.

1. Unplasticised PVC of 50mm diameter installed in 1980
2. Polyethylene pipes of 40mm diameter installed 1980

Harvey et al (2015) noted that the early PVC pipes were stabilised with lead. The leaching of lead from PVC pipes has been an issue of concern since their introduction into water supply systems in the late 1970s. This concern has led to the elimination of lead from PVC pipes destined for water supply systems in the early 2000s. PVC pipes used for water supply in Australia are now stabilised with calcium/zinc formulations (Burn et al (2005)).

The PVC pipes used in the Pioneer water supply system were installed in 1980 and thus presumably contain lead stabilisers. Consequently, these PVC pipes are a potential source of lead in the Pioneer water supply system. A number of studies (Al Malack (2001) and Lasheen (2008)) have demonstrated the potential for lead leaching from PVC piping to contribute to lead levels in domestic water supplies. These studies have shown that low pH and alkalinity, combined with extended contact time and high surface to volume ratio can result in increased lead levels in water above the recommended health limit of 10 µg/L. A CSIRO review (Burn et al (2005)) quotes these results, but also states that “*the consensus being that the concentration of lead leached into water does not pose a health hazard to humans, provided proper flushing is conducted during the commissioning of the new pipes*”. Burn’s comments on the Pioneer data are that, in his opinion, only extended contact time of water with the PVC pipe in a stagnant end zone of the pipe could possibly result in the lead levels being observed. Such levels should not occur in situations where there is significant water flow through the pipe (Burns pers comm (2015)).

Clearly the aged PVC pipes in the Pioneer water supply system are a potential source of lead in the water. However, a number of questions surround this possibility. There appear to be no data available in the literature on the long term (over years) leaching characteristics of PVC pipes. The pipes in the Pioneer system are about 35 years old. If lead was being continuously leached from these pipes over that very long time period, then it would be expected that the pipes become increasingly brittle and an increasing rate of pipe bursts should be noted. Discussion with TasWater personnel indicates that this does not appear to be the case.

As a Source of Copper

Global experience has shown that the main source of copper in household drinking water is copper pipes and brass fittings usually confined to domestic plumbing within the property and building.

TasWater reports that “*local operators have indicated that the vast majority of service pipe material post the meter is laid in HDPE. A small number of cast iron galvanized services still remain but no information available on which exact services these are*”. Nothing is known about the internal plumbing, however it seems likely that there may be some copper pipes involved, but this needs to be verified.

During the site visit by the WaterRA panel, copper pipe was observed at the back of the toilet block. The pipe seemed to be pressure jointed rather than soldered. There were also new brass fittings on many of the town hydrants (Figure 2).



Figure 2. Pioneer town hydrants

Key points

1. While leaching of lead from PVC pipes in Pioneer is possible, a CSIRO report and subsequent discussion with the author state that lead levels should not reach levels dangerous to human health in a well flushed system
2. It is possible that with an aggressive water and stagnant and/or dead-end zones in the distribution system, lead levels could reach elevated levels

5 LINKS BETWEEN DATA AND CONCLUSIONS

Although the data reported by Harvey et al (2015) are sparse and their reproducibility can be questioned, the general conclusions reached in the paper are plausible. There are a number of factors which support this statement.

Firstly, sampling over a period of years by both TasWater and its predecessors has pointed to intermittent levels of lead in the Pioneer distribution system above 10 µg/l. It is the source of this lead which is the main issue under discussion. While data taken from the Pioneer Dam demonstrates very low levels of lead, there is clearly lead entering into the water supply somewhere in the distribution system. The most likely sources of this lead are:

- leaching from accumulated sediment in the distribution system;
- leaching from PVC piping;
- leaching from household plumbing.

An important factor which increases the likelihood of lead leaching is the aggressive nature of the raw water. With a pH ranging from 5.7 to 6.2 and an alkalinity of less than 2 mg/l, the water is clearly aggressive and capable of leaching metals from a variety of substrates. However, there are a number of features of the data provided by Harvey et al (2015) which complicate this picture.

There is the very strong link in the data between copper and lead levels, with copper levels in water samples always significantly higher than lead. The data also show that in the local soils and sediment, copper is always at a lower level than lead. This result suggests that the strong copper/lead relationship in the Harvey et al data is a result of water remaining in contact with brass and copper fittings for lengthy periods of time. If all the samples taken from both town and household taps were first flush samples, then the data would make sense. This conclusion again highlights the need for sampling protocols to include long flush times in order to ensure the samples accurately represent water in the distribution mains.

However, for the samples taken at the Pioneer town end flow valve (cnr of Main Road and Alfred Street) only a 5 second flush time was allowed. This flush time is probably too short to be confident of avoiding any copper/lead accumulation in the piping close to the valve. From examination of all the other town samples where high copper/lead concentrations were measured, it would appear that this lack of adequate flush times before sampling may have impacted on all of the author's results. The other result which adds to this concern is the significant difference between filtered and unfiltered samples for Pioneer houses 6 and 8 and the W20 sample (which appears to be from the Ringarooma River near the Frome Dam). The high particulate or insoluble levels of copper and lead in these samples suggests some copper/lead precipitation in the stagnant zone of the pipe after a long period of stagnation followed by re-suspension after the commencement of sampling. This is one possible explanation of why copper and lead levels went up in Pioneer House 11 after 3 minutes of flushing.

Considering the aggressive nature of the raw water, the leaching of lead from the PVC pipes in the distribution main is a distinct possibility. As described previously, Burn et al (2005), in their report to the Awwa Research Foundation do state that lead leaching from PVC pipes should not represent a health risk to humans, so long as proper flushing procedures are followed during commissioning of the pipe. However, given the aggressive nature of the raw water being supplied in the Pioneer system and the lead leaching results reported by Al Manack (2001) and Lasheen (2008), further testing would be required to validate this conclusion for the Pioneer system.

Key points

1. Although the data reported by Harvey et al (2015) are sparse and their reproducibility can be questioned, the general conclusions reached in the paper are plausible.
2. The strong copper/lead relationship in the Harvey et al data appears to be a result of water remaining in contact with brass and copper fittings for lengthy periods of time.
3. This conclusion again highlights the need for sampling protocols to include long flush times in order to ensure the samples accurately represent water in the distribution mains.

6 CONCLUSIONS

The water supply to the town of Pioneer has been disconnected from the Frome Dam and 900 metres of raceway immediately below the dam since at least 2009. Consequently, the water samples taken by Harvey et al (2015) from these sites are not directly applicable to the water supplied to Pioneer. The samples they took from around Pioneer Dam and within the town itself remain relevant.

Isotopic “fingerprinting” is a widely used tool for identifying the origin of various environmental contaminants and it has potential for identifying the sources of lead in drinking water. However, the paper by Harvey et al (2015) did not report enough appropriate samples of lead in both water and sediments and pipes for isotopic fingerprinting to unequivocally identify the sources of lead in the Pioneer water supply

Water samples from within the town distribution system taken by both Harvey et al (2015) and TasWater have clearly demonstrated the intermittent presence of lead in the water at levels approaching and above the recommended health limit of 10 µg/l. However, application of the data provided by Harvey et al. (2015) is limited by unclear sampling protocols and the lack of duplicate analyses and repeat samples.

Data on the quality of water within Pioneer Dam, although limited in number, indicate that it contains low levels of lead, significantly below those measured in the distribution system. However, the water has a low pH, is very low in alkalinity, and is thus conducive to leaching metals such as lead from any material it remains in contact with for an extended period of time.

Although the data provided in Harvey et al (2015) do not unequivocally identify the sources of lead in the Pioneer water supply, the evidence from all the data made available to the authors of this report indicate that there are three possible sources for the lead.

1. Sediments
 - a. In Pioneer Dam
 - b. In pipes within the town distribution system
2. –Pipes within the distribution system (mostly PVC)
3. – Household plumbing

Much of the data in Harvey et al (2015) appears to be based on first flush sampling of water after extended periods of stagnation in the pipes and local plumbing. These samples do not accurately represent the quality of the main body of water within the distribution system. The high levels of copper found associated with the lead in these samples support these conclusions.

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